13th international conference on design & decision support systems in architecture and urban planning, June 27-28, 2016, Eindhoven

PAPERS

Design & Decision Support Systems in Architecture and Urban Planning

HARRY TIMMERMANS
Editor

13th International Conference on Design & Decision Support Systems
in Architecture and Urban Planning
June 27-28, 2016

PSV Stadion

Eindhoven

The Netherlands

Technische Universiteit Eindhoven
ISBN: 978-90-386-4144-7 NUR code 780

Using Multi Criteria Analyses and BIM to evaluate design solutions of complex buildings

A case study in automated KPI checking in the early desing phase

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Key words: Building Information Modelling, multi criteria analysis, decision support, data management, code compliance, automation, model checking

Abstract: The overall objective of the EU supported ELASSTIC project is to improve security, safety and resilience of large scale multifunctional building complexes against natural and man-made disasters. This improvement is done by providing a methodology and tools which evaluate criteria of security, safety, as well as other criteria, and apply them to early design concepts and therefore planning phase of such projects. The development of a decision support tool based on Multi Criteria Analysis was created to facilitate this. Using this tool, designers and stakeholders can see immediate impact and trade-offs in design changes on the performance of the building. This paper is an explanation to the use of MCA tool and what the possibilities are regarding MCA.

1. INTRODUCTION

1.1 The Elasstic concept

In recent years the use of Building Information Modelling (BIM) has increased in the Architectural and Urban domain.

In the EU supported research project ELASSTIC the BIM concept was used during the early design phase of a complex building. The overall objective of the ELASSTIC project is to improve the safety, security and resilience of large scale multifunctional building complexes to natural and man-made disasters by providing a methodology and tools which enable to include security and resilience from the early design and planning phase of such projects.

The Elasstic concept consists of four main clusters of technology:

- Building Information (BIM)
- Simulation models (e.g. for evacuation, energy, etc)
- Sensor information
- Multi Criteria Analyses (MCA)

The Elasstic concept is about the communication between these four main technology groups. The 'Multi Criteria Analyses' (MCA) is providing the end-user the interface to evaluate safety and security of the building design. This paper will focus on the integration between Building Information Models (BIM), Simulation models and Multi Criteria Analyses.

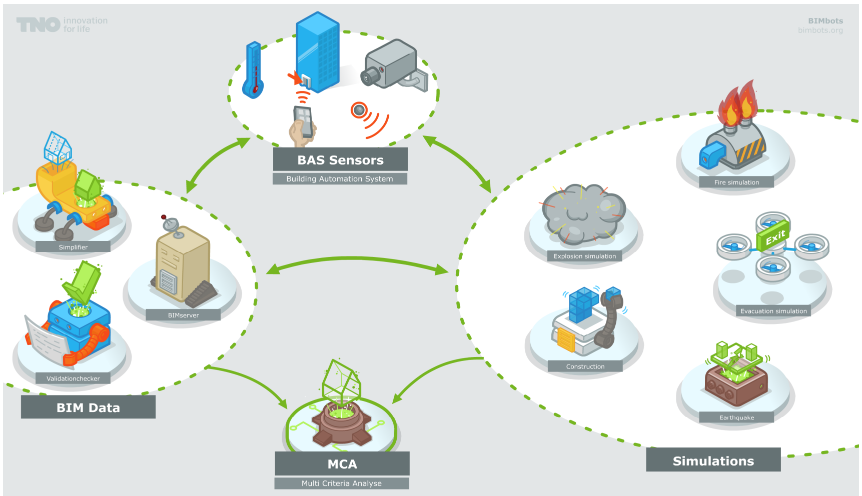

Figure 1. Schematic representation of the ELASSTIC technology concept.

The Elasstic project had a strong focus to get simulation results available early in the design process. In this case the influence on the design is still very high without large consequences.

To reach this goal the simulation models should be able to run in an automated, autonomous way; without human interference.

The combined results of the simulation models are fed into a Multi Criteria Analyses tool. This MCA tool shows results on predefined Key Performance Indicators of the design.

The concept makes it possible to have immediate feedback on the performance of the design without human interpretation or delay.

In the Elasstic project a proof of technology was build and a use case was tested.

This paper describes the technology that was developed and the results of the use-case in the project. The use-case description will elaborate about the different roles that can be evaluated in the MCA tool.

Conclusions indicate that MCA is a valuable technology as a Design and decision support tool in the early design phase of complex buildings, hence the automation of simulations is feasible.

1.2 Example

The concept is best described with an example. Let’s focus on the case of a fire in a building.

In case of a fire in a building, the sensors from the Building Management System (BMS) pick it up. The BMS probably responds with the classic sprinkler system. A notification of the fire is also send to the evacuation simulation. The location of the fire, smoke and maybe intensity are available data at this moment in the process. With advances in building management systems the number of people and their location might also be available as data. The evacuation simulation calculates the most effective evacuation route for the people in the building. To do this, it needs to calculate the spread of the fire so it also triggers the fire simulation. For these simulations information about the building is needed. This data comes from the (static) BIM. In case, parts of the building are destroyed, even this new information is available in BIM and have to be read by the BMS. When the BIM data shows installations with high risk of explosions, the ‘explosion simulation’ can be triggered. The structural integrity of the building might also be evaluated due to the effects of the fire and/or explosions.

The most effective evacuation route, due to the recent state of the building, is send to the building management system. By using signs the people in the building can be evacuated via the safest route in the most effective and efficient way. When people don't use the suggested route, sensors (like cameras) can pick up this deviation and start a new simulation. Resulting in a recalculated optimum evacuation route that is send to the building management system.

Other information from sensors can also influence the process flow. For example when walls break down due to fire; the BIM data set gets updated and this new dataset is used as the base for evacuation simulation. In this case new evacuation routes may come available. Or when parts of the building won't provide structural safety anymore (found by a combination of sensors in load bearing columns and beams) this part might be prioritized in the evacuation (and the BIM data updated).

To get this theoretical idea into practice, the ELASSTIC project was started. During this project we tried to implement the concept with open source and closed tools, simulation models and open data standards. The research methodology was that of applied research.

This report lists the results of the applied research, gives an overview of the work that is done and states the research findings and conclusions.

1.3 IT architecture

The basic principle of this concept is that the sensors, the BIM data and the simulations are not lined up in a predefined workflow. The interaction between these tools is 'event driven'.

The principle of 'even driven' interaction is not new in IT architecture but never applied in this way on a building. It facilitates the use of small 'microservices' that seamlessly connect and integrate. These small services "do one thing and do it well". It is described as follows:

- The services are small - fine-grained to perform a single function.
- The organization culture should embrace automation of tasks.
- The culture and design principles should embrace failure and faults, similar to anti-fragile systems.
- Each service is elastic, resilient, composable, minimal, and complete.

The concept of micro-services is used in ELASSTIC to connect the different simulation tools to the BIM data. Every simulation tool should be developed as an online service that is minimal and complete. The interface to the tools should be BIM compatible.

This brings a challenge for the individual simulation tools, but is the most durable architecture for long term innovations and business models.

The core innovation of the ELASSTIC BIM concept is the automation of human tasks. By automating operations on BIM data the manual workload is eliminated.

At this moment the industry is driven by a process that has little information in the beginning of a project, and high influence on the changes. Later in the process the ability to influence costs is limited. In this stage however, there is much more information.

The ideal is to have valuable information earlier in the process, when there is still the ability to influence the project. BIM is often seen as a technology that could be used to increase the information in the early project process. In this way better information is available earlier to make better informed decisions at a moment where there is still a significant ability to influence the project.

However, research has indicated that using BIM could shift the workload to an earlier phase of the project without always having the benefits of influencing the project. Many project participants are only involved after a certain point in the process. These partners (for example suppliers) don't have an interest in delivering information earlier in a project without guarantee of a stable process.

This situation creates a lock-in. Certain project partners cannot invest in providing information earlier in the process because the risk of changes in the project is too high. Evolving these partners as 'advisers' means they have to be paid for their advice, independent from their role in the project.

A solution could be to deliver an advise to the project based on knowledge rules. An automated expert system could analyse the project data and send back an automated result. This eliminates the costs of human involvement.

By having 'bots' (automated expert systems) analysing the data every time there is a (significant) change of the design, the provided results could actually steer the design team. When the information from the bots is provided within minutes, the design team can use the provided information to change and experiment with the design.

In the current process, energy analyses are only done at the last minute before a permit is needed. By using automated bots to perform a (high level; indicative) energy analysis every time the design changes, the designer can use this to optimize the design. Other performance analyses like CO2 analyses, fire safety simulations or logistic optimizations are barely conducted in a project these days (even in BIM projects). By providing an automated bot for this the costs to perform such a simulation can be very low. This lowers the threshold to use these simulations earlier in the project, and even opens opportunities for expert opinions that could never be given so early in the project.

1.4 MCA

In the ELASSTIC project an extra element is added: the Multi Criteria Analysis. The focus of the ELASSTIC project is to make the simulation models available during the design of a building. In this way the design can be optimized for safe and secure buildings. When multiple simulations are available on the BIM data of the design they need to be compared against each other. Some design decisions may have a positive effect on the evacuation simulation, but a negative effect on the fire safety. The MCA technology creates an interface on the overall view of the different simulations of the design.

Figure 2. Screenshot of the Flooding scenario evaluation.

2. DATA

The Proof of Concept of the approach and developed tools will be done by evaluating the design of a multifunctional, resilient, large scale urban complex called the ELASSTIC complex. This fictitious complex is designed in the project. The building program of the ELASSTIC design complex contains six modules: offices, museum, theatre, hotel, housing and commerce. In addition there is a fifth building block with the function of parking below the ground level.

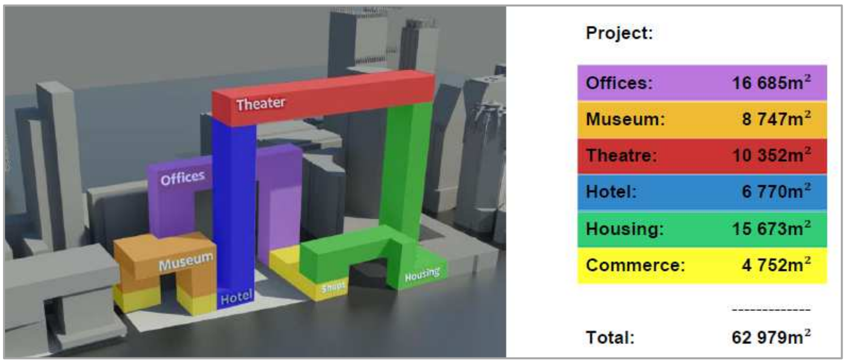

Figure 3. Schematic overview of the building program.

The building model in ELASSTIC was split into 5 different sections. The 5 sections together formed the whole building. Within the 5 sections discipline models were created for the disciplines Architecture, Construction and MEP.

In total 32 revisions were checked into the ELASSTIC BIM server during the creation of the first design. In the final revision of the first design, the total number of BIM objects that was created was almost 20 million.

3. DATA FLOW

Within the ELASSTIC EU project several simulation models use BIM data for their simulations. Before the start of the project these simulation tools had little or no input option for BIM data. The simulations had their own (proprietary) input interface. The biggest challenge was to create a connector to read BIM data to feed the simulations. For reasons of consistency and durability the open BIM data standard IFC was chosen as the interface to BIM data.

Different simulation models need different structured IFC input data. For example the simulation of the evacuation has a strong focus on getting data about staircases, hallways and spaces. For this simulation there needs to be a semantic difference between different spaces like an office, a hotel room, a hallway and an installation shaft. The structural integrity simulation does not have any focus on spaces, but needs information about materialisation, stability principles, etc.

During the ELASSTIC project the development of the simulation requirements and the modelling of the BIM was done in parallel. Therefore the requirements of the input data for the simulation models was not always available for the BIM modellers during the modelling.

To further enrich IFC data with additional semantics, so called ‘classifications’ can be used. In IFC a space is modelled as an ‘IfcSpace’ object. This can be any kind of space. To detail the semantics of a space it can be classified as an ‘office’ or ‘hallway’. This classifying can be done with terms that the BIM modeller just makes up, or a project team agrees to use one specific. For efficiency reasons standardized classification references are used. There are many efforts to map the different classification systems, or to make one overall classification system that replaces all others. These initiatives have not proven to be stable nor effective yet and are therefore not used during the ELASSTIC project.

The services that run operations on data in the ELASSTIC concept also have specific requirements. An example: the explosion model needs to know which walls are loadbearing; need specific (detailed) properties of the glass and can only handle tessellated geometry (without Boolean operations). This is a kind of MVD, although it is not officially registered as a BuildingSMART MVD.

To define a specific MVD a new standard is in the making: mvdXML. This is an XML syntax to define a specific MVD for your own software tool. During the ELASSTIC project the mvdXML development was followed with high interest. Both theoretical desk research, as practical implementations have indicated that the current mvdXML development cannot be used to define MVDs for the tools used in ELASSTIC.

During the ELASSTIC project a new version of BimQL (Mazairac, Beetz, 2013) has been developed to solve these issues. Using a query language to replace the concept of MVDs showed to be a valid approach.

At the end of the ELASSTIC project the project partners found that the MVD concept and/or query language should also be capable of performing rudimentary geometric operations. During the ELASSTIC project we experimented with this and this was brought to BimQL as an addendum to the original consideration.

4. ELASSTIC SETUP

In the ELASSTIC project several services were used to perform operations. The setup is shown in the next image:

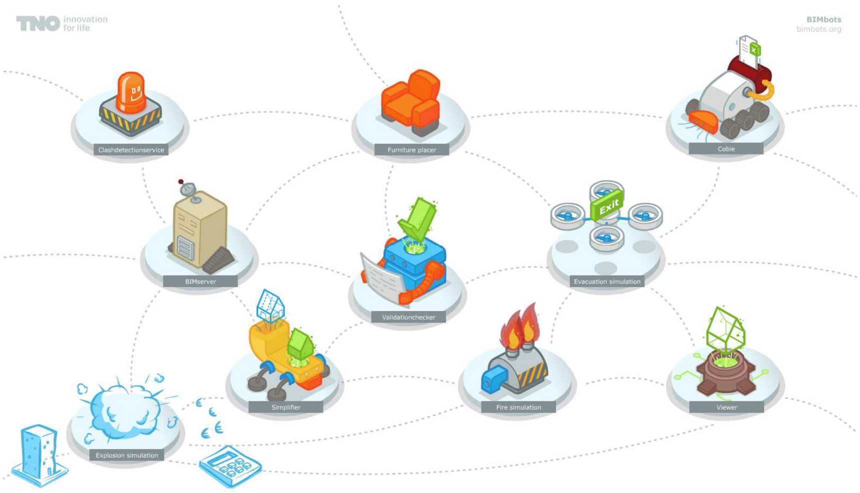

Figure 4. Schematic overview of the Elasstic BIM data flow.

At the core of the workflow a BIMserver.org (Beetz, Berlo et al 2010) instance is used (with the bimvie.ws GUI plugin). When data complies to certain model checks, triggers are send out to a clash detection service; a furniture placer; a validation checker; a simplifier; and the explosion simulation. These services can then trigger the evacuation simulation; a (very simple) fire simulation and a COBie exporter. In the end several services can update the viewer. The MCA link is not shown in this picture.

During the ELASSTIC project we found that there can be several returning loops in this setup. By using correct model checks these loops will not be triggering each other into an endless loop.

As you can see in the image, several ‘support’-bots were used to adapt the BIM data and make it available for the simulation models.

The ‘simplifier’ service, the validation checker and the furniture placer are all examples of implementations that perform automated actions on data to make it suitable for the simulation models.

5. SIMULATIONS

The simulation models used in ELASSTIC are:

1) Explosion simulation: simulating damage after detonation of an explosive inside or outside near the building. Results can be chance of survival per room; broken windows; etc.. The expertise from TNO was used in this simulation.
2) Pedestrian stream / Evacuation simulation: simulating the stream of people leaving the building. Result of the simulation can be the time that the whole building is evacuated; locations in the building that obstruct a smooth evacuation; etc. The expertise of Siemens was used for this simulation.
3) Earthquake simulation: this simulation calculated the structural integrity of the building after an earthquake. Result is a Boolean if the building still stands or not. The expertise of Schüßler-Plan is used for this.
4) Structural simulations: this simulation calculates the deformations and stresses. The results are used for analyses of impacts from strong winds due to climate changes. The expertise of Arcadis is used for this.
5) Energy simulations: simulation of the energy use of the building. The expertise of Arcadis is used for this.

6. POST PROCESSING DATA TO FACILITATE MCA

The MCA tool for ELASSTIC doesn’t only require data from the simulation tools, but also needs information about the building itself. This could be the ratio between usable area and technical area, number of building storeys, etc. This information is not available as an attribute in the IFC data, but can be derived from the data. To facilitate the MCA tool, BIMserver created an internal service that analyses the IFC data and calculates the information required for the MCA tool. This information is stored in a JSON file as extended data (just as the simulation results).

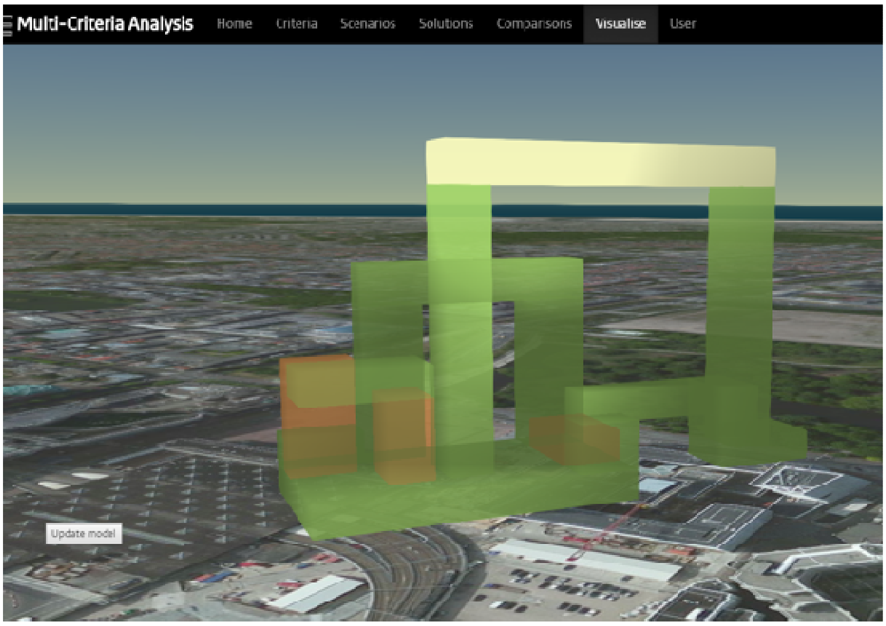

Figure 5. Example where BIMserver aided the MCA tool is by creating a custom made serializer to visualize the building using Cesium.js

7. MCA EVALUATION

The MCA software tool (http://mca.surge.sh) is provided as an open source web application (https://github.com/TNOCS/MultiCriteriaAnalysis). The tool is programmed in the TypeScript programming language and makes use of open source libraries such as Angular.js and Cesium.js.

The home tab is the first screen of the MCA tool. This tab allows the user to create, edit, import and export projects. Additionally, the system breakdown is defined in this tab. In the system breakdown all components of the system should be listed. In other parts of the MCA-tool the user can assign weights and scores to each of the components.

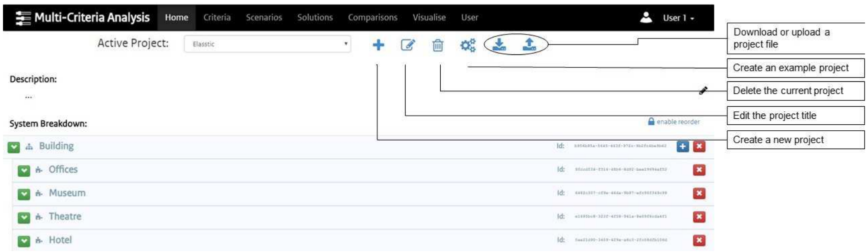

Figure 6. In the home tab the system breakdown can be defined.

Finally, each component is assigned a unique ID. This ID is used for identifying the components in other parts of the tool, such as the 3D-visualization.

In the scenarios tab, the user can define scenarios that should be taken into account when evaluating the building. Each scenario can be assigned a rating according to its importance, as shown in figure 7. Scenarios can also have sub-scenarios, which is useful when a scenario can occur at different locations. The structure of this tab is similar as for the criteria tab. Again, a pie-chart is used to visualize the weight distributions between scenarios.

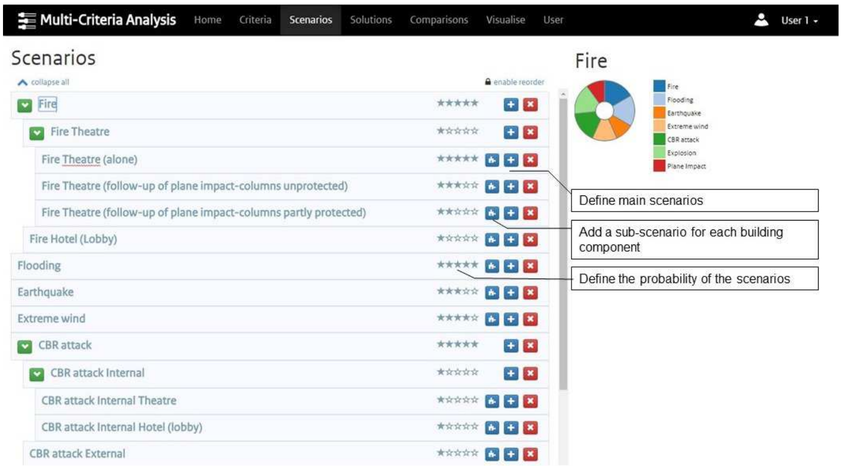

Figure 7. The scenario tab.

The tool automatically calculates the scorings for the designs (in the Solutions tab). When two solutions are selected, the Comparison tab can be used to compare scores of both solutions. Also, the total scores per module are calculated and displayed in this tab.

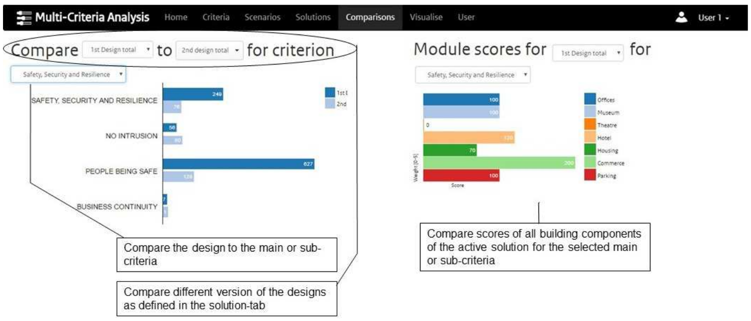

Figure 8. The comparison tab.

8. OBSERVATIONS

The ELASSTIC BIM concept proved to have great potential to the industry. Due to the automation of simulation models (with or without supporting services) the designer is provided with direct feedback of the performance of the building during the (early) design phase.

To optimize the usability of this concept additional features are introduced like model-checking, pre-processing of data (called ‘supporting services’ in this report), post processing of data (in this project to facilitate the MCA tool), advanced query/filter functions, etc.

These additional features facilitate the usability for simulation tools to use the ELASSTIC BIM concept, and BIM in general.

9. CONCLUSION AND DISCUSSION

The ELASSTIC project provided the following conclusions about the ELASSTIC BIM concept, the experiments and BIM in the industry:

1) There are numerous possibilities with the concept of automating simulations based on BIM data. At this moment there are still a lot of manual steps necessary. The potential of the concept is proven, but bringing it to (daily) practice will still be a big challenge.

2) These innovations are only possible with stable open standards (both data and API) and modelling agreements. During this project modelling agreements were made in the beginning of the project, but not honoured during the implementation. Several elements of the IFC where not usable for the simulation models. Good modelling and good export settings are an absolute requirement to use BIM in general, but the automated simulation concept of ELASSTIC in particular.

The use of open standards like the BIMSie API and the IFC data standard have proven to work when modellers keep to the agreements during the modelling of the BIM in the native software tools.

3) Not all software tools in the industry have the capability to support open BIM standards. We recommend every software vendor to support import and export of IFC.

4) The spread out use of classifications caused a problem with running simulations. The models in the project contained at least three different classifications (a French one, Omniclass and NlSfb). The use of multiple classification methods for objects in BIM is not a problem (and sometimes even recommended), but in this case only parts of the model were classified. Different parts were classified with different classification methods and there was no overlap between it. We highly recommend to classify as much objects as possible, with as many classification systems as needed. The accent is on the words ‘possible’ and ‘needed’.

5) Different simulation tools need different data as input; structured in a different way. Advanced BIM users in the industry know this and export several IFC files with different export settings for different collaboration partners. The ELASSTIC BIM concept doesn’t imply knowledge of the input requirements of simulation tools. Therefore there has to be one export setting to facilitate all simulation models. Use of pre- and post-processing services could contribute to the usability, but this still has to be proven in practical use-cases with large amounts of data and different time scales in execution.

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Improving the Strategic Use of PSS for Planning Support

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Key words: Planning support systems, spatial planning, stakeholder communications, strategy making, user-defined parameters

Abstract: Studies have shown that collaborative development of planning support systems (PSS) can benefit communication during the strategic stages of planning. These studies have mainly explored communication around the use of existing PSS. At the same time, significant bottlenecks remain that block PSS adoption in practice like concerns of user friendliness, awareness within organizations and quality of data. Therefore, we developed a planning support method that employs weighting and structuring mechanisms to support stakeholders in the strategic tasks of opening up and closing down about their interests to reach consensus and to define parameters for PSS. We tested the workshop-based method with students and professionals using process, outcome and usability performance variables. Findings showed mixed perceptions of process performance when using the method; however, outcome findings indicated those who used the method opened up and closed down their interests more effectively and defined fewer parameters. User perceptions of usability showed that while the support method provided structure, it also added complexity to the strategic planning tasks. Our findings suggest that planning support (systems) should be facilitated, targeted to planning needs and easily understood. Future research could also explore the extent to which the parameters defined by users represent the critical determinants of land-use change. This, may help to link strategy making to decision making.

1. INTRODUCTION

Spatial planning has changed dramatically as a result of the ‘communicative turn’ in planning (Healey, 1996). What was once considered a bureaucratic process informed by the advice of experts is now seen as a process of collective vision creation and coordinated action based on shared understandings (Innes and Booher, 1999). Communicative planning processes involve actors whose communication interactions continuously reaffirm and change the spatial structure (Mastop, 1999). These interactions are particularly important during strategic stages of the planning process, which are riddled with ‘wicked’ planning problems (Rittel and Webber, 1973; te Brömmelstroet and Schrijnen, 2010). These early interactions to sort out these problems steer pragmatic decision-making steps later in the planning process. They do so through the engagement of various knowledge claims and the testing of these claims, i.e. opening up and closing down (Rydin, 2007).

Researchers have become increasingly interested in the role of planning support systems (PSS) in supporting communication. This departs from PSS research focused on the instrumental value of these GIS-based computer technologies (Geertman, 2013). One line of this research evaluates the perceived added value of PSS based on performance factors such as enhanced communication and shared learning (Goodspeed, 2013; Pelzer, Geertman, & van der Heijden, 2016; Pelzer, Geertman, van der Heijden, & Rouwette, 2014). Another line experiments with new methods in PSS development to support actor communications during strategy making. These methods intertwine PSS development and the planning process through intensive collaboration between developers and users (te Brömmelstroet & Bertolini, 2008; te Brömmelstroet & Schrijnen, 2010; Vonk & Ligtenberg, 2010). These PSS development studies involve the engagement of actors with existing PSS.

Despite these advancements, numerous bottlenecks prevent the adoption of existing PSS in practice. Some of these bottlenecks concern awareness of PSS within organizations, their user-friendliness and quality of data (Vonk, Geertman, & Schot, 2005). These bottlenecks are particularly troublesome during strategy making when the role of (geo)information and knowledge is less evident than during operational decision making (Geertman, 2006) . Consequently, PSS may be perceived to add rather than to reduce uncertainty early in planning processes. It is unlikely that these bottlenecks can be overcome through technological innovation alone. Significant investment must be made in educating potential users about the added value of these systems and in educating IT developers about the supportive role PSS have within the strategic mission of communicative planning (Couclelis, 2005; Geertman, 2013; Pelzer et al., 2016; te Brömmelstroet, 2012).

We aim to enrich the discussion on PSS development in light of the adoption bottlenecks by looking outside the context of existing PSS use. We propose our own planning support method embedded in the strategic tasks of sorting out planning problems and scenario building. Our workshop-based method systematically guides stakeholders through a process of opening up about individual interests and closing down those interests to reach consensus on the planning problem. The method then guides stakeholders through the task of defining parameters used to construct scenarios for later-stage decision making.

After a brief discussion of the theoretical principles used in the development of our support method, we introduce three criteria we used to assess performance during strategy making with and without the use of our method. We then describe the research design for two experiments in which we tested the method- a controlled experiment with students and a workshop with business professionals. After which, we report our findings from the two experiments. We conclude the paper with a discussion of the findings and provide suggestions for future research.

2. ARE WE MODELING THE RIGHT THINGS?

When applying a PSS, an important first step is to decide what should be modeled. There is a tendency toward the inclusion of too much detail. Including more elements in the model creates the illusion of refinement and the elimination of uncertainty, but on the contrary, every additional element introduces more of what is unknown (Lee, 1973). For models to add value to strategy making, we must be weary of including too much detail and of attempting to do too much with them.

Any uncertainties surrounding a planning problem may be reflected in the model; thereby increasing uncertainty during decision making. Therefore, the decision of what to model is closely tied to strategy making. Here, space must be given for the opening up of various knowledge claims and the closing down of these claims (Rydin, 2007). Opening up introduces complexity and uncertainties that must be reduced by making choices. Strategy making in planning follow this iterative cycle of opening up about diverse stakeholder interests and subsequently closing down interests to reach consensus.

2.1 Mechanisms of planning support

Various methods can support the cycle of opening up and closing down. For example, the hierarchical analysis method (Saaty, 1980) is an open group process whereby all views are initially accepted and interests judged to have the lowest priority are ultimately ignored. The method uses weighing mechanisms to prioritize interests. Similarly, multi-criteria analysis (MCA) applies weighted indicators that represent stakeholder values to evaluate scenarios.

PSS often have built-in analysis mechanisms that guide users through strategic planning tasks. For example, *What if?* (Klosterman, 1999) allows users to create land-use suitability scenarios by selecting from a list of pre-defined scenarios and refining them. Opening up and closing down, therefore, occurs within the restrictions set by the system. Due to these restrictions, the analytical outputs the model produces may be problematic. This is because the realm of available options set by the PSS framework may not include the critical determinants of land-use change. By lifting these limitations, we may be able to select interests and define parameters for the PSS that are more representative of what stakeholders perceive to be critical spatial dynamics.

Moreover, according to Vennix et al, "most learning takes place in the process of building the model, rather than after the model is finished," (1997, p.103). If this is the case, then communicating to define parameters for PSS may help stakeholders to open up and close down their interests more effectively. These user-defined parameters (UDPs) provide information about stakeholder interests in spatial terms. We distinguish between UDPs that are descriptive, e.g. 'type of building', and those that can be measured, e.g. 'number of parking spaces'. Most, but certainly not all, descriptive parameters can be sketched in a sketch planning exercise but probably fewer of these can be described in measurable terms. The process of generating UDPs may help to link important interests communicated during strategy making to PSS used to inform decision making.

In this study, we claim a planning support method designed to help stakeholders define the parameters for a PSS may add value to strategic planning tasks. To support this claim, we test a planning support method (PSM) that helps stakeholders to transform their 'fuzzy' interests into user-defined parameters. The method is conducted in a workshop setting and applies weighting and structuring mechanisms to support a set of strategic planning tasks. A description of the method is provided in Section 3.

2.2 Criteria to assess planning support performance

In general, potential PSS users are not aware of the added value of these systems to their established planning processes; they perceive PSS to lack user friendliness and they doubt the quality of data outputs these systems produce. Since PSS, like any intervention on a planning process, risk adding complexity and uncertainty, they should be evaluated in terms of their added value. According to Innes and Booher (1999), process and its outcomes are interrelated in communicative planning. In this study, we evaluate the added value of planning support in terms of user satisfaction with the planning process. And, we explore the quality of data outcomes by measuring the individual interests, selected interests and parameters defined by stakeholders. We expect that users of the PSM will (1) make a narrower selection of interests from a larger list of individual interests; resulting in (2) fewer modeling parameters that are (3) more descriptive and quantifiable when compared to those who do not use the PSM. Since usability is intrinsically tied to utility (Grudin, 1992), we also take usability into account when testing the support method. The usability study provides insights into *why* the support method has a certain impact on process and outcome.

3. METHODOLOGY

In this study, we use our planning support method as a vehicle to explore how planning support interventions impact strategy making. This section introduces our PSM and describes the set-ups for the two experiments we ran using the PSM. We then describe our methods for data collection and analysis.

3.1 The planning support method

The PSM is a 6-step strategic spatial planning exercise conducted in a workshop setting. Materials used to support the exercise include a game board, a scorecard and a paper map of the project site. The game board is shaped like a hexagonal web divided into six triangular zones, one for each player. In Step 1, players list 5 individual interests and prioritize them by placing interest *tokens* at different levels within their zone. Weighting mechanisms help the players to prioritize their interests by placing restrictions on token placement, see *Figure 1*. In Step 2, the players discuss their interests and can add new interests. In the next step, they calculate their shared interests and list all interests with an aggregate value greater than 3 on the scorecard.

In Step 4, the players select the interests with the highest aggregate values to determine their objectives. Then, they link each objective to its corresponding interests using elastic string. In Step 5, the players create parameters for each interest they linked and record them on the scorecard. Finally, the players sketch these parameters on a map of the project site.

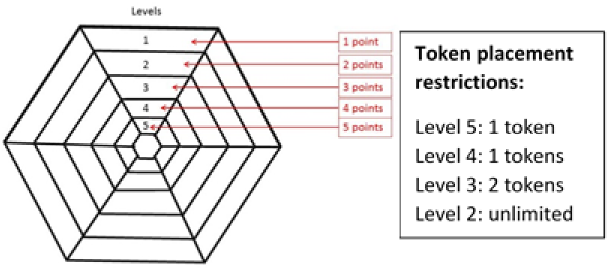

Figure 1. Diagram of the game board showing levels and restrictions on token placement

3.2 Experimental set-up

To understand the impact of our PSM on strategy making, we conducted two experiments. We first ran a controlled experiment with 60 third-year civil engineering Bachelor students from a Dutch technical university to trial the PSM before using it in a professional setting. In the second experiment, we applied the PSM in a workshop with a group of business professionals. The four professionals – a business manager, one Dutch and one German commercial real estate broker and a facility manager –were developing a plan to upgrade their 8-hectare retail terrain.

Since the student exercise involved a fictitious project and the professional workshop involved a real project, we prepared quite differently for the two experiments. For the former, we created a hypothetical case: the revitalization of a derelict harbor in Amsterdam. We provided factual information from online resources so the students could study the project site and generate interests for their fictional characters. For the latter, we researched project documents and met with the facility manager. We learned that the 10-year old retail terrain is a popular shopping destination in the region and is fully rented by leading Dutch and global companies. Over the years, the public spaces and parking zones have aged significantly. While the business professionals met numerous times in the past to set the budget for routine repairs and maintenance, they were struggling to agree on a long-term upgrading plan.

Student experiment: At the beginning of the experiment, we divided the students into 10 groups. Half of the groups used the PSM; the other 5 (control) groups completed the same 6-step strategy making exercise without the PSM. Given the large number of groups, the first author could not facilitate each group individually. Therefore, the students followed instructions in a handout that explained each task. The students were not allowed to move to the next step until instructed by the first author. The only materials the control groups received were a partial scorecard for recording their interests and parameters along with a site map. Since the control groups did not receive a game board, they had no formal way of ranking their interests and most students wrote their interests randomly on extra paper or not at all. *Figure 2* gives an impression of the difference between the two methods during the interest identification and selection steps. Steps 5 and 6 were similar for both groups. Due to time limitations, each group selected one objective and sketched its parameters on the site map.

Figure 2. (L) PSM group using the game board, *(R)* Control group using diverse informative materials.

Professional workshop: The business professional workshop followed the same 6-step strategic spatial planning exercise. In this exercise the first author facilitated the workshop by leading the practitioners through each planning step.

3.3 Data collection

At the conclusion of the exercise, students responded to the planning process questionnaire. The students assessed each step of the exercise using a five-level Likert scale ranging from 1 ‘strongly disagree’ to 5 ‘strongly agree’.

They also ranked 5 aspects of the exercise they felt needed the most improvement. The professionals provided responses to the same questionnaire statements in feedback interviews by telephone. Data recorded on the game boards, scorecards and site maps provided quantitative data about the exercise outcomes, i.e. number of individual interests, number of selected interests, number of UDPs and types of UDPs. Since the control groups were not given materials for recording their interests, we assumed that each stakeholder contributed 5 interests, *see Step 1 of the PSM in Section 3.1*.

The students also worked in teams consisting of a PSM group and a control group to write 5 experiment reports. The narratives in these reports provided comparative insights that help to explain both the students' questionnaire responses and findings from the analysis of the exercise materials.

3.4 Data analysis

We used mixed methods to analyze the data based on the performance criteria: process, outcome and usability. To begin, we explored user responses to the questionnaire that assessed each step of the strategy making process. We compared the mean scores of the responses from the PSM groups (N = 30) against those of the control groups (N = 29). We conducted a t-test on these means to identify statistically significant differences. We triangulated this analysis with an analysis of the group reports and the business professional feedback interviews.

Next, we explored the outcome data in four steps. First, we counted the number of individual interests recorded on the game boards compared to the 30 interests that we assume each control group listed. Second, we counted the number of selected interests each group recorded on their scorecards. Third, we counted the number of UDPs recorded by each group on the scorecards and on the site maps. We omitted data for one group (PSM group 1) that did not hand in exercise materials. Fourth, we calculated the percentage of measurable and descriptive parameters created by each group. We followed the same analytical procedure for the business professional data.

Finally, to assess usability we compared how the students ranked a set of responses to the statement "the exercise could be most improved by providing" and compared this to feedback from the business professionals. We report our findings in Section 4.

4. FINDINGS

4.1 Process

Table 1 summarizes our findings of user perception gathered from the planning process questionnaire. Overall, the results show a somewhat positive attitude from both groups toward the strategy making exercise, i.e. 15 of 18 responses scored above 3.00. Results from the t-test show only two statements with responses that were significantly different. Statement 3 scored substantially higher with the control groups than with the PSM groups, Δ .76, p =.0004. The control groups also scored statement 6 substantially higher than the PSM groups, Δ 0.43, p = .042. Both group types scored lowest on the statement 8.

Table 1. User perceptions of the planning exercise comparing mean group scores

Statement	Method groups N = 30	Control groups N = 29	t-Test p = value
1. The exercise helped me identify the interests of my stakeholder	3.53	3.28	.29
2. The exercise has given me insight into the interests of the other stakeholders	3.57	3.59	.93
3. The exercise helped my group to generate new interests together	2.93	3.69	.0004
4. The exercise helped my group to negotiate and select interests	3.50	3.38	.55
5. The exercise helped my group to generate explicit project objectives based on the selected interests	3.47	3.45	.94
6. The project objectives reflect the main interests of the group	3.47	3.90	.042
7. The exercise helped my group to specify measurable parameters for the project objectives	3.20	3.17	.91
8. Based on the outcome of the sketch planning exercise, I have a clear idea how the parameters of the project objectives could be set up in a computer environment	2.73	2.72	.97
9. Overall, I have a positive feeling about the exercise	3.00	3.21	.40

A review of the team reports provided further insights into these findings. All five of the teams expressed that the PSM provided a more structured process to prioritize interests. Team 3 explained:

> Because of the low number of interests, it was still possible for the [control] group to have an overview of common interests (…) We think that in a case with many more interests, like 10 from every person, the [PSM] group had the benefit of still being able to read the most important interests, only because of the ease of just reading the [interests] closest to the center.

Team 2 explained that the interest selection process of the control group was very random and that since the importance of each interest was not evaluated, less important interests might be chosen. Adding to this randomness, the control groups of Team 2 and Team 3 both changed the sequence of the planning steps. They created project objectives before listing and selecting interests. According to Team 2:

> This created the objectives more randomly without any arguments to the why and how. In real life this would lead to a lot of commotion (…) the [PSM] group has a good argumentation to why the objectives are chosen (…) To conclude, the process of the [control] group was led by instinct rather [than] logic.

We also found explanations to the low scores given to statement 8. Team 2 explained that their PSM group systematically defined parameters based on the objectives, while their control group was "just guessing". Team 4 expressed a similar view. Team 5 stated that the more precise interests of the PSM group led to fewer UDPs, and that the more global interests of the control group led to more UDPs. Both Teams 1 and 3 expressed difficulty defining and sketching parameters.

Comparatively, the business professionals expressed mostly positive opinions. The PSM helped them move step-by-step and they were able to reach consensus. They generally felt that the PSM helped them to effectively communicate and prioritize their interests and to set clear objectives. Businessman J stated:

> [The PSM] helped me to be forced to think about what is really important (…) to really pick the subjects that are of importance and to give a little bit of structure or hierarchy or importance to those items.

Businessman S expressed the added value of the PSM stating:

> I think we had these interests and we knew it but I think it's good to see what the other interests are. And that we have the same interests.

Similar to the students, however, the business professionals expressed mixed views of the parameter defining step. Businessman J explained that while parameters like "accessibility" are clear, it is difficult to measure subjective interests like 'improvement of the area'. According to Businessman

S, the sketch planning exercise triggered an important discussion about finances. He stated:

> Yeah, I think the most important things were written down [on the site maps] (...) And when we checked the financial parts of it, I think it's very difficult to do everything, but I think it's very good that we write down with each other the most important things(…). I think we can discuss about that in the next workshop.

4.2 Outcomes

The PSM groups and the business professionals, showed a more significant reduction of interests than the control groups. *Figure 3* shows that although the practitioners listed the most individual interests (45), they had one of the lowest numbers of selected interests (8). On average, the PSM groups selected 10.6 interests out of 36.8 individual interests; whereas, the control groups selected 13.2 interests out of the assumed 30 individual interests.

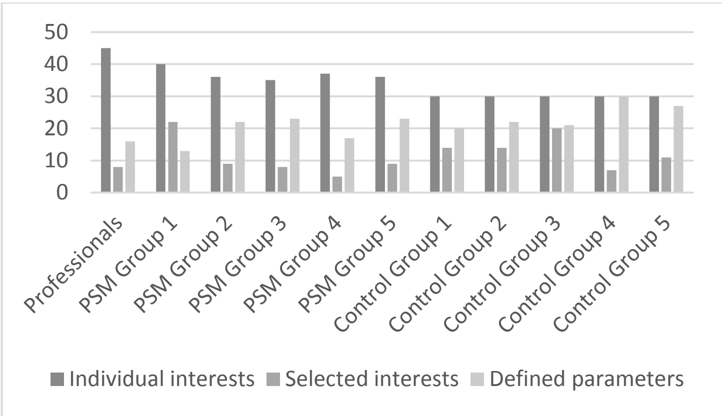

Figure 3. Number of individual interests, selected interests and user-defined parameters

In terms of parameters, the professionals and student PSM groups defined fewer parameters than the control groups. The professionals defined 16 parameters. The PSM and control groups defined on average 19.6 (range: 10.0) and 24.0 parameters (range: 10), respectively. Taking a closer look at the parameters, *Figure 4* shows the percentage of parameters that were sketched (descriptive) and the percentage that are measurable. The professionals were able to sketch 94% of their parameters, 69% of these being measurable. On average, the PSM groups sketched more of their parameters than the control groups, 79% and 75% respectively. However, the PSM groups created fewer measurable parameters than the control groups, 45% and 60% respectively.

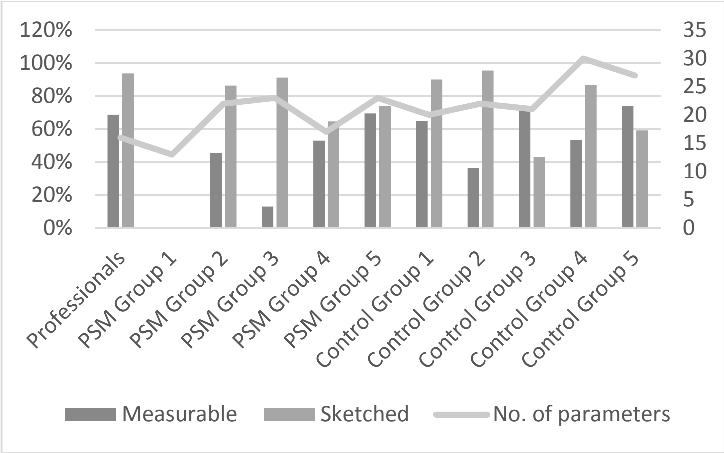

Figure 4. Percentage of user-defined parameters that are sketched (descriptive) and those that are measurable

4.3 Usability

Table 2 shows the comparative mean scores measuring usability for the ranked responses from the students. The PSM students ranked statement 5 (*M* = 3.57) more than half a point (0.54) higher than the second highest ranked answer to statement 1 (*M* = 3.03). In their report, Team 1 students wrote:

> At first the [method] was very complicated when the [strings] were introduced. We didn't have enough time to connect the interests to the objective.

Table 2. Ranking of factors that could most be improved in the two planning exercises

Statement	PSM Groups N = 30	Control Groups N = 29
1. More time to conduct each round	3.03	2.10
2. Better visualization techniques for the objective setting exercise	2.93	3.62
3. Better visualization techniques for the sketch planning exercise	2.77	3.83
4. More information about stakeholder interests	2.83	2.90
5. Clearer instructions for each round of the exercise	3.57	2.83

The control students ranked statement 3 (*M* = 3.83) and statement 2 (*M* = 3.62) significantly higher than the other options. Additionally, their responses to statement 1 ($M = 2.10$) scored lowest of all the factors by 0.73 points. In terms of visualization, the Team 2 students wrote:

> The [control group] identified the different interests, but didn't make it visual. With the visualization of the three types of interests, the [PSM group] had a clear view of where the types of interest came from (…) The method used by [PSM group] created a better view of the value of the interests.

Additionally, we found remarks in the group reports that learning how to use the game board took time away from conversations about individual interests. Furthermore, both the professionals and some student PSM groups found the step of linking the objectives to the selected interests (Step 4) to be confusing, thereby, adding little value to the exercise.

5. DISCUSSION AND CONCLUSION

In this study, we investigated the added value of collaborative PSS development to strategy making in spatial planning projects. Previous research has shown that collaborative efforts to develop content for existing PSS benefits shared learning and communication. Yet, numerous bottlenecks continue to block the adoption of these PSS in practice. Considering this, we sought to explore collaborative PSS development outside the context of PSS use.

We did this by testing our PSM, a method designed to structure the communicative process of opening up and closing down stakeholder interests and translating these interests into user-defined parameters that provide content for PSS. Our guiding principle for the study was that models should not be too comprehensive or attempt to do too much. We conducted both a controlled experiment with students and a workshop with business professionals to test the PSM under different use conditions. Findings from both studies show that use of the PSM resulted in a narrower selection of stakeholder interests and fewer UDPs. While these findings support our initial assumptions about the planning outcome, our process findings were rather unexpected. The use of the PSM resulted in a clear perceived improvement in the planning process according to the business professionals; however this was not the case for the students who used the method. Findings from the usability study help to explain these unexpected results.

Students and professionals agreed unanimously that the weighing mechanism built into the PSM provided a structured and visual way for them to open up and close down their interests. However, the PSM student groups ranked the need for more time and clearer instructions highest in the usability study. The PSM was perceived to be too complicated; therefore, the effort of learning to use the method took time away from other important tasks. This put the PSM groups at a disadvantage compared to the control groups. The PSM groups particularly needed more time to learn about their individual interests. This was not the case with the business professionals probably because they already had a good understanding of their individual interests. Another reason the business professionals encountered fewer problems was likely because the first author was available to facilitate the use of the PSM and answer any of their questions. This is a significant finding, especially in the context of the PSS user-friendliness bottleneck. It suggests that planning support methods, and PSS alike, should be facilitated, easily understood and targeted in scope to address only the specific needs of its users.

In terms of parameter defining, we found that the PSM groups created more descriptive sketches, while the control groups produced a larger percentage of parameters that were measurable. Based on this, we found no clear relationship between the effectiveness of opening up and closing down stakeholder interests and the parameters defined during sketch planning. The descriptiveness of the sketches probably had more to do with whether or not the UDPs could be depicted spatially. It is also likely that user characteristics such as individual knowledge, creativity and understanding of the exercise strongly influenced the outcomes of the sketch planning exercise. In general, the parameters defined by the students were rather vague and the sketched plans lacked sufficient detail to be implemented in a PSS. Comparatively, the business professionals sketched nearly all of their parameters and the majority were measurable. This was likely because the professionals were already knowledgeable about their project site and because the interests they selected were mostly spatial. For example, accessibility was a main interests and they parameterized it in several measurable ways.

In this study we have claimed that to build better models, we should adopt support methods that help stakeholders to define fewer parameters. Of course, the quality of these parameters is also important. Future research should explore the extent to which these parameters accurately represent the critical determinants of land-use change, as this may be an important factor to determine the success of PSS adoption in decision making. Our findings indicate the need for a second workshop to refine the UDPs and to create assessment indicators for scenario planning. IT developers could facilitate such a workshop by guiding users through this process and engaging in a conversation about how different parameters influence one another. For example, three parameters created in the business professional workshop – traffic flows, duration of stay and number of parking places – could be linked under the indicator ‘auto turnover per hour on peak days’.

6. CONCLUSION

Whether or not PSS will achieve their full adoption potential in practice remains uncertain. However, there is growing evidence that exercises in PSS development add value to communication during strategy making. Complex communications about stakeholder interests can benefit from interventions that structure this process of opening up and closing down interests. These strategic tasks are fundamentally linked to later-stage decision making. In this context, our planning support method addresses the gap between the knowledge generated during strategy making and the information that PSS generate to inform decision making. The key mechanisms of the method are twofold: (1) assigning weights to stakeholder interests in a visual and systematic manner and (2) providing steps for stakeholders to systematically translate their interests into user-defined parameters. Testing the PSM in both a controlled experiment and real project setting has given us some indication of where these mechanisms support the strategic tasks of planning and where they risk adding complexity and uncertainty. Findings from this study help us to understand the added value of collaborative PSS development within a context of planning support that extends beyond the use of existing PSS.

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Heterogeneity in choice mechanisms underlying route choice behavior under conditions of uncertainty:

A behavioral mixing latent class model

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Key words: regret, utility, heterogeneity, uncertainty, context

Abstract: Commonly applied models in travel behavior research to include unobserved heterogeneity are the mixed logit, latent class and a combination of these approaches. In this study, we draw the attention to latent class models since our main interest is the distinct classification of travelers into subgroups. Latent class models identify different segments of individuals who share an identical utility function. However, although these models capture some degree of heterogeneity, they are based on the weak assumption of behavioral homogeneity. By way of contrast, different individuals may apply different behavioral principles to arrive at a choice. To relax this assumption, we use a behavioral mixing model that classifies individuals into latent classes that differ in terms of the decision strategy that individuals apply. Utility maximization and regret minimization are two behavioral choice mechanisms, which may lead to different choices. The present study contributes to the literature on behavioral mixing models by estimating a latent classes, based on different behavioral rules (utility maximizing vs. regret minimization) , in which the rules are context-dependent and choices are made under conditions of uncertainty. A further extension pertains to the treatment of the repeated choice nature of the dataset. The data used for this study were collected using a web-based survey, including a stated choice experiment. Route choice is the example used for the decision making process and context variables are incorporated to explore the heterogeneity in travelers' behavior.

1. INTRODUCTION

There have been a number of studies in urban planning and transportation research, focusing their attention on alternative behavioural principles that individuals may apply in making activity-travel decisions. From social sciences to behavioural economics, different theories and models have been proposed to better represent and predict human choice behavior in order to better understand the way in which people make decisions. A key area of investigation is the development of alternatives to the commonly applied random utility maximization paradigm. One, relatively recent, proposed alternative is random regret minimization (Chorus, 2010), which allows for semi-compensatory behavior. Regret arises when an individual experiences the chosen alternative and realizes that a higher payoff could have been achieved if a foregone alternative had been chosen.

Another issue that continues to attract interest is the modelling of heterogeneity in these choice models. It seems self-evident that heterogeneity exists in the decision processes that individuals follow. Whilst abundant research has been carried out to capture unobserved heterogeneity in choice models, the vast majority of these studies have been based on the weak assumption of behavioral homogeneity. That is, these studies have allowed different taste parameters in a single mathematical specification, which represents a single behavioral mechanism (typically utility-maximizing behavior). A second stream of research has suggested the use of latent class modeling to identify latent classes that differ in terms of use different decision rules to represent heterogeneous human choice behavior. Research to date has tended to focus on the restrictive assumption that only one of the two decision paradigms can represent sufficiently all the choices observed in a sample (e.g., Chorus, et al., 2011; Chorus, 2012; Thiene, et al., 2012; Boeri, 2012a, 2012b; Kaplan and Prato, 2012; Hensher, et al., 2013; Chorus and Bierlaire, 2013).

Several recent studies have highlighted the importance of allowing for heterogeneity in terms of decision-making strategies (Hensher, 2008, 2009; Zhu and Timmermans, 2010). The study of a latent class structure in which different decision rules are used in different classes was first carried out by Hess, et al., 2012. On par with this work, (Chorus, Rose, et al., 2013) draws our attention to a mixed model in which some attributes may be processed using one type of decision rule (e.g. utility maximization), while others may be processed using another rule (e.g. regret minimization). Later, in the context of distinguishing sub-groups of respondents, (Hess and Stathopoulos, 2014) investigated a mixed random utility-random regret structure, in which the allocation to a given class is driven by both observed and unobserved personal characteristics, based on an underlying assumption that someone who is more likely to be a regret minimizer is less likely to accept a real life commute journey which performs poorly compared to his/her ideal levels. In a similar vein, Boeri, et al., 2014 proposed a person-specific model structure consisting of a mixture of random utility maximization (RUM) and random regret minimization (RRM) within a latent class framework, in the context of traffic calming schemes. Although original regret theory is concerned with decision-making under uncertainty, no previous study has taken uncertainty into account.. To the best of our knowledge, Sun, et al., 2012 is the only study, which considered multiple uncertain events, allowing for latent classes of risk attitudes. However, utility maximization was the only decision mechanism used.

Another potential limitation of these studies is the assumption that the estimated functions capturing particular choice mechanisms are invariant across choice context. Thus, it is assumed that individuals are either utility-maximizers or regret-minimizers regardless of the context within which a decision has to be made. This paper contests this assumption that human choice behavior is not influenced by external circumstances, implying that the decision mechanism adopted can differ depending on the context.

We use traveler's route choice behavior as the example to illustrate the proposed model. The route choice decision-making process is considered to be a problem under conditions of uncertainty because travel times are inherently stochastic. Consequently, variability in travel times implies that travellers can never be perfectly certain to arrive at a particular time. We contend that the importance of arriving on time may depend on context. Factors influencing the importance of arriving on time include activity type, the number of people involved and the relationship with these people. Moreover, people differ in this respect.

To examine these assumptions, in the present paper, we report the results of a latent class model in which the classes differentiate between utility maximizers and regret minimizers. Class membership is assumed a function of personal characteristics of respondents.

The remainder of the paper is organised as follows. We start discussing the data collection, which involved a stated choice experiment under uncertainty. Next, we report sample characteristics. Then, we turn to the core of the paper, which concerns the estimated coefficients of the latent class model. We complete the paper by discussing some planned future extensions of the current model.

2. DATA

For the data collection, a larger survey was created and administered via Pauline, a platform developed by and for our group for the creation and administration of web-based questionnaires. This web-based survey was implemented in the Rotterdam region, The Netherlands in March 2015. The sample consists of 1003 respondents.

The first section of the survey queried respondents about their socio-demographic (personal and household) characteristics. The data needed to estimate the latent class model involved a stated choice experiment. It differed from standard stated choice experiments in that context and uncertainty underlying the decision making process had to be manipulated. The experiment addresses the choice of route for different trips considering three unlabelled routes as the choice alternatives, which differ in terms of their expected arrival times. The expected arrival time, expressed in minutes, is the main attribute characterizing each route. Respondents were also informed about the frequency of occurrence, i.e. how often travellers will arrive at the destination earlier or later than the desired arrival time. This frequency is used to express the uncertainty of the travel time for each route. In essence, this uncertainty is a probability but for the sake of a more familiar and clear representation for the respondents, it was indicated in such a contextual way. Specifically, it was expressed as the number of days that travellers will experience different arrival times out of 10 travel days, for example, “7 out of 10 days”.

Different scenarios were created to systematically vary the context of the route choice decisions. Three context variables were included: the type of activity, the number of people involved, and the nature of the relationship with these people. Attributes were varied in terms of four or eight levels. Because an additional eight level blocking variable was used, the experiment involved an 8^2*4^8 full factorial design. Because the number of generated choice sets is vast and therefore the design is impossible to complete by respondents, an orthogonal fractional design consisting of 128 profiles was constructed. This design is balanced, meaning that each pair of levels appears equally often across all pairs of attributes within the design and the choice sets were selected in such a way that none of them has a dominant alternative. Thus, the 8-level attributes appear 16 times in the overall design and 4-level attributes appear 32 times. The experiment was orthogonally blocked into 8 orthogonal sets of 16 questions each. One of the blocks with all possible scenarios of 16 profiles was randomly assigned to each respondent. The profiles were randomized within the blocks as well.

Table 1 gives an overview of the characteristics of the sample. Due to limited space, we will not discuss the distributions in any detail.

*Table 1.*Socio-demographic distributions of the sample.

	Description	Frequency	Percentage
Gender	Male	417	41.6
	Female	586	58.4
Age	18-35	275	27.4
	36-65	600	59.8
	>66	128	12.8
Household size	1	320	31.9
	2	400	39.9
	>2	283	28.2
Marital status	Single, with/without children	391	39.0
	Couple, with/without children	535	53.3
	Living with multiple persons	77	7.70
Education	Primary/ lower education	139	13.9
	Middle general/vocational education	422	42.0
	Higher general/ vocational education, university degree	442	44.1
Income	No/ low income	117	11.7
	625-1875	519	51.7
	>1876	367	36.6
Driving license holding	Yes	763	76.1
	No	240	23.9
Driving experience	<1	17	1.70
	2-5	55	5.50
	>5	676	67.4
	Not applicable	255	25.4
Mainly used means of transport	Car	448	44.7
	Bike/Motorbike/e-bike/moped	407	40.6
	Public transport	148	14.7

3. MODEL SPECIFICATION

3.1 Latent class analysis

The basic form of a latent class framework is given by the weighted sum of choice probabilities across the *S* classes:

$$LC = \sum_{s=1}^{S} P_{ns} P_{nc}(\beta_{\mathrm{s}}) \tag{1}$$

In this study, *S*=2 because we differentiate between two behavioral mechanisms. P_{ns} is the probability of respondent *n* belonging to class *s* and P_{nc} is the choice probability of the same respondent. The choice probability within each class depend on the two behavioral mechanisms, and thus are defined differently for each class. Class membership of both classes are defined in terms of a logit model.

We assume that some of the choices of respondents may reflect utility-maximizing behaviour. The corresponding expected utility function for alternative *i* is defined as:

$$U_{\mathrm{int}} = \beta \times \sum_{j=1}^{J} P_{\mathrm{j(i)\,nt}} \times X_{\mathrm{j(i)\,nt}} + \boldsymbol{\gamma} \times \mathbf{C}_{\mathbf{v}} \times \sum_{j(i)}^{J} P_{\mathrm{j(i)\,t}} \times X_{\mathrm{j(i)\,t}} + \varepsilon_{\mathrm{int}} \tag{2}$$

where $P_{j(i)t}$ is the probability of the occurrence for outcome *j* for alternative *i* in choice situation *t*, $X_{\mathrm{j(i)\,nt}}$ is arrival time *j* of alternative *i* for respondent *n* under choice situation *t*, and C_{n} is the vector of context variables.

Other choices are assumed to reflect risk-minimizing behaviour. The corresponding model postulates that the regret associated with an alternative equals the sum of all the regrets comparing the three alternatives in terms of their attributes. The expected regret function for the second class is given by the following equation:

$$R_{\mathrm{int}} = \sum_{\mathrm{i'}}^{\mathrm{I}} \sum_{\mathrm{j(i')}}^{\mathrm{J}} \sum_{\mathrm{j(i)}}^{\mathrm{J}} \max\{0, \beta \times [P_{j,i'} \times P_{j,i}(X_{j,i'} - X_{j,i})]\} - \boldsymbol{\gamma} \times \mathbf{C}_{n} \times \sum_{\mathrm{j(i)}}^{\mathrm{I}} P_{j,i} \times X_{j,i} + \varepsilon_{\mathrm{int}} \tag{3}$$

To determine how socio demographic variables affect the class membership probability the following logit model is specified:

$$P_{ns} = \frac{\exp(\delta_s + \boldsymbol{\tau}_{\mathbf{s}} \times \mathbf{Z}_n)}{\sum_{s=1}^{S} \exp(\delta_{s'} + \boldsymbol{\tau}_{\mathbf{s'}} \times \mathbf{Z}_n)} \tag{4}$$

where δ_s is a class-specific constant and $\mathbf{Z}_{\mathbf{n}}$ denotes the vector of socio demographic variables.

3.2 Repeated choice nature of the dataset

A situation in which a respondent is faced with multiple choices leads to the commonly used assumption that the tastes vary across respondents but not across choices for the same respondent (Revelt and Train, 1998). Thus, conditional on β, the probability of a person *n*'s observed sequence of choices is the product of standard logits

$$P_{nc}(\beta) = \prod_{t=1}^{T} P_{ntc}(\beta) \tag{5}$$

However, not recognizing the possible correlations across choice situations for a given respondent, the repeated nature of the dataset potentially may have a significant effect on model results, especially in terms of biased standard errors (Ortúzar and Willumsen, 2001). Therefore, to allow cross choice correlations we adopt an error components specification as suggested in a previous study on estimating asymmetric discrete choice models within stated choice experiments (Hess et al., 2008). Given the specifications of utility and regret, the random component can be composed as follows:

$$\varepsilon_{\text{int}} = \sigma e_{in} + \tilde{\varepsilon}_{\text{int}} \tag{6}$$

where $\tilde{\varepsilon}_{\text{int}}$ follows the usual i.i.d. type I extreme value distribution and e_{in} is a draw from an independent Normal variate with a zero mean and a standard deviation of 1. The fact that the separate error components are distributed identically means that the model remains homoscedastic and, thus, the probability of an individual *n*, choosing alternative *i*, is still given by the logit equation. Parameter σ is estimated for each class, as if it was weight on attribute, in the same way as β's on the attributes are identified.

4. MODEL APPLICATION

4.1 Estimation

The proposed model was coded and estimated in MATLAB R2013b, using 500 Halton draws for the continuous random component in the choice model part. Multiple estimation runs were carried out to avoid the optimization end up in local minima, which is a common problem in the estimation of latent class models. The levels of context and socio-demographic variables were effect coded. Hence, for *L* levels, *L*-1 indicator variables were created. Each level was coded 1 on the corresponding indicator variable, 0 on all other indicator variables, while the last level of each attribute was coded as -1 on all indicator variables.

4.2 Results

Table 2 gives an overview of the results for the goodness of fit of the model without the error components composition (denoted as Model 1), for which detailed results are not reported here, and for the proposed model with the error components composition (denoted as Model 2). Comparing the log-likelihood value, the adjusted rho-squared and the Akaike Information Criterion (AIC), findings indicate that the suggested behavioural mixing model produces a significant improvement in comparison with the simple latent class mixture. In terms of the class allocation probabilities, the first model suggests an even split between RUM and RRM, while in the second model, the distinction is more clear, since there is a slightly larger probability for RRM (53%).

Table 2. Model fit summary.

	Model 1	**Model 2**
Log-likelihood	-13465.6005	-12669.6425
Rho_sq	0.23623	0.28138
Adj. Rho_sq	0.23362	0.27866
AIC	1.6839	1.585
No. of parameters	46	48
No. of observations	16048	16048
Class allocation probabilities		
RUM	0.50	0.47
RRM	0.50	0.53

Next, the estimation results for each of the two latent classes representing different behavioural mechanisms are presented in Table 3. The parameter which refers to the pure influence of the expected arrival time is shown to be highly significant and positive for both classes, meaning that a higher probability of arriving earlier, significantly increases the utility and decreases the regret for the first and the second class respectively. Noticeably, we see a much higher sensitivity for respondents belonging to the regret minimization class. This implies the tendency of these individuals to compare the different attributes and feel regret if their choice is outperformed.

As for the influence of interactions between the context variables and expected arrival times, we note that for the utility maximization class, a higher positive parameter means that the corresponding category of the variable increases the utility upon arriving earlier, while it decreases the utility of arriving later. For the regret minimization class, a higher positive parameter shows the decrease in regret if the arrival is earlier, while the opposite holds for a later arrival time. Overall, there are small differences in what influences the utility and the regret function for classes one and two respectively, but we can summarize the most important facts. Clearly, for both classes, activities with a scheduled starting time seem to have the biggest influence when making route choice decisions. Regarding the number of people involved, the results are not statistically significant when meeting a bigger group of people. For the first class though, meeting one person corresponds significantly to decreasing utility of a higher probability of arriving earlier. One possible explanation is that people want to avoid waiting alone when arriving at their destination. As for the relationship with people, meeting close friends and colleagues seems to be more important factors for not arriving late for the people belonging to the first class, while only close friends seem to be important for the second class. Lastly, it should be mentioned that the parameter for the error component is highly significant for both choice models of the two classes.

*Table 3.*Estimation results for choice model components.

	RUM		
Attributes			
	Estimate	t-stat	p-val
Expected arrival time	0.0584	9.78	0.00
Dinner at a restaurant	-0.0088	-0.69	0.49
Dinner at a house	-0.0384	-3.02	0.00
Cinema	0.0562	4.27	0.00
Sports game	0.0417	3.14	0.00
Public discussion	0.0088	0.68	0.50
Volunteer work	0.0219	1.70	0.09
Shopping	-0.0529	-4.15	0.00
Meeting 1 person	-0.0222	-2.58	0.01
Meeting 2 persons	0.0113	1.28	0.20
Meeting 4 persons	0.0123	1.43	0.15
Close friends	0.0103	1.30	0.19
Colleagues	0.0056	0.68	0.50
Relatives	-0.0105	-1.30	0.19
Sigma	1.018	24.08	0.00
	RRM		
Attributes			

	Estimate	t-stat	p-val
Expected arrival time	0.3395	39.66	0.00
Dinner at a restaurant	0.0451	2.04	0.04
Dinner at a house	-0.0186	-0.93	0.35
Cinema	0.0716	3.13	0.00
Sports game	0.0402	1.84	0.07
Public discussion	-0.0387	-1.97	0.05
Volunteer work	-0.0208	-1.04	0.30
Shopping	-0.0605	-3.3	0.00
Meeting 1 person	-0.0153	-1.13	0.26
Meeting 2 persons	0.0002	0.01	0.99
Meeting 4 persons	-0.0019	-0.14	0.89
Close friends	0.0193	1.4	0.16
Colleagues	-0.0054	-0.4	0.69
Relatives	-0.0073	-0.54	0.59
sigma	0.4308	14.99	0.00

Further, the results for the class allocation are reported. Only the results from the first class are presented in the table, since the second class is used as a reference. This means that positive values of membership variables relate to the first class, while negative values relate to the second class.

Looking at the constant (δ_s), respondents are more likely to belong to the regret minimization class, if no other covariates were included. In this case, socio demographic characteristics of people are used to explain the class allocation probability. Specifically, we notice that males are more likely to belong to the RUM class, while females are more probable members of the RRM class. Young people, between 18-35, inexperienced drivers, are also more likely to behave as utility maximizers, while middle-aged and elderly people, with more years of driving experience, are more likely to behave as regret minimizers. Individuals with a lower level of education seem to belong to the first class, while people with higher education are more probable members of the second class.

*Table 4.*Estimation results for class membership.

	Estimate	t-stat	p-val
Male	0.0698	0.9	0.37
18-35 yrs	0.4504	3.29	0.00
36-65 yrs	-0.1764	-1.6	0.11
Household size: 1	-0.0092	-0.05	0.96
Household size: 2	-0.0207	-0.16	0.87
Single, with/without children	0.2527	1.29	0.20
Couple, with/without children	-0.2483	-1.61	0.11
Primary/ lower education	0.3308	2.3	0.02

	Estimate	t-stat	p-val
Middle general/vocational education	-0.2152	-2.03	0.04
No/ low income	-0.0455	-0.29	0.77
625-1875 euros/month	-0.1184	-1.07	0.28
Yes	0.1694	0.59	0.55
<1 years driving experience	0.8035	1.65	0.10
2-5 years driving experience	-0.1427	-0.45	0.66
>5 years driving experience	-0.3892	-1.64	0.10
Car users	-0.1627	-1.42	0.15
Bike/Motorbike/e-bike/moped users	0.0988	0.92	0.36
δ_s (constant)	-0.1032	-0.4	0.69

5. CONCLUSIONS AND DISCUSSION

Latent class analysis serves as a powerful tool to account for heterogeneity in choice mechanisms. Particularly for travel behavior modelling, where conditions affecting choices are uncertain and choice behaviour may be highly context-dependent, analysts should reconsider the commonly used but restrictive assumption of a single, sample-wide utility function to characterize individuals. The slowly emerging behavioural mixing models potentially offer a richer approach because they allow individuals to adopt different choice strategies. This study provides new evidence supporting the potential and relevance of behavioural mixing models and at the same time extends the state of the art by examining behavioural mixing models under conditions of uncertainty and incorporating context-dependency.

The empirical evidence presented in this paper, based on a web-based stated choice experiment, supports the above argument. It also confirms that significant improvements in model fit can be achieved by overcoming limitations regarding the existence of correlation across the individual choice situations.

Future research could aim attention at the use of different decision paradigms, as we focused on the case of contrasting random utility maximization and random regret minimization. Moreover, future analysis intends to the extension of the latent class model so that the segmentation process of respondents into classes becomes context-dependent and, thus, obtains, a behavioural interpretation.

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SCENARIO ANALYSYS: ROBUST FUTURE GROWTH POLICY ANALYSIS IN WESTERN REGION OF SRI LANKA

An exploratory framework for planning policies

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Keywords: scenario discovery, cellular automata, robust decision-making, employment creation, urban region

Abstract: Colombo, the largest city in Sri Lanka, has expanded rapidly and continuously since the local economy was opened in the early 1980s. As a contrast to the other cities in the region, one of the main issues that planners have observed with current urbanization pattern was the slow growth of population density in the region to sustain reasonable economic growth that can support modern transportation and other infrastructure. The new Western Region Megapolis Project (WRMP) is attempting to develop a cluster of urban centers connected with modern transportation network. According to the proposed development plan, a cluster of urban centers expected to create an urban development pattern with better territorial balance. The objective of the proposed strategy is increasing the current population base by stimulating migration to the region. The plan has an ambitious goal with an estimated population of 8.5 million by 2030 with 3 million increases. The strategies proposed in the WRMP to attract population to peripheral urban centers are improving connectivity and creating job opportunities by way of increased investments. This research demonstrates a methodology to evaluate urban planning scenarios arising from policies of in the WRMA proposal using CA model and a Latin Hypercube Sample design. This method is useful in situations where the availability of reliable socioeconomic data is not available for data-intensive simulations.

1. INTRODUCTION

1.1 Planning strategy and risk

Colombo, the largest city in Sri Lanka, has expanded rapidly and continuously since the local economy was opened in the early 1980s. Lacking any planned framework, the city has succumbed to various problems such as urban sprawl, unmanaged ribbon developments along the main trunk roads, and fragmentation in the peripheral urban areas.

With the progressive decentralization of activities in Colombo, the suburban areas are growing faster than the central areas (Deheragoda et al., 1992). As a contrast to the other cities in the region, one of the main issues that planners have observed with current urbanization pattern was the slow growth of population density in the region to sustain reasonable economic growth that can support modern transportation and other infrastructure. This was mainly contributed by the uneven development across the region and concentration of economic activities in the core urban areas.

This urbanization process has created several issues such as; very high traffic congestion in the city, lack of good public transportation connection to peripheral urban centers, stagnant economic development, and social issues.

There were several attempts to develop a plan for Greater Colombo Metropolitan Region in recent decades to stimulate high-density growth centers in peripheral urban centers supported with efficient transportation connectivity.

The new Western Region Megapolis Project (WRMP) is attempting to develop a cluster of urban centers connected with modern transportation network. According to the proposed development plan, a cluster of urban centers expected to create an urban development pattern with better territorial balance. The objective of the proposed strategy is increasing the current population base by stimulating migration to the region. The plan has an ambitious goal with an estimated population of 8.5 million by 2030 with 3 million increases. The strategies proposed in the WRMP to attract population to peripheral urban centers are improving connectivity and creating job opportunities by way of increased investments.

Urbanization is a complex process with an inherent risk of uncertainty for any planning strategy. The goal of this research is to apply the computational technique of scenario discovery to the policy of job opportunity creation to identify the robustness of the strategy in future regional centers.

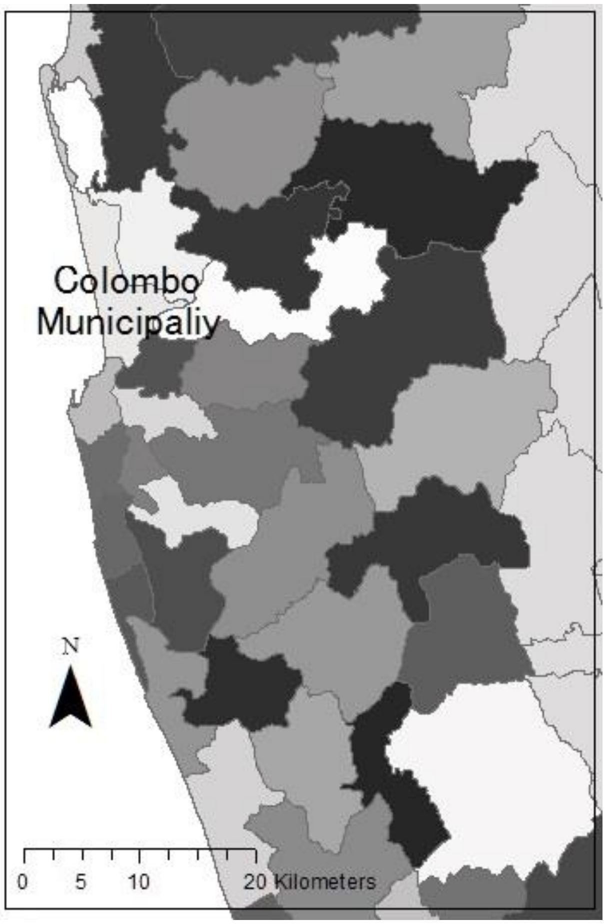

Figure 1. Study area the urban region

1.2 Urban growth simulation

City is a typical complex system. Understanding of urban development process is highly crucial to urban development planning. Urban development process involves multi-actors, multi-behaviors and various policies, which results in its spatial and temporal complexity. Mathematical and theoretical models have long been used to attempt to reduce complexity and a clear understanding of some aspects of urban structure and transportation. While the value of theoretical models are facilitating a broad understanding of some underlying principles of urban development and transportation, much of this models are remains too simple in its assumptions to make decisions about specific policies and investments in particular urban settings.

Computational techniques of scenario discovery are applied in empirical problems that have inherent uncertainties. Urban planning for future state involves exogenous driving forces, which affects the strategies performance. There were several attempts at applying scenario discovery techniques coupled with simulation models to find robustness of urban planning strategies (Swartz and Zegras 2013). The context in this research poses an additional challenge because of the lack of suitable data, which make it difficult to apply mature urban simulation models. This research tries experimenting a method to identify robust urban development strategies with cellular automata model and scenario discovery computation.

Cellular automata models are digital laboratories to test the complex dynamics of cities. Cellular automata models are being widely researched to study the urban spatial and temporal dynamics. Many CA models assume that development units are correlated in space, and they apply sets of rules to reflect the correlations (Batty & Xia, 1997; Clark et al., 1997). These rules are used to calculate changes in land use, and the modeled results can be evaluated by comparison with actual urban growth.

The research implemented a Cellular Automata model to simulate the future urban expansion process based on a range of possible parameter settings to represent proposed urban policies. The outcome of the CA model was analyzed to with the computational technique of scenario discovery to understand the effectiveness and robustness of the policy. The project in question is still in the development stage. Therefore, most of the assumption are made based on current urbanization process making the model essentially an experimental one.

2. METHOD AND DATA

2.1 Data

A cellular automata model was applied in this study simulates the urbanization process in Western Region from 2016 to 2026. CA models rely on historical observations for the calculation of parameter values. This poses a challenge with our topic, as most of the historic map data on the study area are temporally sporadic and spatially incomplete. The labeling of the land-use classifications can be especially erroneous as the definitions have been repeatedly changed. Recognizing that map data can lead us into error in modeling the historic urbanization, we apply a set of classified remote sensing data to derive land-use data on the CMR. The land use data for the Cellular Automata (CA) model and the analysis was derived from two Landsat TM images from 2002 and 2016. The images were selected from the same month of the year and the classified using standard image classification algorithms on a commercial image analysis platform.

In this study, the information of the population growth in local councils was used to learn the population changes across the urban region. Demographic and economic information for the simulation period was used to understand the population fluctuation, employment and labor force in the region. Some of the assumptions were based on aggregate information of the region to fill data gaps

2.2 Cellular automata model

Empirical methods for analyzing data provide more interpretable modeling output. Logistic regression has been used to interpret spatial data in many of the earlier studies (Wu and Yeh 1997; Cheng and Masser 2003; Hu and Lo 2007). By interpreting statistical models we can gain better knowledge on underlying spatial patterns.

Table 1. Scenario discovery formulation features

Feature	Description
Simulation period	2002-2016; historic data from 2002 and projections were used
Goal	Increase the population in regional urban centers.
Strategy	1. 20% incentive for businesses for job creation
	2. Improve the efficiency of regional transport
Input parameters	1. Urban expansion rate
	2. Geographic conditions; soil, terrain
	3. Travel-cost coefficient.
	4. Employment opportunities coefficient

Logistic regression model was used to estimate initial parameters of CA model. The CA model was implemented on commercial TerrSet software. On this platform, it is possible to implement infrastructure changes and incentives within the model. Initial CA model was calibrated using urban extent data from 2002 and 2016. The factors of urbanization should be significant enough to predict the process of urbanization. The chosen factors in the CA model here include existing urban growth at the initial year, cost distance from urban centers, site conditions such as topology, soil, existing land cover types, travel cost coefficient, and employment creation. The travel cost coefficient was calculated using a formula developed using distances to the closest urban center, distance to road and size of the closest urban center for each year within the CA model.

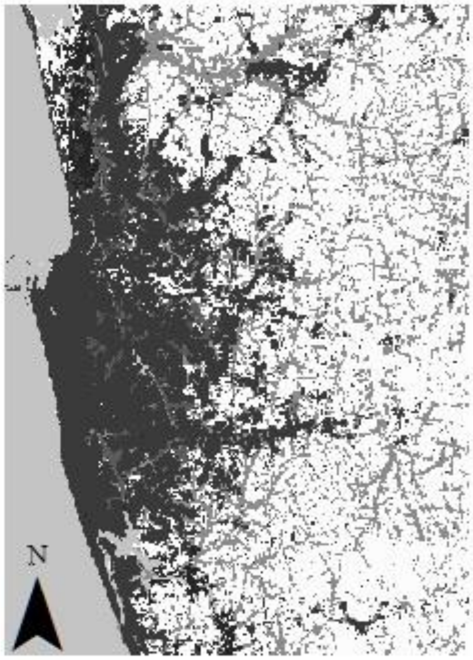

Figure 2. Simulated urban area of 2026 for business as usual scenario

The urban growth of 2026 was simulated for two scenarios. First, the business-as-usual model was simulated with existing parameter settings. In the business-as-usual model, the road networks were updated for second five years period based on the assumption that the project will be commenced within 5 years. A constant rate of annual increase was added to the employment opportunities parameter from 2016 to 2026 to represent employment generation resulting from proposed development activities. Later the second scenario was simulated to understand the increased population concentration in regional urban centers. A constant rate of additional annual increase was added to the employment opportunities parameter from 2015 to 2030 to regional centers to improve the attractiveness of those centers. It was assumed that western region would achieve the targeted population in 2030 in both scenarios.

The experimented policy objective in this research is testing the effectiveness of the policy of increasing job opportunities. The proposal in question does not provide a defined set of proposals to achieve job opportunity development in regional centers, its time frame, scale and economic benefits of such measures. Therefore, we have assumed that providing incentives to business establishments for new jobs and for establishing businesses in designated regional administrative areas as a reasonable measure to be tested in this experiment. It was assumed that a 20% incentives will be provided in that incentive proposal for establishments in regional centers compared to the city center region.

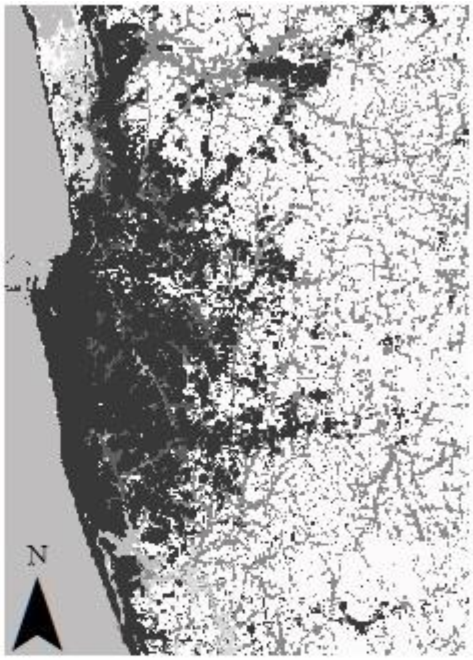

Figure 3. Simulated urban area of 2026 job creation incentive scenario

The calculation of such incentives within CA has several approaches. Such as using a weight within logistic regression model to alter the effect of job availability index variable and using a constraint/incentive layer. In this research, we have applied incentives layer to alter the business as usual model estimated using logistic regression calculation of the parameters (Table 1.). This approach allows testing the effect of incentive on target urban administrative centers in the region.

Demographic and economic statistics of the region was used to calculate of the job opportunity ratios in each administrative area (Figure 1.). The department of census and statistics of Sri Lanka publishes the population, labor participation, industries, and persons involved in the industry in their regular survey reports. While some of the statistics are reported for larger administrative boundaries making them less suitable for this study, basic statistics mentioned above can be used to calculate a ratio for labor participation of the population to job opportunities in each administrative boundary in this study. This ratio for labor participation in the population to job opportunities was used as the employment opportunity coefficient within the CA model. According to this calculation, the ratio will be less than 1 if there are fewer jobs for the population. And it will be greater than 1 if there is a demand for labor. The range of the incentive was set to 0 to 2 to represent incentives and disincentives to capture widest possible situations of the job market.

The calculation of transport cost coefficient an important parameter to simulate the infrastructure improvements to support the job creation and to supplement population increase in regional centers. The transport cost efficiency parameter was a cost distance calculated from CBD and major road network in the region. Minor roads were omitted from the calculation because of their high density in the peripheral areas and the assumption that major roads that connect small urban centers in the region is more effective encouraging even business growth across the region.

The urbanized area data of study only used high density developed areas for the analysis. All land-use classes that encompass built-up structures are classified as urban areas, including urban parks and airports. Wetlands within the core area, large industries, refineries, and military installations are identified from printed maps included as growth restriction areas. The low resolution of the Landsat data somewhat compromises the accuracy of low-density urban areas and mixed rural areas. Therefore only highly urbanized areas that are clearly recognizable in image classification were used as urbanized areas. The classification map from 2002 provides the initial conditions for the CA simulation and for the logistic regression model while the simulated results were evaluated using the classification map from 2016.

2.3 Latin Hypercube experiment

Simple random sampling and a Latin Hypercube Sample (LHS) sampling are two major sampling methods that can apply to select samples. Simple random sampling draws values from the standard normal distribution by generating a uniform random number, without a guarantee of selecting all the subset of a sample space. On the other hand, LHS experimental design distributes simulation points across the sample space in a manner that decrease the variability of results (Helton and Devis, 2002)

In this study, a LHS experimental design was constructed to obtain sample points for scenario discovery analysis. LHS is a stratified random procedure that provides an efficient way of sampling variables from their multivariate distributions. Literature suggests the suitability of LHS in uncertainty quantifying in spatial model simulation because of its ability to capture variability with a small set of samples (Xu, Chonggang. et. al., 2005).

While selecting a small number of sample is a major benefit of using LHS, there is no set standard among the researcher regarding the optimal sample size. Selecting a large sample set has a computational difficulty in CA models. In this experimental study, researcher adopted the density metrics proposed in (Swartz and Zegras 2013) to decide the sample size. According to the above research 10 samples would be suitable to explain the variability of for a model with 2 variable. Therefore, an LHS of 10 was developed for this study (Table 2, Figure 4). Free open sources statistical program with LHS library has the ability build an LHS with range of options. The researcher has developed a 10 LHS sample points for 2 variables of job creation incentive and transport cost coefficient with R. The sample points can be generated separately and be combined later for in the simulation.

After the construction of LHS points, CA model was used to simulate the period of 2016 to 2026 for each simulation point. The LHS points for transport cost coefficient was built as a 1000m buffer for roads and implemented as infrastructure change during the simulated of 10 year period. The job creation incentive parameter was tested for the Gampaha divisional secretariat only. The targeted test of the incentive scheme was expected to give a clear picture of results.

3. ANALYSIS AND DISCUSSION

The Table 2. Shows the simulation results and the success and failure of patterns of incentive for job creation in increasing urbanization and attracting population to subcenters in the study area. The values evaluated during simulations for two variables area given in JobIDX and trCOST. The success and the failure of the incentive policy were measured by the difference between urban growth in two scenarios of business-as-usual and the incentive scenario. The range of the LHS for JobIDX was selected to cover the widest possible range from deep disincentives to high incentives. The Table 2. Shows that diff values vary from -486 to 488 in the simulation results. Out of all 10 experimental simulations, only 4 parameter combinations generated any improvement in the urbanization process. Out of those that has shown an increase in urbanization 3 simulations shown only a marginal improvement in growth. All those success patterns correspond to high values of JobIDX variable.

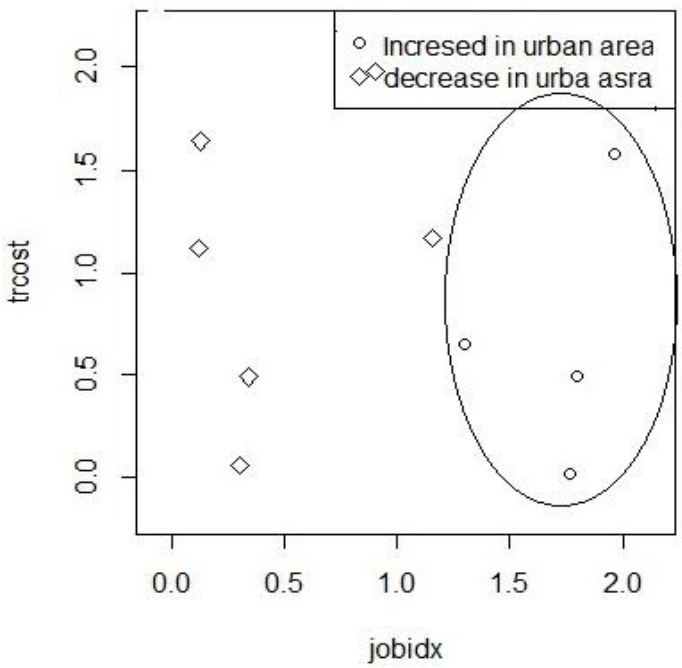

Figure 4. Scatterplot of LHS samples and simulation

Table 2. LHS data and simulation output. NobIDX=incentive index, trCOST= transport efficiency index, sq=growth from business=as-usual scenario, inCEN=incentive scenario, success= success of incentive scheme, diff=inCEN - sq

	JobIDX	trEFF	inCEN	sq	diff	Success
1	0.12	1.12	1111	1597	-486	0
2	1.8	0.49	1689	1597	92	1
3	0.3	0.06	1214	1597	-383	0
4	0.13	1.64	1111	1597	-486	0
5	0.9	1.98	1425	1597	-172	0
6	0.34	0.49	1214	1597	-383	0
7	0.3	0.65	1675	1597	78	1
8	1.77	0.02	1654	1597	57	1
9	1.16	1.17	1597	1597	-6	0
10	1.96	1.58	2085	1597	488	1

The majority of simulation shows a failure in improving the urban growth. Those failures correspond to smaller values of JobIDX variable. Simulation 9 shows the failure to grow although it is much closer to the business-as-usual scenario. It is notable that only very high values of JobIDX guarantee a success in increased urban expansion. Values closer to the center such as simulation 5 and simulation 9 show wide variation in response to incentive scenario. The reason for that wide variation of growth pattern for values in the center of the range is difficult to explain with a current small number of samples. The relationship failure/success to the values of trCOST variable is not as clear as to the JobIDX. Overall the effect of road efficiency factor is lower that the incentive policy. This may be due to the improvement of transportation efficiency is a city-wide application compared to the JobIDS which is a targeted measure to improve the rate of urbanization in suburban centers

The scatter plot diagram of simulation points is in Figure 4. Data points inside the oval shaped figure correspond with the parameters that led to the successful increase of urban areas. The diamond shaped points correspond to simulations that failed to pass the urban growth of the business as usual scenario. Success of incentive scenarios has a narrow range of high values for JobIDX and much wider trCOST range.

4. CONCLUSION

This reach demonstrates a methodology to evaluate urban planning scenarios arising from policies using CA model and a LHS design. This method is useful in situations where the availability of reliable socioeconomic data is not available for more data-driven simulations. The scatter plot diagram clearly demonstrates the distribution of success and failure of the policy and also the complex relationship among parallel policies implemented region-wide or in targeted areas.

The data range and assumptions in this research may sounds arbitrary. Still the parameter range and size of the sample in this research served the purpose of developing a method and demonstrating it further studies needed to understand the underlying behaviors of CA implementation and the scenario discovery process. The other possibility is the application of

Although an optimum number of samples are not specified it is possible that a current larger number of samples may give a more accurate picture compared to the current implementation. The other possibility is using methods such as Patient Rule Induction Method (PRIM)(Friedman) to study the success and failure boundaries of policy scenarios.

Acknowledgment:

This research was supported by the Ministry of Education, Science, Sports and Culture of Japan, Grant-in-Aid for Scientific Research (C), 2013-2015 (Prasanna Divigalpitiya).

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Transit-Oriented Development (TOD) assessment using 3D visualisation and modelling

Prospects and opportunities

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Key words: Land-use- Transport modelling, Transit-Oriented Development, TOD, 3D visualisation and modelling

Abstract: There is little research on tools and techniques that support the assessment of urban growth in the vertical dimension and none, to our knowledge, regarding the use of 3D visualization and modelling for the assessment of TOD. Our claim is that this type of assessment would aid the ability of the urban planner to communicate the impacts and interactions of different urban systems that require a vertical or 3D visualization. In this study, we discuss how 3D visualization can be used for assessment of TOD in the context of the 3Ds of the built environment: Density, Design and Diversity (Cervero and Kockelman, 1997). A design-framework to broadly depict the process of adopting "3D visualization and modelling" applied to the TOD assessment, within the "3Ds of the built environment" framework will be discussed. Our case study is the area around Nijmegen train station in the Netherlands.

1. INTRODUCTION

Urban planning is an extremely challenging activity because it involves a great deal of imagining what the future will be or could be like. According to Vonk and Geertman (2008), p153, "Urban planning concerns the design and organisation of urban physical and socioeconomic space and the measures undertaken to solve existing problems and/or anticipate future problems. The general objective is usually to provide for an organisation of activities (or of urban space) which in some way is better than the pattern existing without planning". Planners' resource to different tools, models and methods to facilitate this imagining exercise and ensure that the challenges and problems encountered will be addressed by the initiatives taken. One of these challenges is rapid urbanization, which drives problems such as spatial and social segregation, increasing need for transportation, and pollution.

One of the ways proposed to deal with the challenges posed by rapid urbanization has been the integration of land-use and transport planning, in the shape of, for example, Transit-Oriented Development (TOD). The main goal of TOD is to encourage lower dependency on cars and use of more sustainable modes such as walking, cycling and public transport. It involves creating compact development with ready access to transit (Calthorpe, 1993; Bernick and Cervero, 1997; Bae, 2002).

In addition, as cities grow fast, especially vertically, there is an increasing need to recognize the processes behind and the impacts derived from this vertical dimension. The vertical dimension is very hard to represent in a 2D surface, which hinders the analytical capacity of the planner. It also influences the ability of the planner to communicate the impacts and interactions of different urban systems that require a vertical or 3D visualization, such as water and sanitation systems (Ahmed and Sekar, 2015) or urban development and the built environment (Trubka et al., 2015); (Durdurana and Temiza, 2015). This is especially relevant when communicating with different stakeholders (Pettit et al. 2004). One way of approaching the integration between land-use, transportation and a city's vertical dimension is using 3D visualization and modelling.

In recent years, an increase in use of three-dimensional spatial information has pushed towards a change from 2D planning to 3D visualization and modelling (e.g. ESRI, 2015; Trubka et al., 2015; Ahmed & Sekar, 2015; Pettit et al. 2004; Shiode, 2000). Rapid technological developments in the fields of photogrammetry, laser scanning and computer vision resulted in effective applications in various fields such as land-use monitoring and transportation planning among others (Freddy et al. 2014; Dunne, 2015). Advanced acquisition techniques for deriving 3D data such as aerial, mobile and terrestrial, have been used for deriving 3D data, such as passive (image-based) and active Light Detection and Ranging (LIDAR) sensors (Remondino and El-Hakim, 2006; Rutzinger, et. al. 2011; Tack, et. al. 2012; Oude Elberink and Vosselman, 2011; Aggarwal, et.al. 2014).

Recent research has focused on so called Unmanned Aerial Vehicles (UAVs), found to be a reliable acquisition technique for numerous applications (Meyer, et. al., 2015, Themistocleous, et. al. 2015). Moreover, the research focus is on possibilities for automatic object extraction (Oude Elberink, et. al. 2015). Nevertheless, two-dimensional CAD plans are still commonly used as a main source for 3D model generation (Gimenez, et. al., 2015). Despite the existence of various acquisition technologies and sources of information, there is little research on tools and techniques that support the 3D assessment of urban growth capturing a vertical dimension, and none to our knowledge regarding the use of 3D visualization and modelling in the assessment of TOD.

In this paper we discuss how 3D visualisation and modelling can be used for assessment of TOD in the context of the 3Ds of the built environment: Density, Design and Diversity (Cervero and Kockelman, 1997). A design-framework to broadly depict the process of adopting "3D visualization and modelling" to TOD assessment, within the "3Ds of the built environment" framework will be discussed and applied to the case of a transit node area in Nijmegen, in the Netherlands. Our paper contributes to existing research on the assessment of TOD; however, its pivotal methodological contribution is with the adoption of 3D visualization and modelling for TOD assessment.

The paper is structured as follows: following this introduction we will discuss the interdependency between land-use and transportation, and what are the basic tenets of TOD. We will then discuss how 3D visualization has been so far used in land-use and in transportation studies, introduce some of the techniques available for capturing and modelling 3D images and representations of the built environment, and sketch how 3D modelling and visualization can be fitted to a TOD assessment. In section 3 we introduce the case study, the type of data that we have already collected for our case study, and discuss further data requirements. The concluding section will further introduce what are the next steps that we intend to take in extending the framework to access the TOD development via 3D in Nijmegen.

2. LITERATURE REVIEW

2.1 Land-Use Transport Interaction (LUTI) and Transit-Oriented Development (TOD)

Land-use and transportation systems are closely related and interdependent, with many researchers exploring the integration of land use models and transportation planning to understand the effects of this interdependence (e.g. Waddell, 2011; Wegener, and Fürst, 2004). Earlier studies of large urban areas have highlighted this relationship. For instance, Newman and Kenworthy conducted a study of 32 world cities and concluded that there is a "very clear relationship between transport and urban form" (Newman and Kenworthy, 1991, page 249) and discussed the questions that this relationship raised when it comes to social, economic and environmental implications. Subsequent research on automobile dependency has also highlighted the connections existing between land-use, urban form and transportation modes (e.g. Boarnet et al., 2011). Bertolini (1999) has developed a territorial organization model – the node-place model – where changes in land use and transportation influence each other. This model identifies station areas as, simultaneously, "nodes" of the transportation network and "places" of a city, and defends that interventions in the "nodes" will have effects in the "places", and vice-versa.

TOD captures this interdependence and Waddell goes as far as to argue that the emergence of TOD attests to the significance of integrating land use and transportation (Waddell, 2011). Calthorpe (1993) defined TOD as development with high density, and the mixture of residential, retail, office, open space and public spaces that explore walkable environments to promote and facilitate transit. Several other authors have explored this relationship between land-use and transportation via TOD by arguing that in a TOD development, a compact, mixed-use neighbourhood, centered around a transit node, invites residents, workers and visitors to give preference to public transportation instead or the private car (Bernick and Cervero, 1997), and that the design and mixed-use character of TOD communities can reduce the use of the automobile (Lund et al. 2004). Moreover, TOD can be understood as a way to reduce automobile dependence, promote more compact urban forms and foster mixed land uses (Bae, 2002).

TOD typically requires the area to be dense and diverse with different types of land uses and should be walking and cycling friendly by design (Calthorpe, 1993). High *densities* of development create transit-supportive passenger flows by creating travel (Bertolini, 1999; Bach et al., 2006; CTOD, 2009). Land use *diversity* are necessary for creating a sense of place around a transit node as it brings liveliness to an area, brings people together for different purposes like work, shopping, education, recreation etc. and in turn it also creates transit demand in off-peak hours thereby improving transit's efficiency (Calthorpe, 1993; Cervero and Kockelman, 1997; Renne and Wells, 2005; Bach et al., 2006; Curtis et al., 2009; CTOD, 2009). The *design* of urban spaces in a walking and cycling friendly environment encourages people to walk or cycle for their short trips and reduces their dependence on cars (Schlossberg and Brown, 2004; Evans and Pratt, 2007). In a nutshell, TOD is best characterized by the 3Ds of the built environment – Density, Diversity and Design (Cervero and Kockelman, 1997; Cervero and Murakami, 2008), dimensions that we explore in this paper.

TOD has been studied and planned for at different scales – regional, urban and local scales, such as by Cascetta and Pagliara, (2008, 2009) for region of Naples and Campania in Italy, Singh et al. (2014) for the Arnhem/ Nijmegen city-region in the Netherlands, Howe et al. (2009) and Lindau et al., (2010) for Curitiba in Brazil, Curtis (2009) for Perth in Australia, Chorus (2009) for Tokyo, Arrington (2009) in Portland, USA, Yan and Lew, (2009) for Singapore, Loo et al., (2010) for New York and Hong Kong, and Cervero and Murakami (2009) also for Hong Kong. Additionally, some of these studies have studied TOD around station areas by measuring indicators related to transit and development (Bertolini, 1999; Reusser et al. 2008; Balz and Schrijnen, 2009; Chorus and Bertolini, 2011; Zemp et al. 2011; CTOD, 2013; DeltaMetropolisAssociation, 2014; Singh et al. 2015).

In the case studies mentioned above, TOD assessment has included the study of the 3Ds of the urban development – the urban density, the diversity of land uses and urban design that should encourage more walk/ cycle trips. Moreover, Renne and Wells (2005) and Evans and Pratt (2007) also emphasize on measuring the 3Ds of the development along with the transit characteristics. Thus, for any kind of TOD assessment, the analysis or study of density, diversity and design of urban development become imperative.

2.2 3D visualization and modelling in land-use and transportation planning

Existing studies on TOD assessment capture only a 2D perspective, which we argue is insufficient in light of an urban development form that has, as core premises, the importance of high density development and a more mixed-use development, and that higher densities promote mixed-uses and vice-versa. Capturing the advantages of density by adding the vertical dimension and volume to the assessment of TOD is thus essential.

Nowadays, 3D is everywhere, from 3D games and movies, 3D navigation systems with 3D routes, 3D land information systems, 3D land cadastre, 3D urban databases, etc. (Billen, 2009). The need to visualize and model the surrounding reality in 3D resulted in the so-called ”3D Cities”. These have been widely used for various applications and urban planning is among them. Some cities are even creating official 3D models, for example Berlin (Kada, 2009). Furthermore, Ban et al. (2008), developed an effective web-based, interactive 5D (3D, time and sustainability) visualisation demonstrator. In addition, 3D city models are very efficient for fast decision-making for emergency response and disaster control (e.g. Tang et al., 2006; Schulse-Horsel, 2007; Schulte and Coors, 2008; Tashakkori et al., 2015; Tiwari and Jain, 2015).

There are very few studies exploring how 3D modelling and visualisation can be applied to explore the interdependency of transport and urban form or transport and land use. However, spatial tools and technologies that include a 3D visualisation and modelling component have been gaining attention as enablers for better decision making and planning in the urban environment. Cervero and Bosselman (1998) worked with visual simulation of TOD scenarios using photo-slide images, to simulate a walk through four neighbourhoods with different density and amenity mixes. This gives the residents a visual idea of what their neighbourhood will look like under higher densities and more amenities. They argued "visual simulations provide a richer context for probing the market potential for TOD than do traditional market research approaches because visual simulations convey a wider array of environmental choices.

3D modelling allows the generation of many possibilities/ scenarios and optimises the plan-making process. According to Trubka et al. (2015), as cities become denser, advanced planning tools are needed to assist decision makers, planners and communities to collectively plan for a sustainable city. 3D visualisation and modelling can thus be used in assessing the performance of built-form in realising low-carbon sustainable development. Their work reviews a number of systems that are better known in this respect and used in the field of urban planning, such as – Urban Canvas, CityEngine, CommunityViz, Precincts, Envision Tomorrow, NASA World Wind, Google Earth and Envision Scenario Planner (ESP) and uses ESP to create redevelopment scenarios and performance assessment techniques for their case of Canning, Western Australia.

ESRI (2013) documented the use of 3D visualization for scenario depiction in contexts as diverse as Hawai, North Carolina, Arizona, Milwaukee and Texas in the U.S.A, Nasiriyah in Iraq, Toulon Provence in France, Singapore and Québec in Canada. In Honolulu, Hawai, planners

Figure 1 Basic 3D model created for an area of Honolulu, showing the elevated rail system (ESRI, 2015)

have harnessed the power of 3D modelling in simulating the scenario of elevated rail transit system to the community (Figure 1) (ESRI, 2015). They also planned for TOD along the network, and with 3D modelling tools showed how the zoning changes would visually redefine the community and how TOD can positively affect the city by preventing future urban sprawl.

The Singapore Urban Redevelopment Authority (SURA) is now using 3D mapping to create a more realistic view of the city and simulate possible future scenarios of better infrastructure development (ESRI, 2015). Neuenschwander et al. (2014) used 3D visualisation techniques in Zurich-Altstetten to visualise green space patterns, and communicate to the community the vital importance of all green space types within the urban environment. 3D modelling has also been used to model underground infrastructure plans for an urban development project like in Ankara, Turkey (Durdurana and Temiza, 2015) and in Raleigh, North Carolina (ESRI, 2013).

Guo et al. (2013) used 3D modelling techniques to make a 3D cadaster for the city of Shenzhen, in China, where urban expansion in the city is quickly happening in the vertical dimension – above and below the land parcels. Different levels can be owned by different entities and hence a 3D cadaster was argued to be an effective technical mean to support the administration of space. There are, however, other ways to manage land records that are neither 2D nor 3D, but somewhere in between. The Netherlands, for instance, has 3D property objects registered on 2D cadasters. Although this is considered as a suitable alternative solution from the point of view of property registration, it is only a temporal one, and a 3D cadastre will soon be preferable (Stoter et al., 2013a). Two main activities for full 3D coverage of the country were recently developed: (1) establishment and implementation of a national 3D standard, mainly done by municipalities and (2) automatic generation of topographic objects from a combination of 2D and 3D laser scanning data, done by Kadaster (National agency in Netherlands responsible for topographic mapping) (Stoter et al. 2013b; Oude Elberink et al. 2013).

3D modelling as described in computer graphics is the process of developing a mathematical representation of three-dimensional surface of any object via specialized software. The main processes involved in 3D model creation are: (1) 3D modelling the shape of the object, (2) layout and animation describing the motion and geolocation of the object in the scene, and (3) 3D rendering which is generating a raster image representation of the object. 3D models can also be web-visualised for interactive representation and recently they can be also physically created using 3D printers (Koeva, 2016). 3D models can be divided in two categories: (1) solids or also so called volumetric representations and (2) boundary represented which are mainly used in computer graphics as polygon meshes, Triangular Irregular Networks (TIN) among others.

Visualisation is one of the most complex parts in the process of 3D modelling, especially for applications like urban planning and disaster mapping. The environment in such cases should be visualised in different scales and for this purpose so called levels of detail (LOD) are proposed for model representation (OGC, 2008). Another important aspect of visualisation is that it is changing over time and in that respect maintenance and regular updating of the information has to be considered. Usually such models, which are regularly updated, are called 4D because they consider the changes in time.

For implementing efficient visualisation, so-called *generalization* of the content is required. This process involves the selection of the represented objects and adaptation to the scale (Ruas, 2000). Generalization can be done manually but recently with the technological development such computations are done automatically (Harrie, 2001; Meng and Forberg, 2007). For 3D modelling, generalization is essential. It is used for creation of models in different LODs. As cities are usually very complex for efficient visualisation algorithms, so-called dynamic generalisation is applied (Anders, 2005).

An important part of 3D modelling is to assess the quality of the final result. Usually it primary depends from the quality of input data but also from the generalization procedures (Harrie, 2001; Forberg, 2007). Unfortunately there is limited research on quality assessment of 3D model generalisation (Bard 2004; Podolskaya et al. 2007; Filippovska et al. 2009).

A variety of geospatial technologies can be used for 3D modelling and visualisation of cities. Many of them have been recently created using lidar data (Oude Elberink et al. 2013), aerial and terrestrial images (Barazzetti et al., 2010) in a combination with classical mapping sources and GNSS data. Recently the data provided from the above-mentioned acquisition techniques is with high accuracy and is reliable for city visualisation and virtual representation. However, to generate and maintain of accurate 3D data used for these application is costly and time-consuming. In the past, 3D city models were mainly created manually. Nowadays, algorithms for automatic model generation were developed (Frueh and Zakhor 2003; Oude Elberink et al. 2013). Conversion from Building Information Modelling (BIM) and CAD data can also be used (Döllner and Hagedorn, 2007).

3D urban models or city models are restricted in terms of detailed semantic information concerning non-physical aspects of the cities. As a result, City GML has been set as standard by OGC Open Geospatial Consortium (OGC, 2008; OGC, 2012). The aim was to set common definitions, rules for visualisation, acquisition and data storing with its attributes, for the city models that have been exchanged between the domains. However, the standard doesn’t provide rules concerning transportation, energy consumption or pollution. Urban planning is one of the most used applications for 3D city models but there is lack of research assessing the qualities of these models for decision-making processes.

There are challenges in working with such a detailed system as 3D modelling. Image gathering is one issue (ESRI, 2015) because advanced techniques like satellite imagery and remote sensing with laser are used to gather data on terrain, and more intensive modelling techniques are needed to create high quality models of the buildings. Often numerous ground surveys and photographs are also needed to create the textures of the buildings for an utmost realistic experience. Additional challenges are the high requirements for software and sufficient computing power to quickly crunch through all the data and images for real time analysis.

2.3 Applying 3D modelling to TOD

Given the attraction of using 3D modelling for visualization of urban development, technology has been primarily used for visualizing possible future scenarios of urban development as discussed in earlier sections. Using 3D modelling to assess urban development characteristics is less common. However, as cities grow fast, especially vertically, there is an increasing need to recognize the processes behind and the impacts derived from this vertical dimension. These impacts can be, for example, 1) the expected volume of traffic that is generated by different building densities and land uses, 2) the use of existing infrastructure (for example water or sanitation, Ahmed and Sekar, 2015) depending on different urban densities and different land uses, 3) the volume and intensity of activities that different land uses generate, and 4) their influence over the existing and planned built environment (Trubka et. al. 2015). The opportunities offered by the 3D representation of the city become even more apparent when talking about large urban areas or areas experiencing rapid urbanization (Hwang 2009).

TOD assessment has so far been conducted using tools supporting solely 2D analyses of urban development and neglecting the potentials of the techniques of 3D modelling. This, we believe is insufficient in light of an urban development form that has, as core premises, the importance of high density development and a more mixed-use development, and that higher densities promote mixed-uses and vice-versa.

Capturing the impacts of density, diversity and design by volume and height in the assessment of TOD can be very helpful. Schlossberg and Brown (2004) discussed the importance of spatial visualisation for analysis of TOD and argued "visualizing urban form is also an important component to understanding walkability, especially for public understanding and participation in the planning process" (Schlossberg and Brown, 2004: 4). The visual simulation of possible TOD scenarios provides a richer context around which to discuss potential alternatives in terms of differences in densities of amenities, the quality of the built environment and how it might stimulate users and residents to prefer walking and biking over using a private car. Visual simulations are thus useful tools in probing the market potential for TOD because they can convey a wider array of environmental choices (Cervero and Bosselmann, 1998).

By using 3D modelling of urban development and incorporating the details such as building heights, the land uses on each floor and building facades (called 'textures' in 3D modelling), planners can make a more accurate estimate of densities, diversity of land uses and even walkability/ cyclability of urban space. Aspects such as wind flows, casting of shadows of buildings (see Figure 2), interactions between buildings and walkways due to opaque or transparent building facades, terrain's contours, etcetera, can be best analysed in 3D modelling and help in planning for smaller details w.r.t urban design.

Figure 2 Shadow of one building visualized using 3D modelling (ESRI, 2015).

In this paper we explore how 3D modelling can be used to assess transit-oriented development around one transit node. We focus on three TOD characteristics – Density, Diversity and urban Design, and visualise how these three indicators behave for the transit node of Nijmegen Central Station, in the Netherlands. The next section will explain our research design and how we explore the 3D component in a TOD assessment framework.

3. RESEARCH DESIGN

As mentioned earlier in the paper, TOD assessment until now has been done using only 2D maps and not 3D visualization and modelling. We argue however, that given the strengths of 3D modelling in assessing built form, as shown in the above mentioned studies, TOD assessment can also benefit from the use of 3D modelling techniques. Thus, in this section, we discuss how 3D modelling can be used to assess three recurrent and often used dimensions/ characteristics of TOD – urban densities, land use diversity and urban design, the 3D framework. To fulfil this objective, we will be studying the development around the main train station in Nijmegen, the Netherlands.

3.1 Case Study

Nijmegen is one of the three oldest cities of the Netherlands. The municipality of Nijmegen is a part of Gelderland province. The city covers about 57 km2 of area and was home to approx. 169,000 people in 2014 (CBS, 2016). Radboud University is also located in this city and attracts many students from neighbouring areas. The city is connected to other parts of the country and Europe by a national rail network (NS – Nederlands Spoorwegen) and is served by national train service, also by NS and a regional train service by Breng.

There are five train stations in the city and Nijmegen station is the central and busiest station in the city. It also acts as the bus terminal, hence all buses serving the city provide access to this node, and the station is a node within the city's Bus Rapid Transit line. In essence, it can be called the transit hub of the city, which implies that this area offers an optimal case study of where to observe and measure density (of population and different functions such as commercial and residential), diversity (of land usage) and design (mixed-ness of residential land use with other uses, characteristics of the built environment for walking and cycling, etc). Thus, we decided to study the TOD around this station area. Given that we already had considerable amounts of data for the Gelderland province, it was also better to study a place within the province for practical reasons.

3.2 Data

To study and assess TOD around Nijmegen station our main source of 3D data was acquired from the Dutch cadastre (known as 'Kadaster') and was further refined for the specifics of this research. It is based on the 2D topographic data and high-resolution airborne lidar data. The "topographic" data used for the model consists of natural (e.g., rivers) and man-made features (building and roads). Topographic data is represented in three types of dimensions: 2D, 2.5D and 3D. The 2D data is a cartographic visualisation of the roads, buildings, vegetation, etc. in a vector format. The surfaces are represented by 2.5D heights and the 3D buildings are visualised as volumes.

The height data is based on the national height model of Netherlands called AHN (AHN, 2012) acquired by airborne lidar system.

The obtained 3D model is in Level of Detail (LOD) 0, which means that the buildings are extruded automatically according to their heights and are visualised as boxes. The algorithm for this automatic 3D model generation was a result from collaboration between the University of Twente, Delft University of Technology and Kadaster (Oude Elberink et al., 2013). Currently, the research is focused on automatic 3D data generation but for the LOD1, LOD2 and higher. For this paper, with the exception of the data mentioned above, the topographic map, OpenStreetMap(OSM) and satellite image available from ESRI TOP 10 NL were also used. For further development and photorealistic representation of the 3D model, additional data need to be acquired.

For façade generation, we expect that oblique or terrestrial images will provide sufficient information. High-resolution aerial images and GPS data for accurate positioning will also be useful. To assess the land use diversity, distribution and usage per floor will be needed, and can be obtained from the Municipality of Nijmegen and/or through field surveys. For data modelling and visualisation, data will be handled using ESRI's ArcGIS, Arc Scene and CityEngine.

Typically, a TOD area is identified to be within walking distance of the node and it can range from 250m to 800m, sometimes even a kilometre radius (Calthorpe 1993; Parker et al., 2002; The City of Calgary, 2004; Renne and Wells, 2005; Hale and Charles, 2006; CTOD, 2009; ITDP, 2014). For assessment of TOD around Nijmegen Station, the area of assessment is defined as the area marked by a radius of 500m from the station. All urban development within this area of assessment will thus, be assessed.

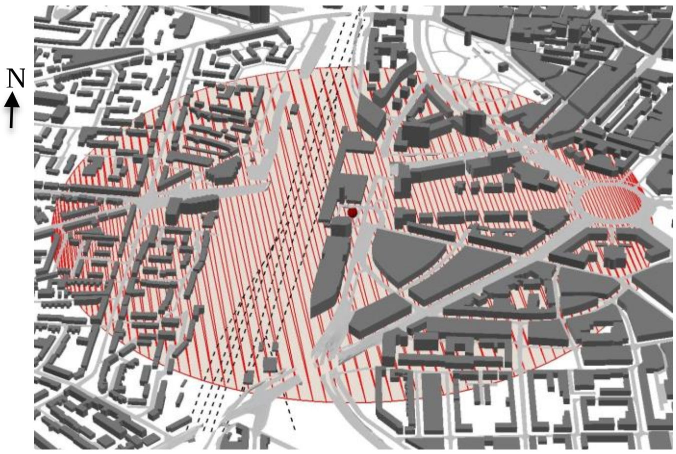

Figure 3 Snapshot of 3D model for the study area - Nijmegen

Using the data already available, we created the 3D model of urban development within the area of assessment. Figure 3 presents a snapshot of the 3D model created for study area. The hatched portion in red is the area encircled by a radius of 500m around the station. The station is represented by the red dot and dotted lines are the railway tracks. The grey blocks are buildings and the light-greys are roads.

3.3 Extending the 3Ds of TOD with 3D modelling

The study area around a transit node for TOD assessment is typically demarcated using walking distance as radius (Euclidean distance). This study area does not necessarily conform to the administrative boundaries of the area. The statistical data, however, is collected for administrative units of space such as wards, neighbourhoods, city's urban limits or regional boundaries. Statistical data for the Netherlands is collected by CBS (in Dutch, *Centraal Bureau voor de Statistiek*), and the smallest administrative unit, over which the data is collected, is the neighbourhood level.

Our study area intersects with one or more neighbourhoods and to overcome this problem, data is proportionately divided and allocated to the study area. This proportionate allocation depends on the spatial information about land or built-up area used for different land uses. For all the neighbourhoods intersected by the study area, available data on building footprints, land use of each building footprint and heights of all buildings were used to find out the built-up area under different land uses.

Although this data is very accurate for computation of population densities using area under residential land use, it can become more accurate with additional information on land uses on each floor of the buildings. In the Netherlands, it is common for urban buildings to house commercial/ business land uses on lower floors and residential units on upper floors. This mix of land uses, i.e, *diversity* in buildings is very conducive to the creation of TOD around transit nodes. By capturing this additional information, most accurate estimation of built-up area (in m^2) per land use can be made, leading to more accurate *density* and *diversity* calculations for the study area.

Similarly, the floor-wise information on land use can be very helpful in most accurate estimation of work opportunities or access to spatially distributed activities in the study area. This measure is useful in assessment of TOD conditions as higher access to opportunities/ activities in an area is expected to create better TOD conditions. Land use *diversity*, that aims to create a sense of place around a node can also benefit from the floor-wise information on land use that is more accurate and closer to reality.

One of the interesting ways to use 3D models in assessment of TOD is to use the cross-sectional views of development in study area and study the density distribution around the transit node (figure 5). In the cross-sectional views, densities represented by the heights of buildings can be studied together with the zoning regulations. Ideally, the buildings next to the transit node should be higher than the buildings farther away because that would represent higher densities near the node. As one moves away from the station in centre, the building heights and hence the densities, should reduce. This pattern of density distribution conforms to the concept of TOD as it indicates that more people are located closer to the transit making transit and attractive, practical and accessible choice for commuting needs. For our case study, we have created a cross-section cutting across the area of assessment, through the station. The line of cross-section is shown in Figure 4, with the station in the centre.

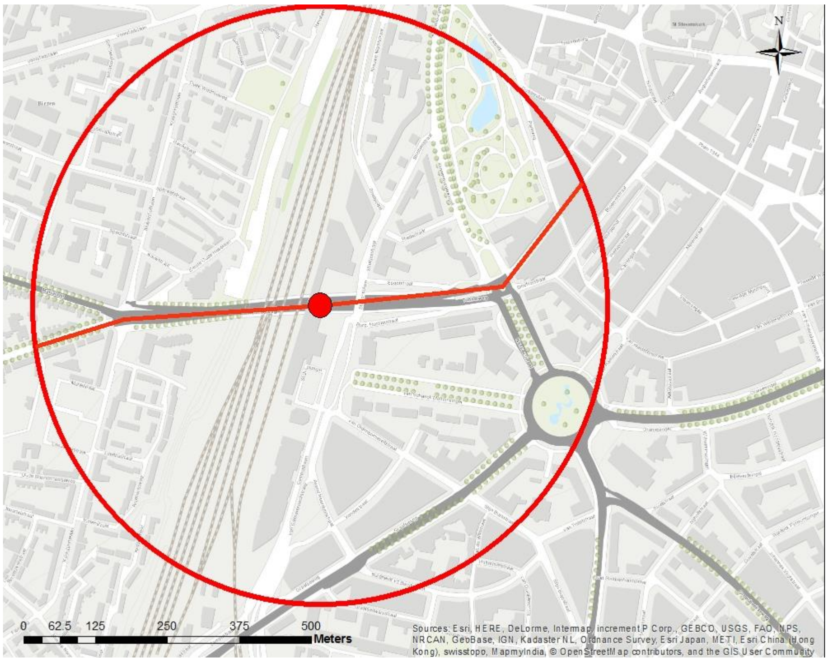

Figure 4 The area of assessment bound by the circle of radius 500m around the station, and the line of cross-section across the area of assessment

The cross-section of the development is also shown in two parts in Figures 5 and 6. They carry basic information about building heights and thus, densities. The development on left of station has low-density while that on the right side is denser. The development overall is not very dense. More detailed understanding of the zoning regulations and the land uses would reveal if the land uses and zoning regulations prohibit denser development, or the current development does not exploit the provisions of regulations to build higher/ denser. To create more transit-oriented development, buildings closer to the station should be taller, thereby allowing denser development closer to transit. Typically denser land uses such as apartments, commercial activities and others, rather than row-housing, parks and such, can also be recommended for areas/buildings closer to station. These can help in creating denser areas closer to the transit node. Additional cross-sections can help in better assessment of the whole area around transit node.

Assessment of urban *design* for walkability and cyclability purposes stands to gain the maximum from 3D models. Walkable environments can be best created when the walkways are integrated with the surroundings including the buildings along which they are designed. A 3D model can be used to assess those factors that create a sense of space, sense of enclosure, sense of safety and integration with the surroundings. The location of streetlights, the contours, and transparent building façades created by more windows or glass interfaces under modern architecture, can all be used to create very realistic 3D models of the study area (Jacobson and Forsyth, 2008; Pojani and Stead, 2015). However, for these studies, very detailed datasets are required that in turn require primary surveys of the sites. Since the TOD areas can be very large (about 0.8km2 within 500m of Euclidean distance from a transit node), it is not a very user-friendly manner to collect the data. Sampling exercises may be undertaken to survey most-representative sections of development.

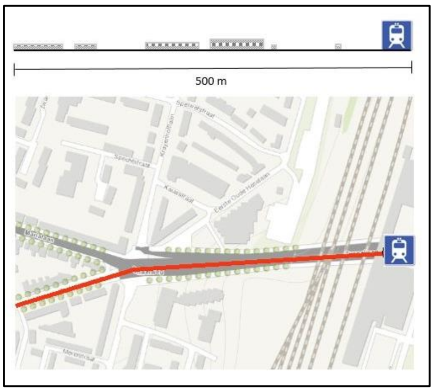

Figure 5 Cross-section of development on the left side of the station

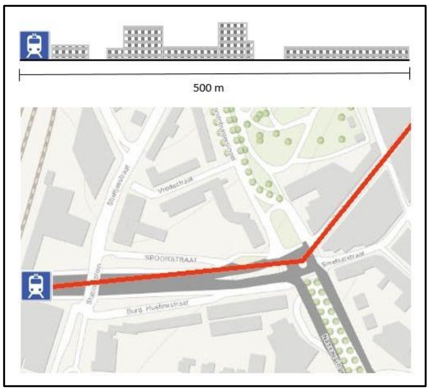

Figure 6 Cross-section of development on the right side of the station

4. DISCUSSION AND THE WAY FORWARD

In this paper we established a research framework to depict the process of using of 3D visualization and modelling for the assessment of TOD, under the scope of the commonly used 3Ds of the built environment (Density, Design and Diversity, Cervero and Kockelman, 1997). The city of Nijmegen (the Netherlands) was used as a case study, where available data was used for illustration.

It can be concluded that the added value of using 3D in a TOD assessment are manifold: it serves as a tool to capture different land-uses *diversities* that can overlap or be miss-represented in a 2D plane; to explore the relationship between different land-uses and potentials for further *densifying* an area; facilitates the communication between stakeholders as it serves as a tool to experiment and communicate different scenarios, in relation to, for instance, urban *design* strategies. Additionally, TOD is partly based on densification and this entails building vertically - up and/or down, an aspect that is not properly captured in a 2D plane.

The challenge is not only in the limitations current TOD assessment pose to spatial visualisation, scenario building and the participation of different stakeholders, but it is also about the ability of planners and developers to acquire and deal with the necessary data and techniques that are required to build these types of scenarios and visualisations. It is important to state that this paper does not deal with how to simplify these techniques, and it does not conduct an evaluation of the existing techniques. Furthermore, the data requirements for any kind of 3D assessment are large and it can be a challenge to gather all the required data in specific formats and accuracy.

The central station of Nijmegen was chosen because, since this station is one of the busiest in the city, it was expected to contain more commercial/ office/ business activities in the vicinity of the station. However, most of the urban development around the station was found to be residential in nature. Some of the buildings adjacent to the station on East side are used for locating offices and educational use, while central commercial area, also called the ‘centrum’ is about 600m away from the station area.

We plan to extend the present paper to complete our TOD assessment using 3D visualization and modelling, by extending the 3D dimensions to include indicators that are specifically developed for 3D visualization and modelling. Additionally we are collecting missing data to further analyse the missing indicators for Diversity, Density and Design, and we will extend our analysis to include at least two more stations in Nijmegen, along the Bus Rapid Transit route of the city.

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Synchronisation of Home Departure and Arrival Times in Dual-earner Households with Children: Panel Regression Model with Random Effect for Time Gaps

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Key words: Synchronisation, Time Gap, Departure and Arrival, Panel Data, Regression Model

Abstract: This paper reports the results of an analysis of the degree of synchronization of home departure and arrival times between working parents and children. Using activity-travel diary data of different household members, a random effects regression analysis is estimated to examine differences in time gaps in home departure and arrival times between respondents and children as a function of gender, day of the week, age of the youngest child, and socio-demographic characteristics. The results provide insight into the relative effects of factors influencing the degree of synchronization and coordination of scheduling decisions of double earner households with children. In addition, the results can be used to model work schedule arrangements. Findings indicate that gender role, number of children in the household, age of the youngest child, day of the week and education level significantly affect time gaps, especially arrival time gaps.

1. MOTIVATION

The spatial and temporal distribution of observed traffic flows reflects the accumulated result of a multitude of scheduling decisions of individuals and households. Daily, people need to decide where, when and in what sequence to execute the activities on their agenda and how to organise associated travel. Some activities do not offer much flexibility; for others, people can choose from a wide set of options and times.

Scheduling processes in dual-earner households with children are even more complicated. Household members do not only have to consider the effects of alternative schedules in terms of their personal preferences, tasks and resources may also need to be allocated and coordinated, while in addition the presence of children implies that scheduling needs to be synchronised, at least to some extent, with those of the children. The latter topic is addressed in this study.

Different agendas and degrees of commitment, jointly with the possible lack of flexibility, may imply that children need to spend home alone for some time. How do parents organize their work schedules under such circumstances? What is the time gap between their departure/arrival times from/to home and the departure/arrival times of their children? Does symmetry exist in home arrival times? Is there evidence of gender differences in the synchronisation of schedules? What is the influence of characteristics of children? What is the impact of context? These questions will be addressed in the present study.

An examination of the literature reveals that little research has been conducted on this topic. The vast majority of travel behaviour studies has been concerned with the outcomes of scheduling decisions rather than with scheduling decisions themselves. Moreover, the limited number of scheduling studies has been concerned with individual-level decisions rather than with the coordination and synchronisation of activity scheduling processes at the household level.

Mohammadian & Doherty (2005, 2006) developed different models to analyse activity schedule time horizons. Their results suggested that individuals' choice of activity schedule is not only influenced by activity type, but also by flexibility in time and space, and household and personal characteristics. Ruiz & Roorda (2008, 2011) confirmed these findings using activity-based models. Arentze & Timmermans (2000) developed a rule-based model to analyse the time horizon under temporal and spatial constraints.

In most studies in travel behavior research that were concerned with scheduling arrangements, the work activity is considered as a given activity. People organize their daily schedule on the basis of the work activity. Only few studies have investigated work schedule arrangement processes. Khan & Bhat (2012) developed a multivariate binary probit model to estimate individual work arrangement decisions, which also took interactions among household members into account. The work arrangement decisions included employed or not, work full-time or not, be self-employed or not, holding more than one job or not, and work at home or not. Gupta & Vovsha (2013) formulated a hybrid discrete choice-duration model for work schedules with intra-household interaction in multiple-workers households. The estimated results showed that there is significant synchronization of work schedules of household members. Compared to modeling traditional workers with a full time job at a fixed work location, and travel between home and office every working day, Vyas & Vovsha (2014) paid attention to flexible work arrangement decisions, which involved part-time, flexible workplaces, and communication using high technology. Three interlinked sub-models were formulated to model this decision process: A strategic long-term model to predict the type of employment, a long-term choice model of workplace location, and a mid-term model related to frequency and flexibility of the daily commute. Saleh & Farrell (2005) developed a departure time choice model, taking into account different levels of scheduling flexibility of individuals.

Summarizing these studies, although some aspects of work schedules have been investigated, the particular research questions that we pose in this study have not been addressed in the literature. This observation at the same time marks our contribution to the literature. Our study sheds more light into work and household scheduling processes. It constitutes a building block to the formulation of a more formal model of work arrangements and household scheduling processes.

The remainder of this paper will provide details of the design of our study and the answers to the formulated questions. We set out with a discussion of the data collection. Next, we will explain the analysis that was conducted and discuss the results of the analyses. A summary and discussion of main findings and future work completes the paper.

2. DATA

2.1 Design strategy

Synchronization of schedules, or the lack of it, can be captured in terms of gaps between the home departure, respectively arrival times, of different household members. In order to analyze the effect of co-variates on such gaps, data are needed from a sample of two-adults households with children about departure and arrival times of the household members, together with contextual information. To that end, a web-based survey, including socio-demographic characteristics, work schedules of the parents, children-related agendas, household task allocation, and attitudes towards the trade-off between work and children-related activities, were collected in January 2015 in the Netherlands. This paper is based on the part that the collected data, particularly the part concerned with socio-demographic characteristics, the work schedules of the adults, and children-related agendas. Information of work schedules included the departure times from and arrival times at home of both adults, work duration, travel time, and transport mode from home to the workplace, while information about the children-related agendas included activity type, duration, travel time, and escorting spouse.

2.2 Sample characteristics

The total number of households is 1575. After checking the data, 1037 valid questionnaires were used for the present analyses. The frequency distributions of selected socio-demographic characteristics are shown in Figure 1. The frequency distribution of male and female respondents is 43.7% vs. 56.3% respectively. The percentages of the three age categories are 4.62%, 82.68% and 12.70% respectively, indicating that the majority of the respondents is between 26 to 45 years old. As shown in Figure 1, the percentage of respondents with respectively a low level of education and a high level of education is 5.96% and 11.07%, while 82.97% of the respondents has a medium level education, which indicates that most respondents at least have medium level education. Similarly, household income of the majority of the respondents is between 1401 and 4200 euros per month. In contrast, the number of respondents with a low household income level or a high household income level is 7.70% and 19.15% respectively. Figure 1 also indicates that only 8.85% of the respondents has more than two children, which means that more than 90% of the respondents only has one or two children in their household. Finally, it shows that more than 50% of the respondents' youngest child is less than five years old, while 22.52% respectively 23.48% is between 5-8 and 9-12 years old

Figure 2 shows work schedule characteristics and the distribution of working days across weekdays. Figure 2 (a) shows that more than 68.47% of the households are dual-earner households, while only 2.7% of the households involve non-workers. A total of 92 males and 263 females does not have a job, as is shown in Figure 2 (b), which suggests that the employment rate is higher among men than among women. This reflects traditional gender role in the Netherlands. As shown in Figure 2 (c), less people work on Wednesday and Friday, especially females.

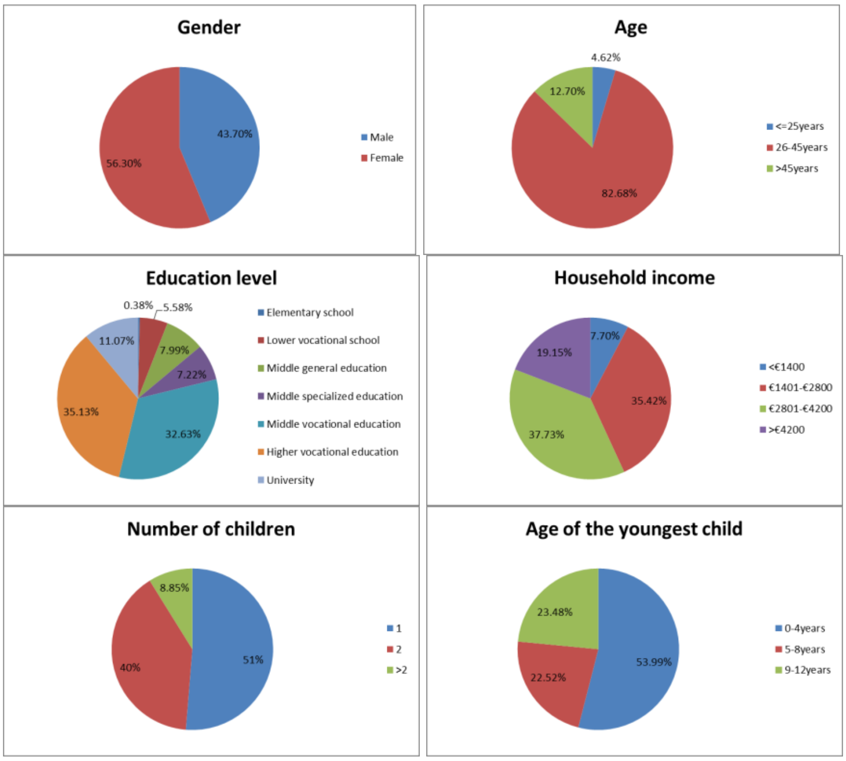
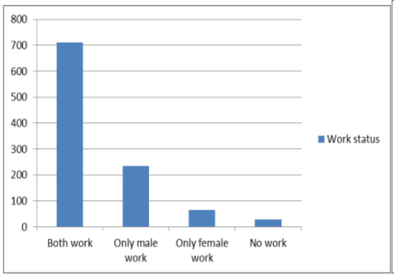
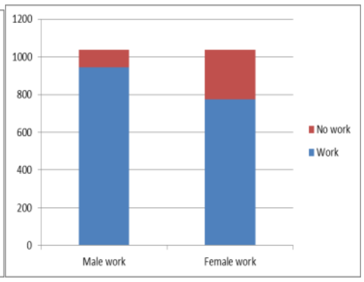


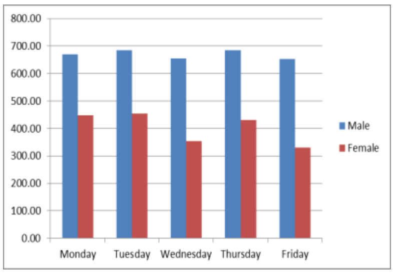
FIGURE 1. Sample Characteristics (N=1037)



(a) Work status



(b) Working rate of male/female



(c) Distribution of working day

FIGURE 2. Work schedule characteristics

To understand these statistics, it is important to realize that elementary schools tend to be closed on Wednesday afternoon, and therefore people working part-time may not work on that day to take care of the children at home. Friday is a popular non-working day for people working part-time. Because the aim of this paper is to analyze the degree of synchronization of home departure and arrival times between parents and children, households with only one earner or no earner, and the days when they were working at home were not taken into account. Thus, the analyses reported in this paper, are based on dual-earner households only for the days when they go to work.

3. ANALYSES AND RESULTS

The collected data allow the construction of different gaps, providing different perspectives on the synchronization and coordinating of schedules. In particular, the following gaps were calculated from the data on work schedules and children-related agendas. Information about work schedules included respondents' departure time from home and arrival time at home, work period, travel time, and their spouses' work status, while data on children-related agendas included activity type, duration, travel time, and escorting spouse. Gaps can be divided into departure time gaps and arrival time gaps, which are defined as parents' departure time minus children's departure time, and parents' arrival time minus children's arrival time respectively. Thus, a negative gap means that the respondent departs/arrives earlier than the child, while a positive gap means that the child leaves respectively arrives earlier, which is the time they will stay at home alone. This difference should be taken into account considering the focus of our analysis, which is to analyze the extent of and the conditions under which a child is home alone. Therefore, two different gaps were calculated: Departure time gap between second parent and the last child (DGap), and arrival time gap between the first parent and the first child arriving home (AGap) The magnitude of the gaps was analyzed as a function of socio-demographic characteristics, day of the week and related parameters.

The estimated results are summarized in Table 1. The R-squared of the DGap and AGap model is equal to 0.3825 and 0.2500 respectively, which suggests that the strength of the relationships are modest. As shown in Table 1, the estimated constants of the DGap model are positive, indicating that the second parent on average leave home later than the children, suggesting that parents do not want their children to stay at home alone in the morning. Whether or not parents depart at the same time significantly affects the departure time gap. If parents depart from home together, the departure gap is smaller than if they depart from home separately.

Table 1. Estimation result for the DGap

Attributes	Levels	Coefficient DGap	P-Value DGap
Constant		1.3587***	0.0000
Who departs later	Male	0.3143***	0.0000
	Female	0.2553***	0.0000
	At the same time	-0.5696***	
If travel in peak hour	Yes	-1.8803***	0.0000
	No	1.8803***	
Number of children	1	-0.1428***	0.0000
	2	0.0136	0.6723
	>2	0.1292***	
Education level	Primary education	0.1917**	0.0174
	Middle education	-0.0331	0.4507
	High education	-0.1586	
Household income	=<1400 Euro/month	-1.4797***	0.0000
	1401-2800 Euro/month	1.2768***	0.0000
	2801-4200 Euro/month	0.1302***	0.0000
	>4200 Euro/month	0.0727	
Age of the youngest child	=<4 years	0.1743***	0.0000
	5-8 years	0.0033	0.9094
	9-12 years	-0.1776***	
Day of the week	Monday	-0.0385	0.4269
	Tuesday	0.0189	0.9714
	Wednesday	-0.0043	0.9261
	Thursday	-0.0012	0.9836
	Friday	0.0251	
Random effects			
Constant		0.0423**	0.0150
Who departs later	Male	1.3155***	0.0000
	Female	0.2949***	0.0000
	At the same time		
If travel in peak hour	Yes	0.7678***	0.0000
	No		
Number of children	1	0.7886***	0.0000
	2	1.0909***	0.0000
	>2		
Education level	Primary education	0.1969***	0.0000
	Middle education	0.7085***	0.0000
	High education		
Household income	=<1400 Euro/month	0.4809***	0.0000

	1401-2800 Euro/month	0.2865***	0.0000
	2801-4200 Euro/month	0.3369***	0.0000
	>4200 Euro/month		
Age of the youngest child	=<4 years	1.5440***	0.0000
	5-8 years	0.3842***	0.0000
	9-12 years		
Day of the week	Monday	0.0274	0.4950
	Tuesday	0.1981***	0.0000
	Wednesday	0.1563***	0.0000
	Thursday	0.0059	0.8881
	Friday		

An explanation may be that the parent who needs to leave earliest restricts departure time options. Travel in peak hours show a significant effect on the departure time gap, which suggests that if people travel during peak hours, in general the travel time is longer than travel time during off-peak hours, and the departure time should be earlier correspondingly.

Table 1 also indicates that in single child households, the average departure time gap decreases, while in more than two children households, it increases. The departure time gap significantly increases in lower educated households, which may be explained by the probability of lower educated households working less hours generally.

Table 1 also indicates that the average departure time gap significantly decreases in lower income level households, and significantly increases in medium income level households, which may suggest that people with lower income levels start work earlier than people with higher income levels. The estimated effects for the age of the youngest child indicate that the departure gap significantly increases when they have a young child, which may suggest that at least one of the parents needs to spend more time at home. Table 1 also shows that the effects of days of the week are not significant.

Table 2 shows that the estimated constant of the AGap model is positive, implying that on average the first parent arrives later than the first arriving child. Similar to the DGap, the arrival time gap is larger if parents arrive at home together, and it significantly increases if people travel during peak hours. In the case of single child households, the arrival time gaps are substantially smaller than the average, indicating that people with only one child tend to shorten the arrival gap to spend more time with their child or tend to avoid that the child stays at home alone. Table 2 also indicates that households with lower education and income levels have significantly smaller arrival time gaps than households with other education or income levels. The explanation may be that those people have shorter working times and finish earlier in general.

Table 2. Estimation results for AGap

Attributes	Levels	Coefficient AGap	P-Value AGap
Constant		0.1738***	0.0031
Who departs later	Male	-0.2940***	0.0000
	Female	-0.3336***	0.0000
	At the same time	0.6276***	
If travel in peak hour	Yes	1.1174***	0.0000
	No	-1.1174***	
Number of children	1	-0.8132***	0.0000
	2	-0.1603***	0.0000
	>2	0.9735***	
Education level	Primary education	-0.9096***	0.0000
	Middle education	0.3458***	0.0000
	High education	0.5638***	
Household income	=<1400 Euro/month	-1.0584***	0.0000
	1401-2800 Euro/month	0.3782***	0.0000
	2801-4200 Euro/month	0.6109***	0.0000
	>4200 Euro/month	0.0693	
Age of the youngest child	=<4 years	-0.3512***	0.0000
	5-8 years	-0.0340	0.2994
	9-12 years	0.3852***	
Day of the week	Monday	-0.2965***	0.0000
	Tuesday	-0.3114***	0.0000
	Wednesday	0.6850***	0.0000
	Thursday	-0.3802***	0.0000
	Friday	0.3031***	
Random effects			
Constant		0.4757***	0.0000
Who departs later	Male	0.2140***	0.0000
	Female	0.4604***	0.0000
	At the same time		
If travel in peak hour	Yes	1.5612***	0.0000
	No		
Number of children	1	0.3548***	0.0000
	2	0.1437***	0.0000
	>2		
Education level	Primary education	0.0173	0.5159
	Middle education	1.0418***	0.0000
	High education		
Household income	=<1400 Euro/month	0.4270***	0.0000

	1401-2800 Euro/month	0.0988***	0.0002
	2801-4200 Euro/month	0.0870***	0.0000
	>4200 Euro/month		
Age of the youngest child	=<4 years	0.1293***	0.0000
	5-8 years	0.0125	0.6565
	9-12 years		
Day of the week	Monday	0.4107***	0.0000
	Tuesday	0.4502***	0.0000
	Wednesday	1.0886***	0.0000
	Thursday	0.1550***	0.0000
	Friday		

The households with young children (<=4 years) have a significantly lower AGap than the average, indicating that people tend to avoid young child staying at home without parents. Because the school time finishes earlier for younger children than for older children, this may indicate that people tend to decrease the arrival time gap when they have younger children.

Table 2 also indicates that the arrival time gaps are strongly influenced by day of the week. The arrival time gaps are lower on Monday, Tuesday and Thursday, while they are higher on Wednesday and Friday. The highest average arrival time gap is found for Wednesday. Taking into account that most elementary schools are closed on Wednesday afternoon, results may suggest that people tend to trade-off between work and taking care of children, but not simply pursue the synchronization of arrival times.

The second part of Tables 1 and 2 lists the estimated random effects, which were assumed to follow a normal distribution. Most effects are significant for both the DGap and AGap model, suggesting that people differ widely in their departure time gap and arrival time gap, both in general and within each of the categories of the covariates. However, heterogeneity seems much higher in the departure time gap for Monday and Thursday, and also in arrival time gap for the households without young children (<=4 years).

4. CONCLUSIONS AND DISCUSSION

The purpose of this study has been to analyze the degree of synchronization in home departure and arrival times between working parents and their children in dual-earner households with children. Synchronization of schedules was measured in terms of time gaps in home departure and arrival times between working parents and their children. The choice of time gap of working parents is not a simple individual decision of work start and end time, but also relates to household task allocation and cooperation, attitudes toward the trade-off between work and children-related activities, expected travel times, and various constraints related to company policies about working hours and public transport timetables. The more parents are involved in children-related activities, the more temporal and spatial constraints will restrict parents' departure and arrival time decisions, which affect the time gaps between parents and children.

A panel regression model with random effects was estimated to examine the explanatory power of gender differences, contextual effects, children effects and the effects of socio-demographic characteristics on the magnitude of the time gaps. Estimation results give rise to some interesting conclusions.

- Arrival time gaps are more influenced by various attributes than departure time gaps, which may be caused by the shorter available time in the morning to organize household activities.

- If parents depart/arrive at the same time, time gaps are affected significantly. When they can depart/arrive separately, time gaps significantly decrease, suggesting that one can organize escorting, and the spouse has more flexibility to choose this/her departure/arrival time.

- Arrival time gaps in single child households are relatively small, indicating that parents tend to synchronize arrival times to avoid the child stays home alone.

- Arrival time gaps in households with young children are also small, which indicates that parents tend to synchronize arrival times to spend more time taking care of young children.

- Day of the week affects the arrival time gap significantly but less the departure time gap, which suggests that parents' and children's arrival times are quite different across days of the week.

- Different education can lead to different types of work, affecting time gaps significantly.

These findings about time gaps are related to work schedule arrangements synchronization and coordination between the working adults and constitute the basis for the allocation of non-work household tasks. A model of this process will improve the activity-generation part of current activity-based models of travel demand (Rasouli & Timmermans, 2014). To that end, our future work will address the ultimate problem of the larger research project: estimating work schedule arrangements and task allocations across household members in two adults dual-earner households with children. We plan to report these further developments in the near future.

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User behavior transition mapping for bus transportation planning based on time series data analysis of travel e-ticket information

A Case Study in Tainan City, Taiwan

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Key words: Travel behaviour, e-ticket data, behaviour transition

Abstract: In the past, the bus service planning in the metropolitan area is an individual procedure of bus operators, private organization, or local government. Most of them use their own data and analyse them to build an appropriate planning to operate. One of the important topic of bus service improvement is that understanding users' decision. However, there are only rare users will announce their thought. In order to understand user's will, we use a data mining technique to obtain information from large e-ticket data. Last decade, the e-ticket system apply on many public transportation systems widely, and it is easy to get all transaction information of e-ticket users. In order to obtain user's decision based on e-ticket, we propose a method to cluster Behavior and conduct the Behavior transition calculation. In the Behavior transition map, manager can understand the overall transition tendency in whole system, and target clusters need to improve.

1. INTRODUCTION

Bus service is a highly flexible transportation system. It needs to have fast reaction for any slight modification, e.g. business building construction, new vehicle type, or the user's socioeconomics. After service adjusted, user may change their Behavior according to the new service. Therefore, manager needs to understand what the user think about new service and the decision, when they want to make new planning. However, it is time and cost consuming to collect user's response. Manager usually obtains the information via sampling survey with high cost, except rare users announce their feedback voluntarily. Moreover, such kind of method is useless for bus service planning which need fast reaction and large number of user.

Fortunately, e-ticket system application grow quickly, bus companies can get row data of each transaction that user board or alight bus, includes time, location, and route. Large data set not only present operating performance via ridership calculation but also obtain user's Behavior information via advanced statistical method (Morency, Trépanier, et al, 2006; Morency, Trépanier, et al, 2007; Bagchi and White, 2005, Zhong, Manley, et al, 2015). Therefore, this study propose a method to obtain user Behavior quickly via e-ticket data analysis. Moreover, user Behavior information is an important foundation that help manager can make bus service planning.

1.1 Background

Bus service is a general public transit transportation system, and its construction cost is lower than other transit like subway. It is also a flexible service, so it is almost existed in all area. Due to that bus service only need vehicles and stops, it only takes shirt time (less than 1 month) to modify route or stops. In addition to there are bus exclusive lane, buses drive on general roads with other private vehicles.

According to the characteristics above, manager can easily change planning contents in planning procedure. Also, due to the flexible planning, it is hard to find optimal solution. Moreover, bus user demand changed time by time, and bus service needs to make improvement for demand changed.

However, "Professional Judgement" is in common use to make bus service planning (CSTR, 2009; FHWA , 2015; TRB, 2006). Except a new bus service may need a new area wide transportation planning. Bus service makes planning based on existed OD information. Main cause is time and finical cost of area wide data are too high, so it does not suit planning in small area or scale.

During "Professional Judgement" planning, the most important is basis data, besides planner's professional knowledge. It includes transportation environment, demands, and operator resource. Like others, traffic demand is the hardest one to obtain. In the past, traffic demand comes from area wide transportation planning, demand survey, professional judgement, and user feedback. Among them, area wide planning is a long term forecasting, there may larger error; sampling survey needs higher time and finical cost. Therefore, most planning made by professional judgement and feedback. It needs a quick method to short progressive schedule, in order to assist that understanding demand or feedback.

1.2 Objectives

Last decade, general e-ticket system can provide user's detail usage data quickly, and it can produce various data for planning (Bagchi and White, 2005). And, bus user will have only 2 decisions, use or not to use, according to any variables. The 2 decisions directly impact the ridership of bus service. In the other words, the ridership is related to user's decision. Therefore, this study obtain the reliable user Behavior according to above characteristic and Behavior transition at continuous time interval. After that, it can provide reliable information of user's will via deriving it from Behavior transition.

1.3 Research architecture

The rest of this paper is organized as follows. Chapter 2 discussed pervious study about Behavior clustering; chapter 3 discussed method to clustering and computing Behavior transition. A case study in Tainan city shows in chapter 4. Chapter 5 discuss the application of Behavior transition map. Chapter 6 is conclusion of this study. *Figure 1* is the research flow chart. First part is that using the expectation-maximum algorithm to cluster e-ticket data based on ridership and departure time. The other is that proposing decision support based on travel Behavior.

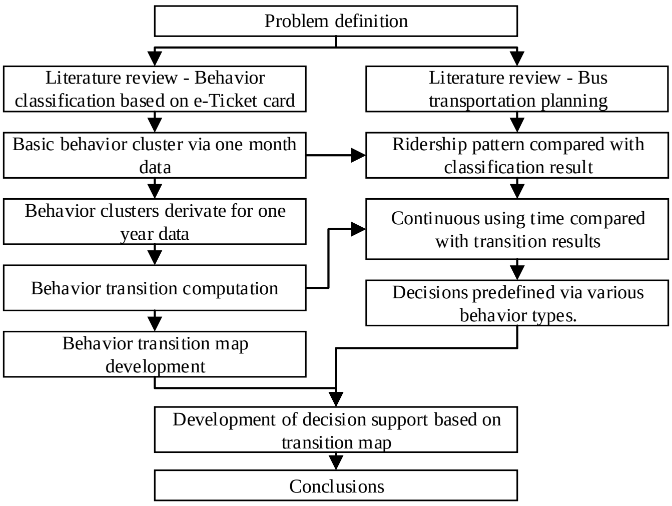

Figure 1. Research flow

2. LITERATURE REVIEW

Application of e-ticket data discussed from 2005. E-ticket data is simple but it can extend to various material for transportation user Behavior research, according to the time, location, and service information. Although e-ticket can help to understand Behavior, but cannot what trip purpose is. It needs more advance method to study deep information from large e-ticket data (Bagchi, et al, 2005).

In research fields of e-ticket data, time interval is a very important variables. Electrical data could be recorded any time, and different research object may influenced the appreciated time interval. Too small time interval will increase computing loading, and too big time interval will lose some data characteristics. As bus service, weekly interval is a proper time interval to present the user Behavior. Regularity of departure time can classify different Behavior. Using the k-means method to cluster the regularity shows weekly data can cluster user Behavior and derive user’s commuting type (Morency, Trépanier, et al, 2006).

Continuous period analysis on smart card data is another behaviour transition understanding method for operators. In London, the data show that number of cards remaining active in following period are decreasing in similar pattern at various routes (Ortega-Tong, 2013). That situation also found in Tainan city. When users exit bus service, also means they change their behavior due to some reasons. But it is hard to consider all reasons without high cost survey. A simple method to know who change behavior and change to what behavior is valueable for bus service managers.

Although ridership is easy to understand performance of user service, it may lost important information for managers to realize the real causes. By aggregating data, it is easy to conduct statistical process or knowing tendency. However, people are not following a common rule to live, any reason might influence their decisions. (Flyvbjerg, Holm, et al, 2005; Hägerstraan, 1970). Behavior clustering is a clear method to cluster user with similar behavior to decrease noise or error in finding target users.

More advance Behavior analysis on weekly data consider that estimating mixture of unigrams model from trips captured through e-ticket data can retrieve weekly profiles depicting different public transportation demands. Clustering results provide better suggestion based on user socioeconomic characteristics. Grouping similar clusters also shows Behavior information in different level. Land use data will enhance the model to estimate the user’s socioeconomic (El Mahrsi, Côme, et al, 2014; Sun, Axhausen, et al, 2013).

Another study identify 11 clusters user travel pattern in London, and use the clustering results to improve travel demand model. They show the clustering results in two different month to understand the stability of clusters.

Stability of cluster shifting can show the users' Behavior are stable or not (Langlois, Koutsopoulos, et al, 2016).

3. USER BEHAVIOR TRANSITION TENDENCY

This chapter discusses how to cluster bus user Behavior from e-ticket data and computing of Behavior transition. Weekly profile is the key concept to conduct the clustering and average ridership in one month would be used.

3.1 Dataset

E-ticket data are used in this study, and each row data contains the boarding and alighting information of single trip by the same card. Data items in each row includes card ID, date, time, location, and route ID. We will use the data in 2014 March to conduct the clustering calculation. One single month includes 4 weeks and 4 weekend. By averaging the ridership in each hour of 4 weeks will present usage profile of 7 days in a week. But there are over 80% users use less than 4 times per month, it also means less than 1 time per week. In order to prevent the over distributed random usage influence the clustering, the user use less than 4 times per month are grouped as random user cluster.

Frequency of most bus user Behavior are weekly, includes weekday and weekend trip which can show in weekly profile. Therefore, we consider that there are 168 (24 hours * 7 days) variables in a week and average the ridership in each hours (Pas, 1988; El Mahrsi, et al, 2014). *Figure 2* shows the weekly profile. Difference between weekday and weekend is easy to determinate and peak hour characteristics are also.

Ridership

Day of week	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
MON	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
TUE	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
WED	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
THU	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
FRI	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0
SAT	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
SUN	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Time of day

Figure 2. Sample of average single user ridership in each time of day of whole week

3.2 Clustering

Main concept of clustering in this study is grouping users with similar Behavior, and definition of bus user Behavior is decision of departure time and ridership. Other variables are not considered in order to simplify clustering calculation. Although other variables, like weather, may influence user's decision, user do not change their Behavior permanently according to the accidental event. Therefore, it pick a simple month without special event and long holidays to conduct clustering process. Variables of Behavior are departure time and ridership, it also means users departure at similar time or ridership is similar are in the same cluster.

EM algorithm is used to find maximum likelihood parameters of a statistical model like formulation (1). *Figure 3* is diagram of EM. All samples belong each cluster is a probability value instead of a boolean value, and all probability of each sample belong to all cluster are sum to 1. By iterative E-step and M-step in EM, it will get higher likelihood. But EM is a time consuming algorithm, it needs to improve in order to apply in real world.

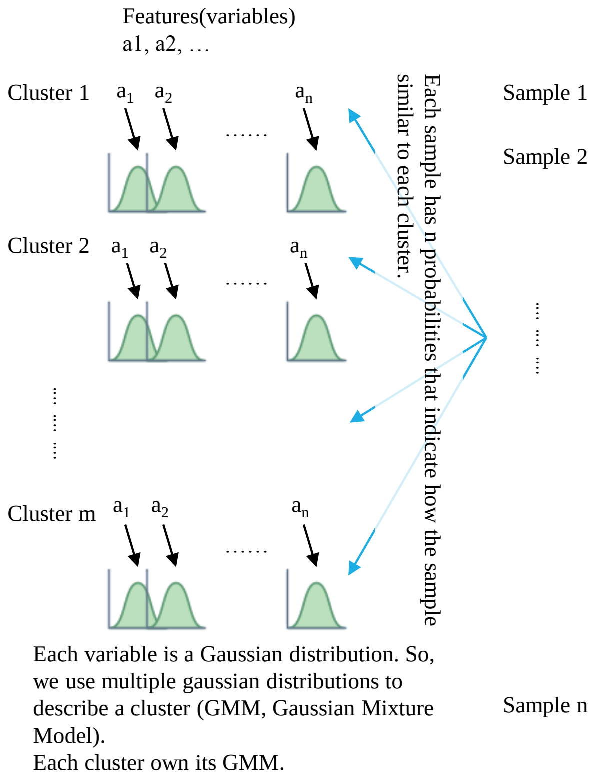

Figure 3. EM algorithm and clustering problem diagram

$$p(X \mid \lambda) = \prod p(x_i \mid \lambda) \quad (1)$$

X is all samples; x_i is sample i; λ is parameters.

Expectation-Maximum algorithm (EM) used to cluster users from previous simple month data. EM is appreciate for clustering and is also an unsupervised algorithm, like k-means. Advantages of EM are simple, robust and easy to implement. It also has better explanatory for missing data (Dempster, Laird, et al, 1977).

Due to that accidental variables are not considered, a simple month is selected to compute clustering parameters. And, the parameters are used to obtain clustering results of other months. Whole year data split in months, and cluster in each month too. *Figure 4* is clustering process.

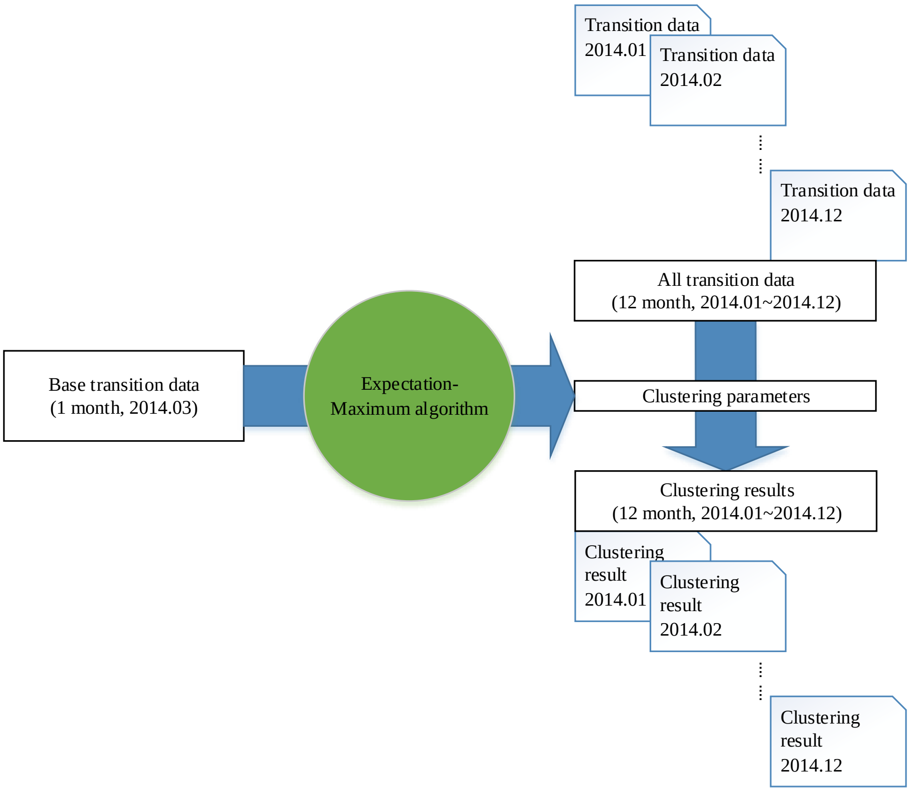

Figure 4. Clustering process for all data

3.3 Behavior transition

In case of computing Behavior transition, clusters should be ordered for understanding key characteristic of a cluster. In this study, regularity is used to evaluate that how user attend to use bus service. As a regular user, more regular means more ridership took, like students or commuters. Departure time is a significant value that indicate the regularity. Besides, commuters usually take the bus at peak hour, e.g. 7:00-9:00 and 17:00-19:00. So, the regularity value split into morning peak and afternoon peak, 12:00 is the middle. Cluster regularity is considered as formulation (2), regularity value is the sum of standard deviation of morning and afternoon peak for all trips in the same cluster. The random cluster which all users in it use less than 4 times per month, is forced to be the most random cluster.

$$\text{Cluster regularity} = S_{MP} + S_{AP} \tag{2}$$

S_{MP}: Standard deviation of boarding hour in morning peak (0-11) of all ridership in each cluster.

S_{AP}: Standard deviation of boarding hour in afternoon peak (12-23) of all ridership in each cluster.

After regularity sorting, Behavior transition in adjacent month is conducted by computing shifting rate from before cluster to after cluster. Shifting rate is the ratio that cards in before cluster belong to after clusters. There are two special clusters in before and after clusters. One is “New” cluster, it means the cards only used in after month; the other is “Exit” cluster, it means the cards only used in before month. *Figure 5* is a Behavior transition result, it shows all ratios from before shift to after cluster in each row.

	2014.03->2014.04	After clusters (Shifting rate from before cluster (%))											
		1	2	3	4	5	6	7	8	9	10	Exit	Total
Before clusters	1: Regularly, both MP and AP	78.9	0.0	0.4	5.0	2.5	2.5	5.4	0.8	0.8	1.2	2.5	100
	2: Regularly, AP only(Stu.)	0.0	63.5	0.0	0.0	0.0	1.4	12.2	5.4	9.5	4.1	4.1	100
	3: Regularly, half r. in AP	0.0	2.3	80.5	0.8	0.8	2.3	3.8	4.5	0.8	1.5	3.0	100
	4: Regularly, MP only.	5.3	0.0	0.0	71.5	0.0	0.5	6.3	6.3	1.4	3.9	4.8	100
	5: Regularly, AP only	0.7	0.7	2.1	0.7	56.3	24.6	0.0	3.5	2.8	4.2	4.2	100
	6: Regularly, half r.	6.9	0.6	2.9	0.0	14.4	29.3	2.9	5.7	10.9	10.3	16.1	100
	7: Randomly in peak hour.	2.9	3.8	1.0	2.5	1.3	0.6	63.1	14.0	4.1	2.2	4.5	100
	8: Randomly, more r. in evening	0.5	0.5	0.7	0.7	0.2	1.8	5.2	30.4	25.7	23.4	10.9	100
	9: Randomly, more r. in weekend	0.1	0.3	0.0	0.4	0.2	0.6	0.3	6.7	18.9	31.2	41.3	100
	10: Randomly, r. less than 4	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.6	2.8	15.3	81.0	100
	New	0.2	0.1	0.1	0.2	0.0	0.5	0.1	1.2	6.8	90.9	0.0	100

MP: Morning peak; AP: Afternoon peak; r.: Ridership

Figure 5. Behavior transition ratio at adjacent months

3.4 Behavior transition map

Except before cluster itself, the after cluster with maximum shifting rate is the cluster that user more attend to shift. It also means the desired level that users want to shift. Using a directional link to connect all before cluster to the maximum shifting rate after cluster will draw a transition map. *Figure 6* is an example shows connection in the map. Not only the after cluster with maximum shifting rate, but also the after clusters with second or more top shifting rate could be considered in transition map. In this map, manager can easy to understand the tendency of all users in the service, includes New and Exit users. Moreover, each cluster indicates a specific Behavior, manager is easy to know who the target user is.

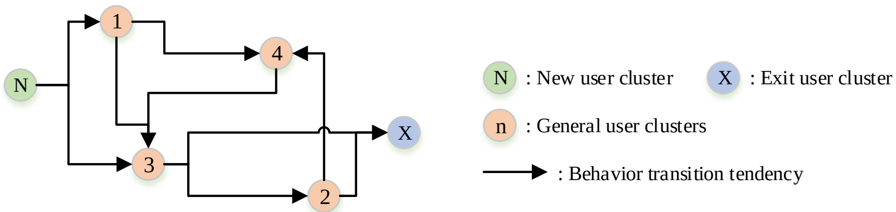

Figure 6. Behavior transition map at adjacent months

4. BUS USER BEHAVIOR IN TAINAN CITY

This chapter use Tainan city data as an example to examine the bus user Behavior transition via the process in section 3. The process translate e-ticket data to Behavior transition tendency, in order to understand bus service performance and improvement target.

4.1 Tainan city introduction

Tainan city is located at south of Taiwan, shows in *Figure 7*. Population is 1,885,199 (2015), area is 219 km^2 and there are 105 bus routes and 3 bus companies in it. Bus network also shows in *Figure 7*. Downtown area is located at west south. From 2012 December, e-ticket system applied in whole bus service. Although the total ridership is continuous growing, the city bus mode share still stop at 1%. E-ticket data of one bus company in 2014 are used in this study, and the amount is 867,328.

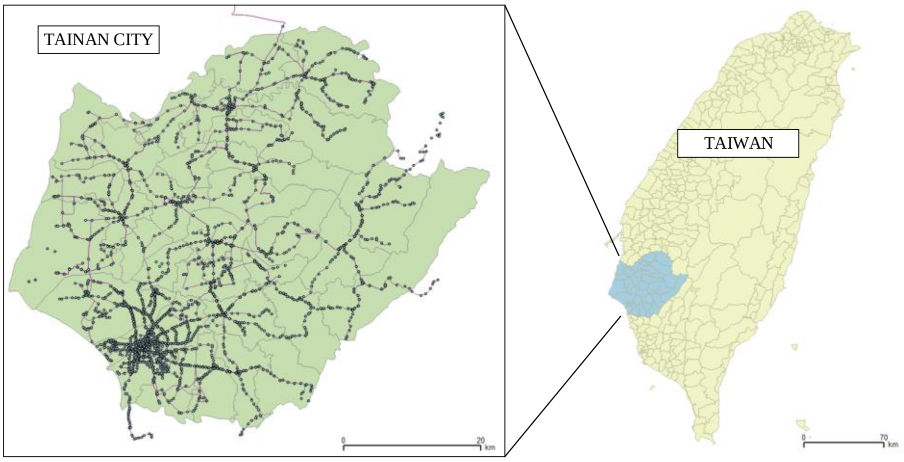

Figure 7. Tainan city bus network

4.2 Bus user Behavior clustering

There are 21,357 e-ticket be used in 2014 March, and 17,532 (82.8%) of them are random users who use less than 4 times in that month. Other 3,825 data are users who use more than 3 times clustered via EM algorithm. After the clustering and regularity sorting, there 9 clusters and 1 random cluster list in *Figure 8a* and *8b*. Cluster 1 is the most regular user, who use bus at 6 and 17, should be standard commuters and the average ridership shows they almost use bus every weekday. Cluster 2 is the regular user who use bus at 16, the special departure hour indicated they could be elementary or junior high school student. Cluster 3, 4 are the users use bus at morning peak only. Cluster 5, 6 are opposite one, they use bus at afternoon peak. Cluster 7 is the user who use bus at distributed hour, like college students or employees. Cluster 8, 9 are random users who bus at random departure time, the difference between 8 and 9 is that cluster 9 prefer to use at weekend.

The results shows clear regularity sorting and closed to the real world. Cluster regularity of cluster 1 – 6 are less than 3 (hours), and they are considered as regular group. Cluster regularity of cluster 7 – 10 are over 3, and they are considered as random group.

4.3 Bus user Behavior transition

Whole year data could be clustered via clustering parameters in section 4.2, and draw 11 behavior transition table at adjacent months like *Figure 9*. *Figure 9* is an example that is bus user transition from 2014 January to 2014 February. Except cluster 8, 9, other clusters have maximum shifting rate to itself, it could be 66.2% in regular group. But cluster 8 has only 23.3% shifting rate to itself, it means the users in it changed very soon. In regular group, the shifting rate of 1 to 4, 1 to 7, 2 to 8, 4 to 1, 6 to 5, 6 to 9, 6 to 10, and 6 to Exit are over 10%, and 6 of them attend to become more random. In case of bus service, the result is a warning for manager.

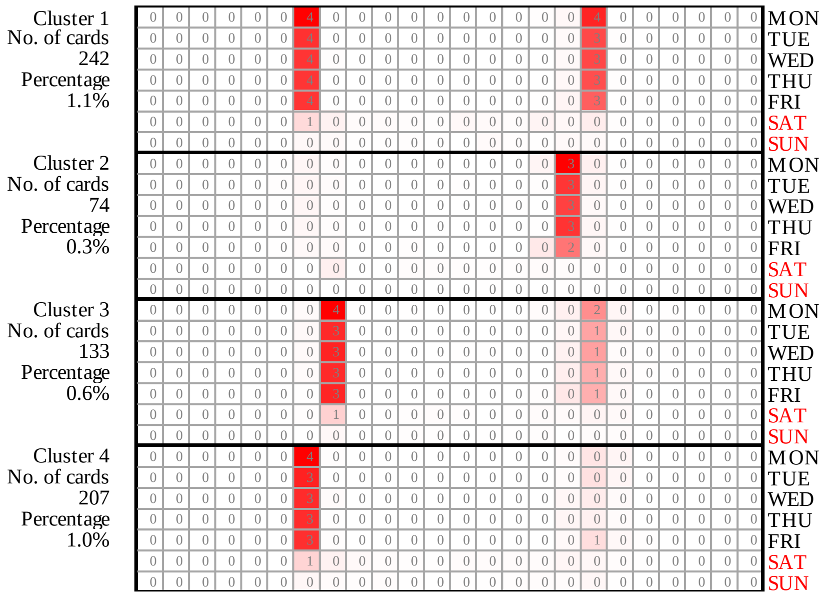

Figure 8a. Behavior pattern of all clusters (1/2)

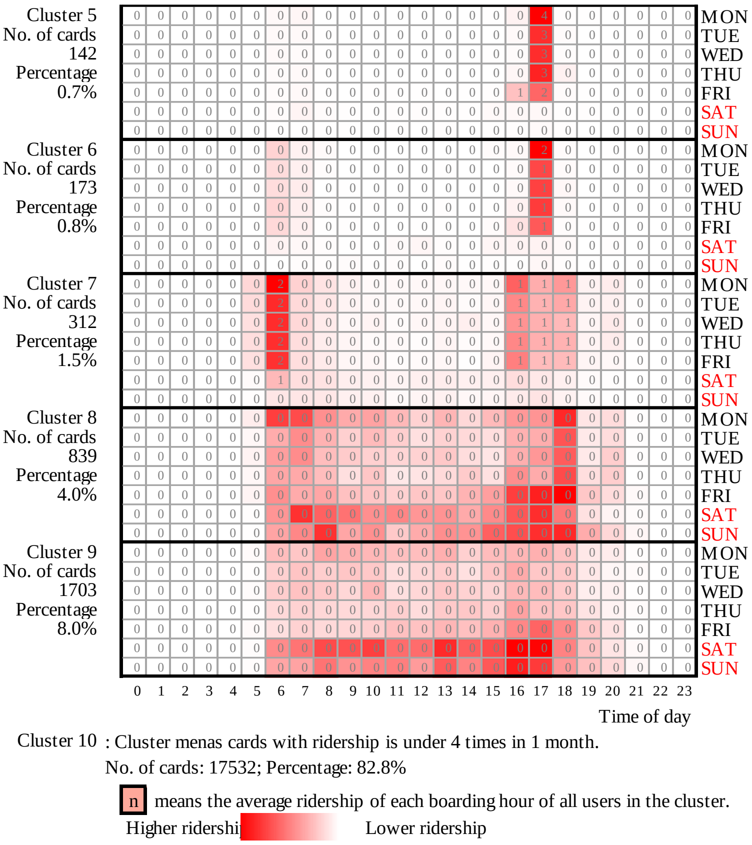

Figure 8b. Behavior pattern of all clusters (2/2)

2014.01->2014.02		After clusters (Shifting rate from before cluster (%))											
		1	2	3	4	5	6	7	8	9	10	Exit	Total
Before clusters	1: Regularly, both MP and AP	54.4	0.0	0.0	14.6	2.9	5.8	12.6	0.0	1.9	2.9	4.9	100
	2: Regularly, AP only(Stu.)	0.0	65.9	2.3	0.0	0.0	2.3	4.5	13.6	6.8	0.0	4.5	100
	3: Regularly, half r. in AP	0.0	6.2	66.2	0.0	2.3	5.4	2.3	9.2	4.6	1.5	2.3	100
	4: Regularly, MP only.	14.0	0.0	0.0	51.8	0.4	5.7	7.0	6.6	2.2	3.1	9.2	100
	5: Regularly, AP only	5.7	0.0	0.0	0.0	34.3	34.3	5.7	5.7	2.9	8.6	2.9	100
	6: Regularly, half r.	3.4	0.0	2.4	2.9	14.9	29.8	0.5	5.8	11.1	13.9	15.4	100
	7: Randomly in peak hour.	3.8	2.9	3.8	9.6	1.9	3.8	42.1	19.1	3.8	2.9	6.2	100
	8: Randomly, more r. in evening	0.2	1.9	1.6	1.3	1.6	4.9	2.1	28.2	22.9	21.3	14.2	100
	9: Randomly, more r. in weekend	0.1	0.2	0.3	0.3	0.1	1.3	0.3	7.4	23.3	33.4	33.3	100
	10: Randomly, r. less than 4	0.0	0.0	0.1	0.0	0.0	0.4	0.0	0.9	5.8	30.1	62.6	100
	New	0.1	0.1	0.0	0.1	0.0	0.4	0.1	1.0	7.6	90.7	0.0	100

MP: Morning peak; AP: Afternoon peak; r.: Ridership

Figure 9. Behavior transition result at 2014.11 to 2014.12

4.4 Bus user Behavior transition map

In 2014 data, there should be 11 transition results like *Figure 9*. Table 1 comes from the after cluster with maximum shifting rate of each before cluster. Clusters in random group in Table 1 are all attend to shifting to more random cluster or Exit cluster. Clusters in regular group may have 3 or more after clusters in Table 1, and it means the after clusters are varied. Therefore, it pick the after clusters with top 2 shifting rate to draw transition map as *Figure 10*.

Table 1. Behavior transition result at 2014

Clusters		Transition with maximum shifting rate expect itself										
		Jan→ Feb	Feb→ Mar	Mar→ Apr	Apr→ May	May→ Jun	Jun→ Jul	Jul→ Aug	Aug→ Sep	Sep→ Oct	Oct→ Nov	Nov→ Dec
Before clusters	1: Regularly, both MP and AP	4	4	7	7	6	8	8	5	7	4	7
	2: Regularly, AP only(Stu.)	8	7	7	7	9	Exit	10	8	7	9	7
	3: Regularly, half r. in AP	8	7	8	8	8	Exit	8	8	7	8	7
	4: Regularly, MP only.	1	1	7	8	8	8	8	1	1	7	7
	5: Regularly, AP only	6	1	6	6	6	Exit	6	Exit	6	6	6
	6: Regularly, half r.	Exit	5	Exit	10	Exit	Exit	9	10	10	Exit	5
	7: Randomly in peak hour.	8	1	8	8	8	8	8	8	8	8	8
	8: Randomly, more r. in evening	9	9	9	9	9	Exit	9	10	9	9	9
	9: Randomly, more r. in weekend	10	Exit	Exit	10	10	Exit	Exit	Exit	Exit	Exit	Exit
	10: Randomly, r. less than 4	Exit	Exit	Exit	Exit	Exit	Exit	Exit	Exit	Exit	Exit	Exit
	New	10	10	10	10	10	10	10	10	10	10	10

(blue) means the after cluster shows most often in all year of each before cluster.
(yellow) means the after cluster show second often in all year of each before cluster.

n: means the after cluster number with first highest probability evaluate from before cluster except before cluster itself.

Cluster 4 in table 1 is the only one cluster attend to be more regular cluster, others attend to be more random, and become Exit cluster finally. The tendency shows users prefer to shift to more random cluster. But manager cannot consider that from data base on only ridership, due to the total ridership may slowly growing from tourism. That also could be the cause that city bus mode share stop growing.

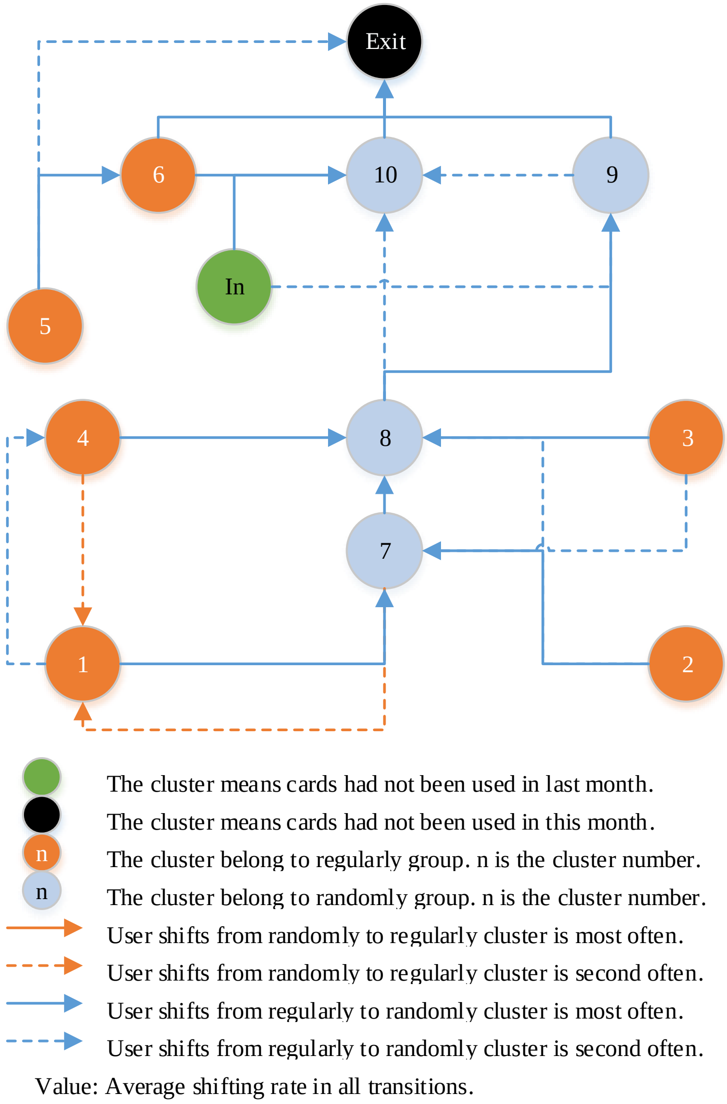

Figure 10. Behavior transition map at 2014

5. DECISION SUPPORT BASED ON BEHAVIOR TRANSITION

Base on the computing results in section 4, e-ticket data in whole year could translate to bus user behavior transition. Drawing the transition map via connected to after clusters with top 2 shifting rate. When manager needs to know transition tendency of specific cluster, it needs a path to show. Here, Critical Path (CP) is considered to determine the path. For example, setting the Exit cluster as end of CP and New cluster as start, and average shifting rate is link cost. The CP result show in *Figure 11*. Cluster 10 is the only one cluster between New and Exit clusters. It means most users attend to use bus service as cluster 10 and stop to use in the near future. When total ridership keeps growing and many users are not stable users in the service. Manger should pay attention to improve bus service to prevent users are easy to be influenced.

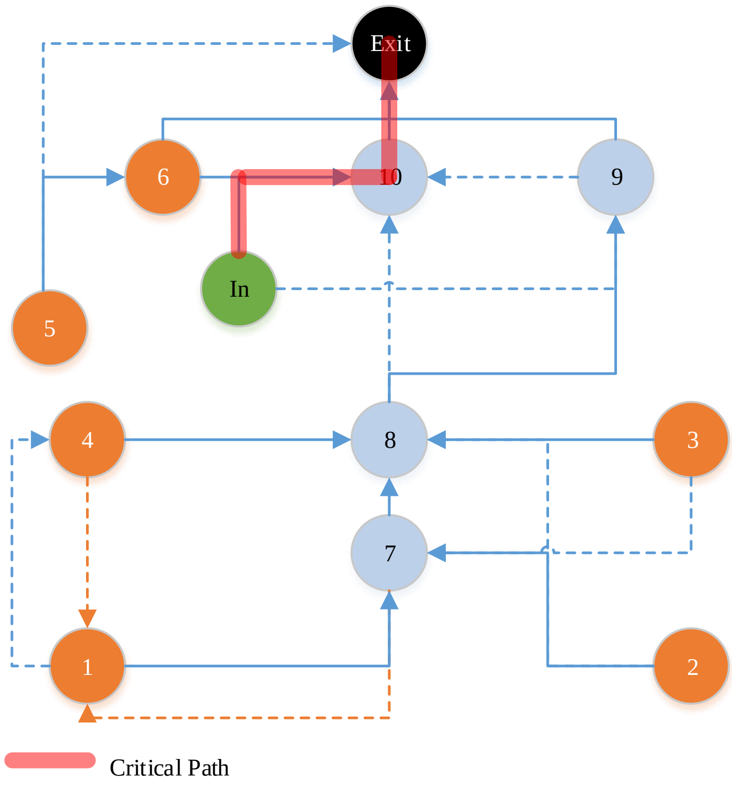

Figure 11. Critical path on Behavior transition map

6. CONCLUSIONS

This study proposed a simple and fast method to translate e-ticket data to Behavior transition. By EM algorithm, users clustered into 10 clusters, and computing their behavior transition between each adjacent months. Transition map drawn by connected to after clusters with top n shifting rate. The map shows transition tendency of bus user in each cluster. Generally speaking, if tendency is getting more regular, it means the bus service is getting more appreciate for users. If tendency is getting more random, there should be an improvement plan to change the tendency base on service or cluster user.

Critical Path in transition map is important for manager to find out the transition tendency of some clusters. In section 5, it shows an example of CP from Exit cluster. It helps manager to know what cluster will become the Exit one. Moreover, managers can make improvement and allocate resource to prevent user become Exit one.

The method in section 3 is different from previous researches which considered all ridership are the same. Actually, ridership is a composition of various user type, and they changed as time goes by. Resource allocation could be more appreciate according to the understanding who are target.

Case study discussed only 1 bus company and did not consider other variables. More variables, like routes or OD, could be considered to enhance clustering results in the future.

7. ACKNOWLEDGE

The authors thank Department of Transportation in Tainan City, Taiwan for providing e-ticket data and GIS map of Tainan.

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Latent structure analysis of a city center using spatial and categorical co-occurrence relations of facilities

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Key words: Spatial Evaluation, Stochastic Block Model, Latent Structure Analysis, Network Analysis

Abstract: In this study, we revealed the latent structure of co-occurrence information using the extended stochastic block model. We validated our approach via a case study in Osaka's city center near the Namba station. From our study, we conclude that (1) the facility accumulation of the target area was classified by latent classes based on co-occurrence information, (2) each latent class indicates its quantitative property, and (3) the relationship between the latent classes correspond with their geographic distribution.

1. INTRODUCTION

1.1 Background

Many city centers decline and become homogenized because of depopulation, an aging population combined with a diminishing number of children, and uniform urban development. In these situations, generally, attempts are made to reinvigorate city centers by changing and extending the use of existing buildings, e.g., for community development and renovations;

however, there are many cases in which such changes do not last or have a lasting impact around the facility. These well-intentioned activities do not often function well because we do not clarify the mechanism of facility accumulation as what is gathered together by individual facilities; thus, we cannot introduce facilities and policies that generate an overall improved livelihood.

Present city centers already comprise various facilities. Given large- or small-scale developments in a city center, we must attempt to create or extend facilities in existing facility groups. The mechanism behind facility accumulation focused on individual facilities is useful knowledge for efficiently revitalizing a city center that does not generate a strong enough livelihood from individual facilities but shares a livelihood with surrounding facilities.

1.2 Viewpoints

Research related to facility location and accumulation has been conducted using a variety of approaches. In such research, facilities are often classified using business type and land price as exogenous attributes, thus facilities are totaled for each business type and land price ranges, making it difficult to identify individual facilities. Facilities in a city center have diversity even if a specific business type is identified as the same. Further, such diversity becomes increasingly obvious as a city center becomes more active. Thus, a key question here is—what do we have to focus on to clarify the mechanism of facility accumulation focused on individual facilities without classifying facilities previously?

Similar and uniform commercial areas exist in Japan; however, there are unique commercial areas such as Harajuku and Omotesando in Tokyo and Horie and Nipponbashi in Osaka. These areas succeed in differentiating themselves from other areas by providing products and services that reflect a unique sense of values and preferences of facility owners and customers. The uniqueness of these commercial areas is the result of a complementary relation and synergistic effect between the given facilities and surrounding facilities. In this way, the accumulated condition of the facilities in a city center are not uniform but follow mutual interactions between facilities based on the kinds of facilities surrounding each facility.

Given the above, in this paper, we focus on the relationship between an individual facility and surrounding facilities. We assume that latent attributes that can clarify the mechanism of facility accumulation exist. We also assume that these latent attributes generate co-occurrence information between the given facility and surrounding facilities. As a result, it is possible to express the tendency of the kind of facility attributes that are easily accumulated.

1.3 Objective

In this paper, we attempt to empirically clarify the latent attributes that can explain the mechanism of facility accumulation based on facility co-occurrence information in a city center. We express facility accumulation as the facility co-occurrence network that consists of nodes representing facilities and links representing co-occurrence information between such facilities; we solve the inverse problem by estimating latent attributes of facilities that generate a facility co-occurrence network. This approach is workable by applying a framework based on the stochastic block model proposed by (Nowicki and Snijder, 2001) to the facility co-occurrence network generated only by location information of facilities. In this paper, we estimate latent attributes of facilities that generate facility accumulation around Namba station and empirically clarify the quantitative and qualitative properties of the mechanism of facility accumulation as a case study in Osaka's city center near Namba station.

1.4 Contribution

The academic contribution of this paper is the development of an empirical method for analyzing the mechanism of facility accumulation based on co-occurrence information between facilities. This approach enables us to classify latent attributes that generate facility accumulation into several types. The discovery of a new facility classification axis enables us to grasp quantitative properties of facility accumulation, i.e., (1) properties of latent attributes, (2) relationships between attributes, and (3) relationships between facilities and these latent attributes.

One of the social contributions of our paper is the location planning of facilities based on the mechanism of facility accumulation. A facility owner can select products based on latent attributes of surrounding facilities and determine an optimum location. Further, the government can introduce facilities and policies that strengthen or change latent attributes of existing facilities based on the relationships between latent attributes and properties of the latent attributes.

2. PREVIOUS STUDIES AND THE POSITION OF THIS PAPER

2.1 Previous studies related to facility location and facility accumulation

In this section, we present previous studies related to facility accumulation in a city. As an example of a study related to regional science, (Jones and Simmons, 1992) clarified that where a facility is located depends on the distance from a nodal point; further, this tendency is different according to different business types. As an example of a study related to sociology, (Matsuzawa, 1992) clarified that the downtown area of Tokyo consists of three layers surrounding the station. These studies help to clarify the tendency of each business type location depending on the accessibility a nodal point has; however, they classify a facility by a business type and do not consider the mechanism of facility accumulation focused on each facility.

As an example of a study related to the accumulation of specific business types, (Yamamura and Goto, 2013) clarified that there is a strong tendency of accumulation of the knowledge industry as compared to that of the general service industry; further, aspects of urbanity, such as food and a nightlife, greatly affects the accumulation of the knowledge industry. (Ito and Arita, 2014) clarified that apparel retail stores in Harajuku accumulated in different areas for each target age group and that the participation of real estate companies and government greatly affected the accumulation of these entities. These studies focus on the accumulation of a specific industry and therefore do not consider the diversity given a city center has.

2.2 Previous studies related to functional region

In contrast to the previous section, studies that clarify practical regional divisions have been performed around specific geographies, i.e., apart from a general regional division such as an administrative division and a specific industry. This regional division is called a functional region and serves as a special region that functions integrally and in a mutually complementary manner through interactions between various social activities, such as traffic and economic activity. Identifying functional regions and totaling statistics for each are helpful for better grasping the exact activity of people in those regions.

(Goddard, 1970) quantitatively evaluated the relationship between activity patterns of taxis and a selection of London’s city center. As a result, using taxi trajectories, this study found five districts with defined functions, including for example, a business district. (Ratti, Sobolevsky, et al., 2010) estimated that the boundary between two districts reflected the intercommunication of people; to study this, they used the communication history of telephone calls and confirmed that these boundaries corresponded to boundaries between administrative districts. These studies were performed within the science of information field, a result of the increased and ubiquitous use of information technology.

Numerous active studies use facility information of location-based social networking services (SNSs) ((Lawlor, Coffey, et al., 2012), (Noulas, Scellato, et al., 2011)), taxi trajectories ((Yuan, Zheng, et al., 2012), (Yuan, Zheng, et al., 2015)), image data containing location and text information ((Kling and Pozdnoukhov, 2012), (Lee, Wakamiya, et al., 2013)), and so on. These studies collectively suggest that practical travel behavior and economic activity characterize districts rather than specific industries and administratively defined districts.

2.3 The position of this paper

Studies related to functional regions often target wide regional divisions represented by commutable areas and the corresponding economic sphere according to the optical resolution of the available data. Therefore, it is difficult to grasp the difference between districts in a city center. In this paper, we consider the possibility of analyzing the macroscopic urban structure and microscopic facility attribute based on facility accumulation, considering that travel behavior and economic activity is represented as facility accumulation in a city center just as the notion of functional region is. Thus, in this paper, we do not empirically classify a facility by a business type and estimate latent attributes of a facility, clarifying the mechanism of facility accumulation based on the co-occurrence relation between facilities related to these latent attributes.

3. PROBLEM DEFINITION AND HYPOTHESIS

3.1 Spatial conditions of analysis subjects

Analysis subjects in this paper are defined as the facility and facility accumulation in a city center. In this paper, we express each facility in the target area as i and a set of facilities as N. Further, we express the type of business of facility i as x_i. Some facilities $i; j$ can be classified by whether both facilities are located within a fixed distance. In this paper, there is a co-occurrence relation between facility i and j if the linear distance between facilities $i; j$ is less than 50 m. We express a set of existence of co-occurrence relation a as $\{0,1\}$. If there is a co-occurrence relation between facilities i and j, we express it as $y_{ij} = 1$; if there is not, we express it as $y_{ij} = 0$. Further, we define set E_i of facility i that satisfies $y_{ij} = 1$, $\forall j \in N \backslash \{i\}$ as surrounding facilities of facility i. Here, $N \backslash \{i\}$ is a set that eliminates facility i from the set of facilities N, i.e. we use "\" to eliminate a factor from a set. We next define facility accumulation $\boldsymbol{L}$ of the target city center as a network that consists of nodes in which facility $i \in N$ is in the city center and links that represent co-occurrence relation $yij = 1$, $\forall i, j \in N, i < j, i \neq j$.

3.2 Problem definition and hypothesis

A key problem defined in our paper is identifying factors that generate facility accumulation $\boldsymbol{L}$ in a target city center. From the above spatial conditions, we propose below our hypothesis for analyzing and grasping the factors that quantitatively generate facility accumulation $\boldsymbol{L}$.

· **Presupposition**： Facility accumulation $\boldsymbol{L}$ in a city center is affected by business type x_i of each facility.

· **Hypothesis**： Facility accumulation $\boldsymbol{L}$ is generated by the surrounding facilities attributes.

Co-occurrence relation $y_{ij} \in \boldsymbol{L}$, which is a component of facility accumulation $\boldsymbol{L}$, can be explained using latent attributes z_i and z_j, which are defined by the relation between surrounding facilities E_i and E_j of facilities i and j, rather than using business types x_i and x_j of facilities i and j. We call this latent attribute the "surrounding facilities attribute (SFA)"; if our hypothesis is verified, we have discovered a new classification axis of facilities.

3.3 Verification policy of the hypothesis

In this section, we consider the generative probability of facility accumulation $\boldsymbol{L}$ in a city center based on business type. We express a set of business types as M, with each business type identified as $m, l \in M$. If the business type of facility i is m, we express this as $x_i = m$. Further, we define the co-occurrence probability between a facility with business type m and a facility with business type l as $\eta(m,l)$. The generative probability (i.e., likelihood) of facility accumulation $\boldsymbol{L}$ is then defined as shown below.

$$P(\boldsymbol{L}) = \prod_{m,l \in M} \eta(m,l)^{n^1_{m,l}} \cdot (1 - \eta(m,l))^{n^0_{m,l}}$$

Here, $n^1_{m,l}$ is the number of co-occurrence relations $y_{ij} = 1$ between a facility with business type m and a facility with business type l; further, $n^0_{m,l}$ is the number of co-occurrence relations $y_{ij} = 0$ between a facility with business type m and a facility with business type l. These are both expressed as shown below.

$$n^1_{m,l} = \sum_{i \in N} \sum_{j \in N\{i\}} \delta(x_i = m) \cdot \delta(x_j = l) \cdot \delta(y_{ij} = 1)$$
$$n^0_{m,l} = \sum_{i \in N} \sum_{j \in N\{i\}} \delta(x_i = m) \cdot \delta(x_j = l) \cdot \delta(y_{ij} = 0)$$

Here, $\delta(\cdot)$ is the Kronecker delta. We can verify that the factor that generates facility accumulation $\boldsymbol{L}$ in a city center is not based on business type, but rather on the SFA if the likelihood of facility accumulation $\boldsymbol{L}$ expressed by the SFA is larger than the business type of the facility.

4. EXTENDED STOCHASTIC BLOCK MODEL

4.1 Assumption of the generative model of the facility accumulation

In this paper, we express the generative process of facility accumulation as the generative model based on the assumption indicated at 3. The generative model proposed in our paper is an extended stochastic block model originally proposed by (Nowicki and Snijders, 2001). This model assumes that the attribute of surrounding facilities, which is the latent class for each facility, generates business type of facility x_i and co-occurrence information between facilities y_{ij}, respectively. As a result, the facility accumulation $\boldsymbol{L}$ is generated. The left side of Figure 1 represents the generative process of facility accumulation. First, an attribute of surrounding facilities is generated for each facility. Second, the business type of a facility is generated based on attributes of surrounding facilities. Third, co-occurrence information between facilities is generated based on attributes of surrounding facilities. In this paper, we assume that the present facility accumulation $\boldsymbol{L}$ is generated through multiple iterations of this process.

In this paper, we assume facility i has one attribute of the surrounding facilities; this attribute is expressed as z_i. The set of SFAs is expressed as K, with attributes identified as k, $h \in K$; further, the latent class of facility i with attribute k is expressed as $z_i = k$.

The generative process of facility accumulation $\boldsymbol{L}$ is described as follows. First, for each facility i, SFA $z_i \in K$ is generated from the multinomial distribution with parameter $\boldsymbol{\theta}$. The probability that facility i has a SFA k is expressed as θ_k and the number of facilities that have a SFA k is expressed as n_k. Next, for each facility i, business type $x_i \in M$ is generated from the multinomial distribution with parameter π_{zi} depending on SFA z_i. The probability that facility i has business type m is expressed as π_{m,z_i} and the number of business types m that have SFA k is expressed as $n_{m,k}$. Finally, co-occurrence information (i.e. link) y_{ij} is generated from the binomial distribution with parameter $\eta(z_i, z_j)$ for each combination of facilities $ij \in \boldsymbol{C}$ based on the SFA z_i, z_j. Here, a combination set of all facilities in a city center is expressed as $\boldsymbol{C}$. The probability that facilities i and j have co-occurrence information is expressed as $\eta_1(z_i, z_j)$ and the number of links that co-occurrence information between facilities have SFAs k, h is a is expressed as $e_a(k, h)$. This is the generative process of facility accumulation $\boldsymbol{L}$. Note that each parameter of the multinomial distribution $\boldsymbol{\theta}, \boldsymbol{\pi}$ is generated from the Dirichlet distribution with hyper parameter α, γ. The parameter of the binomial parameter, i.e., $\boldsymbol{\eta}$, is generated from Beta distribution with hyper parameter β.

Assuming that the co-occurrence information $\boldsymbol{y}$, business type $\boldsymbol{x}$, and SFA $\boldsymbol{z}$ do not depend on one another, the joint distribution of $\boldsymbol{y}$, $\boldsymbol{x}$, and $\boldsymbol{z}$ on this generative model, i.e. the generative probability of facility accumulation considering the business type of the facility, is expressed as shown below.

$$P(z, y, x|\theta, \eta, \pi) = P(y|z, \theta, \eta) \cdot P(x|z, \theta, \pi) \cdot P(z|\theta)$$
$$= \prod_{a \in \{0,1\}} \prod_{k,h \in K} (\eta_a(k, h))^{e_a(k,h)} \cdot \prod_{m \in M} \prod_{k \in K} \pi_{m,k}^{n_{m,k}} \cdot \prod_{k \in K} \theta_k^{n_k}$$

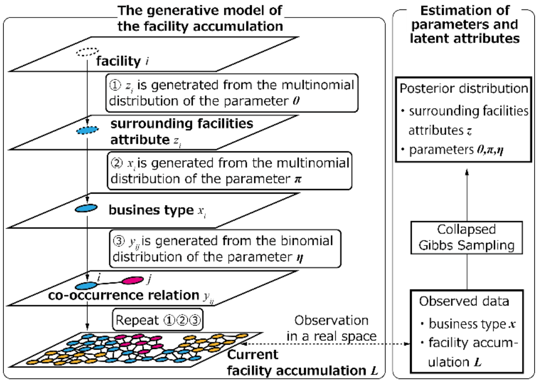

Figure 1. Illustrating the generative process of facility accumulation based on the assumptions of this paper

4.2 Derivation of the posterior distribution of latent variables and parameters

Next, we derive the posterior distribution of SFA $\boldsymbol{z}$ and parameters $\boldsymbol{\theta}, \boldsymbol{\eta}$, and $\boldsymbol{\pi}$ based on observed facility accumulation $\boldsymbol{L}$ and business type x_i of each facility. The posterior distribution of each latent variable is obtained by marginalizing other latent variables. This method is called Collapsed Gibbs Sampling. The right-hand side of Figure 1 illustrates this process. In this paper, we derived the posterior distribution of SFA $\boldsymbol{z}$ as follows, using Collapsed Gibbs Sampling.

$$P(z_i = k|\boldsymbol{y}, \boldsymbol{z}\backslash\{i\}, \boldsymbol{x}, \boldsymbol{C}, \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{\gamma}) \propto \prod_{a\in A}\prod_{h\in K}\frac{e_a(k,h) + \beta_{(k,h)}}{\sum_{k,h'\in \boldsymbol{C}}\left(e_a(k,h') + \beta_{(k,h')}\right)} \cdot \frac{m_k + \alpha_k}{\sum_{k'=1}^{K}(m_{k'} + \alpha_{k'})} \cdot \frac{n_{f,k} + \gamma_k}{\sum_{k'=1}^{K}(n_{f,k'} + \gamma_{k'})}$$

The posterior distribution of SFA $\boldsymbol{z}$ can be derived based on observed facility accumulation $\boldsymbol{L}$ and business type x_i of each facility. Further, the posterior distribution of parameters $\boldsymbol{\eta}, \boldsymbol{\theta}, \boldsymbol{\pi}$ can be similarly derived.

5. ANALYSIS OF FACILITY ACCUMULATION USING ACTUAL DATA

5.1 Analysis area

Shown in Figure 2, the analysis area covered in this paper is a 2.5 km square district around Namba station in Osaka. Midosuji Street crosses in a north-south direction, while Nagahori Street crosses in an east-west direction. The Shinsaibashi area spreads on the east side of Midosuji Street, while the America-mura and Horie areas are spread out on the west side of Midosuji Street. The Shinsaibashi area is a downtown area primarily consisting of shopping venues. The America-mura area is packed with small-scale retail shops focused on young shoppers. The Horie area is filled with small-scale retail shops supported by older generations rather than the youth. Namba station is located at the starting point of Midosuji Street. The station’s front area spreads around Namba station and primarily consists of large-scale compound commercial buildings and shopping malls. Finally, the Nipponbashi area spreads from the station’s front area toward the southeast and primarily consists of electronics stores.

5.2 Overview of the data

The data used in this paper was obtained from positional information of Foursquare within the target area surrounding Namba station. Each data point is comprised of a facility name, a business type, latitude, and longitude. There are 9032 data points and 276 business types. The business type is specified in as much detail as possible by the Foursquare user. For example, a restaurant is classified in more detail as an Italian restaurant, Chinese restaurant, and so on. Figure 3 shows the facility accumulation of target area ***L*** based on these facility data.

Figure 2. Areas surrounding Namba station in Osaka

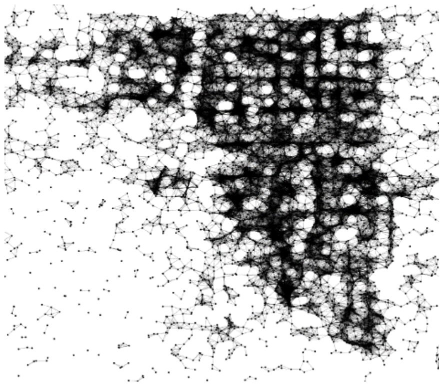

Figure 3. The network of 9032 facilities around Namba station

5.3 Analysis

5.3.1 Co-occurrence information between business types in facility accumulation *L*

In this section, we first analyze the business type accumulation that acts as the premise of the hypothesis introduced in Section 2.2 above. In this paper, we used nine categories created by Foursquare as a large-scale classification of business types; these nine categories are: (A) food, (B) shops and services, (C) nightlife spots, (D) arts and entertainment, (E) travel and transport, (F) outdoor and recreation, (G) professional and other places, (H) colleges and universities, and (I) residences.

Figure 4 shows co-occurrence information between business types as blocks in which gray cells indicate that there is co-occurrence information between business types. These blocks clarify the following: (1) it is easy for the same business type to co-occur, and (2) there are combinations of business types that often co-occur, such as shops and services (B) and arts and entertainment (D), food (A), and nightlife spots (C), as well as other such pairings. From the above, our analysis reveals that facility accumulation ***L*** is affected by co-occurrence information between business types, thus the premise of our hypothesis is confirmed.

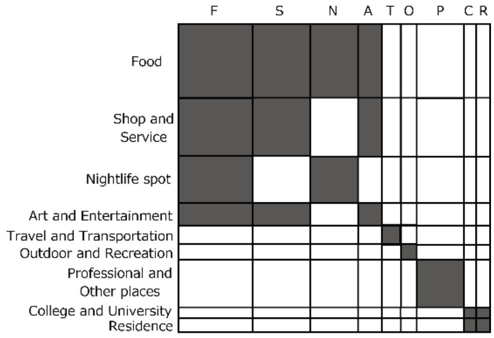

Figure 4. Blocks representing co-occurrence information between business types

5.3.2 Co-occurrence information between business types for each area

In the previous section, we confirmed that facility accumulation ***L*** is affected by co-occurrence information between specific business types. In this section, we focus on whether this tendency generally applies to all studied areas, i.e. we clarify the above by analyzing the tendency of the co-occurrence information between cafés in the entire target area, the Horie area, and the Nipponbashi area as a case study.

Figure 5 shows the tendency of co-occurrence information between cafés in the entire target, Horie, and Nipponbashi areas. The horizontal axis shows all business types and large classifications, while the longitudinal axis shows the percentage of business types that co-occur with café. The figure indicates that cafés in the entire target area tend to co-occur with various business types, specifically with department stores and cinema complexes. Next, the figure indicates that cafés in the Horie area tend to co-occur with specific business types, specifically with thrift and vintage stores. Finally, the figure indicates that cafés in the Nipponbashi area tend to co-occur with specific business types, specifically with other nightlife and gaming cafés. From the above analysis, we conclude that the tendency of co-occurrence information of cafés is different between the entire target area and the Horie and Nipponbashi areas. Note that other business types exhibit similar tendencies.

From the above, the business type can explain the global mechanism of facility accumulation, but it cannot explain the partial mechanism of facility accumulation in each area. In this paper, we analyzed the latent structure of facility accumulation in the target area by using the extended stochastic block model to verify our hypothesis that the SFA can explain the mechanism of facility accumulation focused on individual facilities in comparison to business type.

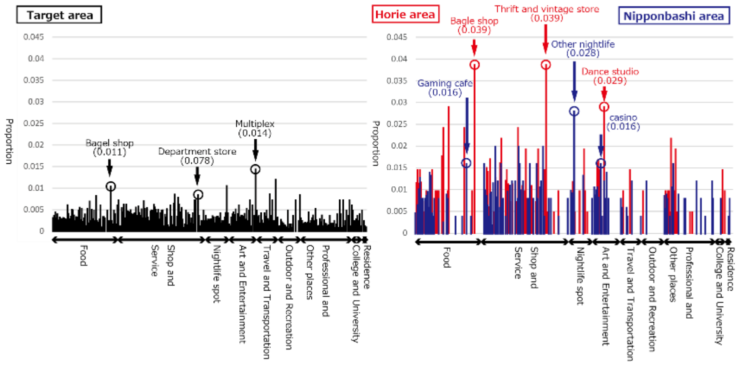

Figure 5. The tendency of co-occurrence of cafés in the target area

6. RESULTS OF ANALYSIS AND CONSIDERATIONS

6.1 Verification of our hypothesis

In this paper, we set the number of SFAs to |K|=10. This setting was determined based on the ease of interpreting and analyzing each SFA. For our analysis, as described above, we assign 9032 facilities the SFA.

In this section, we compare the generative probability (i.e. likelihood) of facility accumulation ***L*** using the business type as facility classification and using the SFA as the verification the hypothesis of this paper. The log likelihood using the business type is -396,902, while the log likelihood using the SFA is -290,761. These results show that the SFA improves the log likelihood more than the business type.

Further, the number of parameters explaining facility accumulation ***L*** using the business type is $|M|\times|M| = 76{,}176$. Conversely, the number of parameters using the SFA is $|K|\times|K| + |K| + |K|\times|M| = 2780$. Thus, there are big differences between these approaches, showing that the methods proposed in this paper do not improve the interpretability of facility accumulation when the number of parameters is increased. The SFA explains the mechanism of facility accumulation more compactly than the business type. From the above, the validity of our hypothesis is thereby verified.

6.2 Estimated results of $\boldsymbol{\pi}$

In this section, we clarify the characteristic business type of facilities that we assign to each SFA have using the estimated result of $\boldsymbol{\pi}$. Table 1 shows the estimated result of $\boldsymbol{\pi}$ and the interpretation. For example, toy and game stores, hobby shops, electronics stores, and hardware stores are characteristic business types of SFA 3. These stores are visited by customers with specific purposes based on their hobby, so the SFA 3 is interpreted as this type of hobby. Using this approach, each SFA can be interpreted; Table 1 shows the results.

6.3 Estimated results of $\boldsymbol{\theta}$

Table 1 shows the number of facilities assigned to each SFA based on the estimated result of parameter $\boldsymbol{\theta}$. The table shows that the given type "Daily life" has the largest number of facilities (2195) and the type "Average" has the least number of facilities (505). These types can be interpreted as the macroscopic attributes of facilities that constitute the district around Namba station.

Table 1. characteristic business type of each SFA and the interpretation

SFA	interpretation	characteristic business type	The number of facilities	percentage
1	Average	Itarian restaurant, restaurant	505	0.056
2	Traffic Node	optical shop, bakery, bank	1488	0.165
3	Hobby	toy and game store, hobby	1179	0.131
4	Hobby buffer zone	furniture and home store, electrics store	621	0.069
5	Fashionable life	boutique, clothing store	651	0.072
6	Japanese style bar	Karaoke bar, bar	586	0.065
7	Restaurant	restaurant(Japanese,Chinese)	698	0.077
8	Restaurant buffer zone	restaurant, bar	590	0.065
9	Nightlife	lounge, nightclub	519	0.057
10	Dairy life	gas station, park	2195	0.243

6.4 Estimated results of $\boldsymbol{\eta}$

In this section, we show the existence of co-occurrence information between surroundings facilities attributes based on estimated results of parameter $\boldsymbol{\eta}$. Figure 6 shows the matrix representation of co-occurrence information between SFAs; in the figure, blocks identify each SFA, and each cell represents co-occurrence information between facilities. In this paper, the block that represents co-occurrence information between facilities is shown in gray, and there is a co-occurrence relation between SFAs if an occurrence probability between SFAs is larger than 0.02.

Figure 7 illustrates the abovementioned block as a network to grasp the macroscopic structure of the facility accumulation in the target area based on the SFA. The figure helps to clarify the latent structure with position information eliminated from co-occurrence information as follows: (1) the type of traffic node, hobby buffer zone, fashionable life, and Japanese style bar, (2) the type of average, restaurant, restaurant buffer zone, and nightlife, and (3) the type of hobby and daily life that are in the periphery.

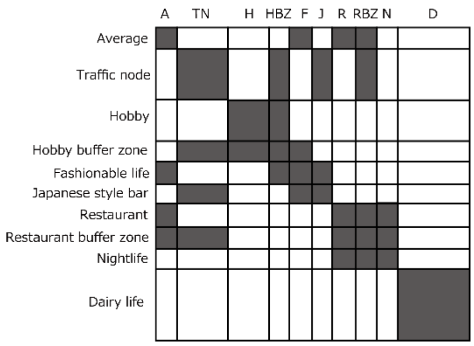

Figure 6. Blocks represent co-occurrence relations between surrounding facilities attributes

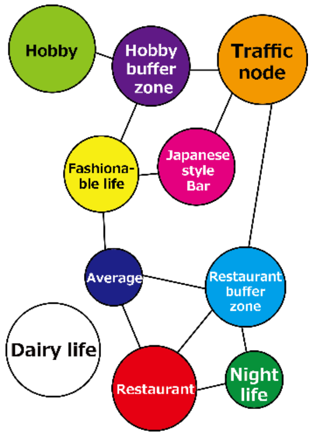

Figure 7. Co-occurrence relations between surrounding facilities attributes

6.5 Estimation results of *z* and the geographic distribution

Finally, in this section, we indicate the estimated result of SFAs ***z*** of each facility. Figure 8 shows a map in which all facilities are colored based on every surrounding facilities attributes. The figure shows that co-occurrence relations clarified in Figure 7 are spatially related.

We also focus on cafés in this section, as we did in Section 6.4 above, to confirm what SFAs of each facility are estimated to be. The estimation result of ***z*** shows that a chain of cafés in the station's front area is classified as the type of traffic node (i.e. SFA 2), a café that is added to a clothing store in the Horie area is classified as the type fashionable life (i.e. SFA 5), and a maid café in the Nipponbashi area is classified as a type of hobby. From the above, we confirm that facilities can be classified considering not the business type, but rather the existence of surrounding facilities using the methods presented in this paper.

7. CONCLUSION

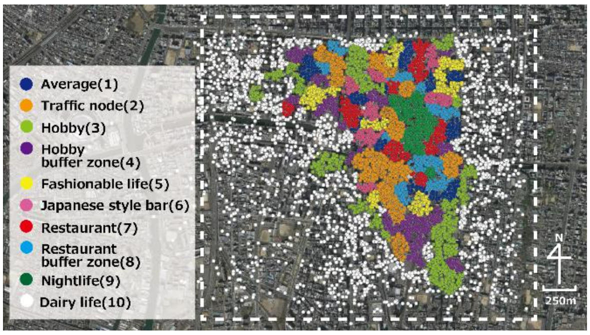

Figure 8. Geographical distribution of surrounding facilities attributes

In this paper, we attempted to clarify latent attributes that can empirically explain the mechanism of facility accumulation based on co-occurrence relations between facilities.

First, we defined the facility accumulation as the co-occurrence network consisting of nodes for facilities and links for co-occurrence relations between facilities. Next, we constructed a generative model of facility accumulation based on the assumption that facility accumulation is generated by a latent attribute of each facility (i.e. the SFA) and proposed the extended stochastic block model for estimating the posterior distribution of SFAs using observed business types of facilities and co-occurrence relations between facilities. Finally, we estimated SFAs that generated facility accumulation around Namba station and empirically clarified both quantitative and qualitative properties of the mechanism of facility accumulation through a case study in Osaka's city center near to Namba station.

We summarize our conclusions below. (1) Regarding the SFA, each such attribute quantitatively has properties in terms of characteristic business types. Further, each surrounding facility's attribute can be interpreted by these quantitative properties. (2) Regarding the relation between surrounding facilities' attributes, facility accumulation can be expressed by the co-occurrence relation between surrounding facilities' attributes, enabling us to grasp a latent structure of facility accumulation that eliminates positional information from co-occurrence information between facilities. (3) Regarding the relation between facilities and their surrounding facilities' attributes, facilities can be classified based on surrounding facilities' attributes independent of their respective business types.

For our future work, we have identified two key avenues of further research. First, we aim to discover and identify the universality of the mechanism of facility accumulation. It is not known whether the obtained knowledge from this paper can be applied to other city centers, because this paper analyzed only one case, i.e. in Osaka's city center near to Namba station. We plan to identify and model a universal surrounding facilities' attribute and co-occurrence relation between them by analyzing other city centers in the future. Second, we plan to investigate facility accumulation by considering time variations of such accumulation. In this paper, we were able to explain the current facility accumulation of a target area, but we did not consider time variations of such accumulation. In the future, we must clarify the process and the factors of facility accumulation considering time variations of each facility.

ACKNOWLEDGMENT

Part of this paper was supported by JST Presto, which we gratefully appreciate.

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Bias and Sources of Error in Discrete Choice Models:

A Critical Reflection

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Key words: Sources of Error, Random Utility Maximization, Random Regret Minimization

Abstract: Discrete choice models have attracted a lot of attention since decades as an alternative to traditional aggregate transport demand models. Since discrete choice models assume that the total utility of an alternative is not exactly known to analysists, researchers have commonly assumed that the utility consists of two components: deterministic utility and error term. The error term is assumed to be composed of different sources. This paper reviews studies on the effect of the different sources of uncertainty (Manski, 1973) such as measurement error, omitted relevant variables, and taste variation in discrete choice models. All this research is based on different assumptions about the source of uncertainty. In this study, we will compare the assumptions and discuss future research directions. In addition, we will discuss the possible effects of the different sources of uncertainty in a new type of discrete choice model: the random regret model.

1. INTRODUCTION

Discrete choice models, which have the principle of utility maximization (RUM) as their most commonly used theoretical foundation, have found many applications in travel demand forecasting, replacing traditional aggregate transport demand models. Random utility theory (Luce, 1959; Domencich and McFadden, 1975; Williams, 1977) postulates that individuals derive a utility from their choice of an alternative, and choose the alternative that maximizes their utility. It reflects the notion of rational behaviour. However, in reality, individuals do not necessarily possess complete information about all components of utility. Therefore, researchers have commonly assumed that the utility consists of two components (Ortuzar and Willumsen, 2011):

- an observable, measureable, certain, or systematic part, called deterministic utility
- an unobservable, uncertain, or random part, called error term

Consequently, the total utility of alternative *i* of individual *n* can be formulated as:

$$U_{in} = \mu_{in} V_{in} + \varepsilon_{in} \tag{1}$$

where V_{in} is the observable part (deterministic utility) and ε_{in} is the random part (error term). μ_{in} is called the scale factor, which is inversely proportional to the variance of ε_{in}.

The deterministic utility V_{in} is generally expressed as a linear-additive function of observed attributes.

$$V_{in} = \sum_{k=1}^{K} \beta_k x_{ink} \tag{2}$$

where x_{ink} is the measured value of attribute *k* for alternative *i* of individual *n*, b_k is the taste weight for attribute *k* assumed to be homogeneous across alternatives and individuals. This assumption implies that utility is derived by independently and separately processing the attributes of each choice alternative.

The error term ε_{in} allows the model to represent irrational behaviours, for example, some individuals may choose not choose the alternative with the maximum utility due to the lack of information. It is assumed to follow a certain distribution. There is no generally accepted theory to normatively decide on the type of distribution. Therefore, researchers subjectively formulate, implicitly or explicitly, assumptions about the error terms. These assumptions about the distribution of the error terms dictate which choice model will be derived:

- If the random part follows a uniform distribution, the model is called the linear probability model. This model is computationally convenient. However, the uniform distribution derives a zero probability when the difference in error terms is large and negative, and hence is limited in expressing randomness.

- If the random part follows a normal distribution, the multinomial probit model can be derived. The normal distribution may represent the most persuasive shape of error terms considering the central limit theorem. However, it has the disadvantage that the integral of the multivariate normal density function is cumbersome to compute. Therefore, in the early years with limited computing power, researchers avoided this specification and the underlying assumption of normally distributed error terms.

- If the error terms follow a Gumbel (Weibull or type-1-extreme-value) distribution, and are identically and independently distributed across alternatives and individuals, the multinomial logit model is obtained. It has become the most generally used specification in discrete choice modelling. The identically and independently Gumbel distributed error terms have a similar shape to the normal distribution, but the result of this assumption is a closed form expression for the choice probabilities.

Since RUM assume that individuals choose the alternative in their choice sets such as to maximize their utility, the probability of choosing alternative *i* equals

$$
\begin{aligned}
P_{in} &= \text{Prob}(U_{in} > U_{jn}) \\
&= \text{Prob}(\mu_{in} V_{in} + \varepsilon_{in} > \mu_{jn} V_{jn} + \varepsilon_{jn})
\end{aligned}
$$

$$
\begin{aligned}
&= \text{Prob}(\varepsilon_{in} - \varepsilon_{jn} > \mu_{jn} V_{jn} - \mu_{in} V_{in}) \\
&= \text{Prob}(\varepsilon_{in} - \varepsilon_{jn} > \mu_{jn} \sum_{k=1}^{K} \beta_k x_{jnk} - \mu_{in} \sum_{k=1}^{K} \beta_k x_{ink}) \quad \forall j \in C_n
\end{aligned} \tag{3}
$$

The taste weights b_k are obtained using log likelihood function.

$$
L^*(\beta_1, \beta_2, \cdots, \beta_K) = \prod_{n=1}^{N} P_{in}^{y_{in}} \cdots P_{jn}^{y_{jn}} \tag{4}
$$

$$
y_{in} = \begin{Bmatrix} 1: if \;\; individuals \; n \; choose \; alternative \; i \\ 0: if \;\; individual \; n \; choose \; other \; alternative \end{Bmatrix} \tag{5}
$$

$$
\log L^*(\beta_1, \beta_2, \cdots, \beta_K) = \sum_{n=1}^{N} [y_{in} \log P_{in} + \cdots + y_{jn} \log P_{jn}] \tag{6}
$$

where L^* in equation 5 is the likelihood function and $\log L^*$ in equation 6 is log likelihood function.

The combination of b_k that maximizes the log likelihood value in equation 6 is considered to identify taste. If we assume the error terms are identically and independently Gumbel distributed, equation 3 can be easily transformed using the exponential function (Thiel, 1969).

$$
P_{in} = \frac{\exp(\mu_{in} V_{in})}{\sum_{j} \exp(\mu_{jn} V_{jn})} \tag{7}
$$

Since the parameters of the deterministic utility function in the multinomial logit model cannot be separately estimated from the scale factor, Ben-Akiva and Lerman (1985) normalized the scale factor as μ_{in} indicating an identical scale across alternatives and individuals. In this case, the variance of the error terms is $\pi^2/6$.

Since the assumption of identically and independently distributed error terms is too extreme to explain choice behaviour in many settings, several alternatives to the multinomial logit model, allowing more flexible error terms, have been proposed. Examples include the general extreme value (GEV) model (McFadden, 1978) allowing positive correlations among error terms and the conditional probit model (Hausman and Wise, 1978) allowing correlation among error terms and differences in variance (see e.g. Timmermans and Golledge, 1990 for more detail). These developments extended to the recent development of the mixed multinomial logit (McFadden and Train, 2000).

As discussed, the error terms reflect the effect of all unobservable, uncertain or random components. Manski (1973) identified different *sources of uncertainty*: 1) measurement error 2) omitted relevant variables 3) taste variation, and 4) instrumental or proxy variables.

Because of the sources of uncertainty, we can only obtain estimated parameter values, not the true values. If we are able to formulate the size of the effect of the various sources of uncertainty, we may obtain the true parameters to explain choice behaviour, at least approximate the true values. However, the sources of uncertainty are unobservable, uncertain, or random, and therefore it is very difficult to estimate the size of the effect, while the mixture of the effects of the various sources of uncertainty is even more difficult to figure out. Therefore, prior studies have focused on how to overcome the bias from a single source separately. However, the proposed methods are based on assumptions, implying that the effect of the specific source of uncertainty can be only formulated when the assumptions are valid.

This paper reviews these studies on the effect of the different sources of uncertainty in discrete choice models. In this study, we will compare the approaches and discuss future research directions. This paper is organized as follows. We review the literature, classified according to the different sources of uncertainty: measurement error, omitted relevant variables, and taste variation. Since the effect of instrumental or proxy variables is closely related to the other components, we will not discuss it in a separate section. Next, we introduce a new type of discrete choice model, the random regret model, and discuss the effects of the error components for this type of model. The final section discusses potential directions of future research on the effects of error in discrete choice models.

2. MEASUREMENT ERROR

Measurement error, also called errors in variables, is one of the main sources of uncertainty. It generally occurs when network models are used to measure level of service variables, such as travel time and costs, at the individual level. Since the level-of-service variables in network models are obtained from the centroids of two different zones, this measurement process leads to incorrect results in representing individual behavior as it introduces measurement error. These zone-based values from network models may cause severe systematic bias in disaggregate choice models (McFadden, 2000).

Assume measurement error occurred in the *k*th variable, and is fixed across alternatives.

$$x_{ink} = x_{ink}^{true} + v_{ink} \tag{8}$$

where x_{ink}^{true} is the true value of the *k*th variable, x_{ink} is the measured value of the *k*th variable, and v_{ink} is the discrepancy between the true and the measured value. It follows a certain distribution.

If the random utility model is specified as shown in equation 2,

$$U_{in} = \sum_{k=1}^{K} \beta_k^{true} x_{ink}^{true} + \varepsilon_{in}^{true} \tag{9}$$

introducing measurement error results in

$$U_{in} = \sum_{k=1}^{K} \beta_k^{true} (x_{ink} - v_{ink}) + \varepsilon_{in}^{true} = \sum_{k=1}^{K} \beta_k^{true} x_{ink} + (\varepsilon_{in}^{true} + \sum_{k=1}^{K} \beta_k^{true} v_{ink})$$

$$= \sum_{k=1}^{K} \beta_k^{true} x_{ink} + \varepsilon_{in} \tag{10}$$

If the measurement error is correlated to the explanatory variables $Cov(x_{ink}, v_{ink}) \neq 0$, this causes endogeneity.

Now, the variance of error term is changed by measurement error in equation 10 $(\varepsilon_{in}^{true} \neq \varepsilon_{in})$, implying a change of the value of the scale factor. However, we generally ignore the effect of measurement error, and use the normalized scale factor, causing bias in the parameters of equation 11.

$$U_{in} = \sum_{k=1}^{K} \beta_k x_{ink} + \varepsilon_{in}^{true} \tag{11}$$

Much of the effort to identify the effect of measurement error has focused on the random utility model. As we discussed, the measurement error is exogenous bias, caused by extracting attributes values from two centroids in transportation networks. Therefore, the extracted attributes value is an aggregated zone-based value, which is different from the disaggregated individual-specific attributes values. The early research about measurement error focused extracting more accurate attributes values. Train (1978) analyzed the effect considering time-dependent travel times and differences in proximity to bus routes. He found that the use of these disaggregate measures led to accurate prediction of real behavior. Ortuzar and Ivelic (1987) compared model fit and values of time when estimating mode choice models between standard network data and accurate data measured at the individual level. They showed that model estimation using individual level data generates more precise estimation results. Steinmetz and Brownstone (2005) represented measurement error for missing observations using Rubin's multiple imputation method to derive consistent estimates. They concluded that the multiple imputation method improves model prediction power and value of time savings, compared to the single imputation method. These additional considerations show better representation of behavior. However, it only overcame part of bias from measurement error, since we cannot fully approach individual-level attributes value from networks.

More recent approaches have focused on mathematical formulations to represent the effect of measurement error. Since the size of measurement error is uncertain, assumptions have been made about the distribution and its mean and variance, to represent the measurement error. Some researchers view the measurement error as a latent trait. Walker et al. (2010) used a hybrid choice model to correct the measurement error problem. They used a data set from developing countries, which is expected to include low quality data containing a high degree of measurement error. They considered the travel time attribute as a latent variable, and then estimated a hybrid choice model. Brey and Walker (2011) assumed self-reported travel time preference to be a latent variable. They used structural equations of the latent variable, which is expressed as a function of individual characteristics and assumed the errors in self-reported travel times are statistically significant, and affect the preferred travel time that influences itinerary choice. Yamamoto and Kornori (2010) used a latent class model. They found that the latent class model better represents mode choice behavior than the model based on TAZ data. However, as discussed, while measurement error represents exogenous bias, latent traits imply endogenous bias of individuals. Bhatta and Larsen (2011) investigated how measurement error affects the bias in parameters using synthetic data. They assumed the variance of measurement error corresponds to the variance of the measured variables. They explored three types of distributions: normal distribution, log-normal distribution, and triangular distribution. This approach is able to express diverse types of measurement error, but does not consider possible endogeneity. They concluded that measurement error leads to bias in parameters that may result in poor policy decisions.

Diaz et al. (2015) tried to express measurement error in variables using stochastic (random) variables. They formally showed that the multinomial logit model with stochastic variables, representing the measurement error, has the same structure as the error component mixed logit model (random coefficient model). Based on the assumption of normally or log-normally distributed measurement error, they concluded that incorporating stochastic variables may effectively deal with the measurement error problem. However, the effect of random coefficients may be derived from a mixture of stochastic variation in variables and taste variation of respondents.

To summarize this discussion, this literature review suggests that few studies have actually investigated the effect of the measurement error problem on parameter bias. Several solutions for this problem have been proposed. However, the proposed methods are difficult to generalize. The main reason may be the effect of measurement error varies by data collection method, number of respondents, and time of data collection. Therefore, it is advisable to apply more advanced econometric methods to account for possible measurement error in discrete choice models.

3. OMITTED RELEVANT VARIABLES

For a variety of reasons, the number of variables included in the deterministic part of the utility/regret function is limited. First, the principle of parsimony is still widely adopted in travel behavior research. A simple equation with few variables is still seen as the hallmark of academic research. Secondly, many models of travel demand are estimated from secondary data sets, which tend to contain general-purpose variables of limited scope and depth. Consequently, researchers have no choice but to accept the available data. Thirdly, even when researchers know a larger set of variables is potentially influential to the phenomenon under investigation, budget constraints and/or (un)justified concerns about survey length and complexity reduce the number and kind of explanatory variables. Therefore, omitted relevant variables are another important source of error/uncertainty in discrete choice models.

Assume the *K*th variable is omitted from a random utility model, as shown in equation 12. Then, the random utility model can be expressed as in equation 13.

$$U_{in} = \sum_{k=1}^{K} \beta_k^{true} x_{ink}^{true} + \varepsilon_{in}^{true} \tag{12}$$

$$U_{in} = \sum_{k=1}^{K-1} \beta_k^{true} x_{ink}^{true} + \varepsilon_{in}$$

$$\varepsilon_{in} = \varepsilon_{in}^{true} + \beta_K^{true} x_{inK}^{true} \tag{13}$$

If the omitted relevant variable(s) is not correlated with the explanatory variables $Cov(x_{ink}^{true}, x_{inK}^{true}) = 0$, the effect of omitted relevant variable(s) can be represented as a certain amount $\beta_K^{true} x_{inK}^{true}$. Therefore, Tardiff (1978) suggested using alternative specific constants (ASCs) to represent the *average effect* of the omitted variable(s). Note that since the ASCs are alternative-specific parameters to be estimated, and the effect of omitted relevant variable(s) is individual-specific, the ASCs represent the aggregated average of the effect of omitted relevant variable(s).

$$U_{in} = ASC_i + \sum_{k=1}^{K-1} \beta_k^{true} x_{ink}^{true} + \varepsilon_{in}^{true} \tag{14}$$

Otherwise, if the omitted relevant variable(s) and the explanatory variables are correlated $Cov(x_{ink}^{true}, x_{inK}^{true}) \neq 0$, the effect of omitted relevant variable(s) cannot be represented by a certain amount since the correlation causes additional errors. The correlation is called endogeneity (Train, 2009). Evidence of endogeneity is easily observed. For instance, when analysists estimate mode choice models, they usually omit variables about comfort. However, comfort may be correlated with travel time, which is typically included, causing endogeneity (or non-orthogonality). Some studies (Wardman and Whelan, 2011; Tirachini et al. 2013) suggested that endogeneity causes upward bias in the parameter for travel time, overestimating the value of time. Likewise, quality attributes such as space between seats and kindness of the cabin crew are often omitted when modelling airline choice. However, these attributes may be correlated with ticket's price. Mumbower et al. (2014) found that the endogeneity between quality attributes and ticket's price cause underestimation of the price coefficient. Therefore, the importance of the econometric issue of endogeneity has recently been recognized in discrete choice modeling. Guevara and Ben-Akiva (2006) argue that omitted relevant variable(s) mainly generate the endogeneity.

3.1 BLP method

One approach to correct for endogeneity in discrete choice models is the BLP method proposed by Berry et al. (1995, 2004). The term BLP is derived from the authors: Berry, Levinsohn, and Pakes. This method assumes that endogeneity is generated at the market-level.

Assume the *K*th variable is omitted and that it is correlated with the explanatory variables. In the BLP method, the error terms are decomposed into two parts: the error representing endogeneity caused by correlation between the omitted relevant variable(s) and the explanatory variables ε_{in}, and pure random error ε_{in}^{true}.

$$U_{in} = \sum_{k=1}^{K} \beta_k^{true} x_{ink}^{true} + \varepsilon_{in}^{true} \tag{15}$$

$$U_{in} = \sum_{k=1}^{K-1} \beta_k^{true} x_{ink}^{true} + \{(\beta_K^{true} x_{inK}^{true} + \varepsilon_{in}) + \varepsilon_{in}^{true}\} \tag{16}$$

The term $(\beta_K^{true} x_{inK}^{true} + \varepsilon_{in})$ represents the observable and unobservable components of the omitted relevant variable in the given market. ε_{in} is assumed to be correlated with x_{ink}^{true} and uncorrelated with ε_{in}^{true}.

Then, the endogeneity occurs at the market level.

$$U_{in} = \sum_{k=1}^{K-1} \beta_{k_m}^{true} x_{ink_m}^{true} + \{(\beta_K^{true} x_{inK_m}^{true} + \varepsilon_{in}) + \varepsilon_{in_m}^{true}\} \tag{17}$$

where *m* is a given market. Then, the term $(\beta_K^{true} x_{inK_m}^{true} + \varepsilon_{in})$ represents the average omitted utility in the given market. The effect of omitted variable $(\beta_K^{true} x_{inK_m}^{true} + \varepsilon_{in})$ can be represented as a market-specific constant α_{i_m} .

$$U_{in} = \alpha_{in_m} + \sum_{k=1}^{K-1} \beta_k^{true} x_{ink}^{true} + \varepsilon_{in}^{true}$$

$$\alpha_{i_m} = \beta_K^{true} x_{inK_m}^{true} + \varepsilon_{in} \tag{18}$$

The effect of omitted variable $x_{inK_m}^{true}$ can be regressed on the instrumental variable I_{in_m} .

$$x_{inK_m}^{true} = \theta_i + \theta_K I_{in_m} + \upsilon_{in_m} \tag{19}$$

where υ_{in_m} is a random error, assumed to be orthogonal with I_{in_m} and θ_i and θ_K is a parameter to be estimated. Then, the market-specific constants (α_{in_m}) are regressed on the fitted value $(\hat{x}_{inK_m}^{true} = \hat{\theta}_i + \hat{\theta} \theta_K I_{in_m})$:

$$\alpha_{i_m} = \gamma_i + \gamma_K \hat{I}_{in_m} + \varepsilon_{in} \tag{20}$$

Therefore, the random utility with omitted variable x_{inK}^{true} in equation 16 can be expressed with instrumental variable I_{in} :

$$U_{in} = (\gamma_i + \gamma_K \hat{I}_{in_m} + \varepsilon_{in}) + \sum_{k=1}^{K-1} \beta_k^{true} x_{ink}^{true} + \varepsilon_{in}^{true} \tag{21}$$

Berry et al. (1995, 2004) proposed the BLP method in discrete choice modelling. They assumed the unobservable features of products such as automobiles may be correlated with their price, since automobiles with higher unmeasured quality might sell at a higher price, and the correlation is generated by the automobile market. Walker et al. (2011) applied the BLP method in a study of social influence. They assumed that endogeneity by not considering social influence is generated at a peer group level. By applying the BLP method to represent the effect of social influence, the models are statistically different between including and excluding social influence.

As discussed, the BLP method assumes the endogeneity occurs at the market (or group) level. Therefore, this method is constrained in representing individual-level endogeneity. On the other hand, this method is very easy to apply, and requires only this simple assumption.

3.2 Control Function method

The second method to address endogeneity in discrete choice modelling is the control function method, originally proposed by Hausman (1978) for linear regression models. Heckman (1978) applied the control function method to nonlinear models. Rivers and Vuong (1988) extended this approach to the binary probit model in discrete choice modeling, while Petrin and Train (2003) proposed its use in mixed logit models. In this study, we introduce the control function method based on the multinomial logit structure.

Consider a choice set in which each of the choice alternatives *i* is characterized in terms of two variables - variables *a* and *b*. Then, the utility of alternative *i* can be described as

$$U_{in} = \beta_a^{true} x_{ina}^{true} + \beta_b^{true} x_{inb}^{true} + \varepsilon_{in}^{true} \tag{22}$$

Assume variable *b* is omitted and correlated with variable *a*. Then, the correlation causes additional error term ε_{in} representing endogeneity.

$$U_{in} = \beta_a^{true} x_{ina}^{true} + \{(\beta_b^{true} x_{inb}^{true} + \varepsilon_{in}) + \varepsilon_{in}^{true}\} \tag{23}$$

The important feature of the control function method is that it requires an auxiliary variable for omitted one. Assume *c* is an auxiliary (instrumental) variable for omitted variable *b*. Then, the omitted variable can be expressed as a function of variables *a* and *c*:

$$x_{inb}^{true} = \beta_c x_{inc}^{true} + \beta_{a'} x_{ina}^{true} + e_{in} \tag{24}$$

If we assume ε_{in} and e_{in} are jointly normal distributed, the conditional expectation of ε_{in}, given e_{in}, can be expressed, following Wooldridge (2002), as:

$$\varepsilon_{in} = E(\varepsilon_{in} \mid e_{in}) + \nu_{in} = \beta_e e_{in} + \nu_{in} \tag{25}$$

where ν_{in} is assumed to be normally distributed with zero mean, and is independent of e_{in}.

Then, the error term ν_{in} is independent of x_{ina}^{true} and x_{inb}^{true}. Therefore, if e_{in} can be measured, random utility with omitted variable x_{inb}^{true} in equation 23 can be solved with instrumental variable x_{inc}^{true} as shown in equation 26.

$$U_{in} = (\beta_a^{true} + \beta_{a'}^{true}) x_{ina}^{true} + \beta_c^{true} x_{inc}^{true} + \beta_e e_{in} + \nu_{in} + \varepsilon_{in}^{true} \tag{26}$$

Petrin and Train (2003) explored the effect of endogeneity in consumer choice. They assumed that omitted product attributes may cause correlation between price and the error terms in utility. That is, the market mechanism causes the price to be higher. The omitted attributes are observed by consumers but not measured by researchers. By using the control function method, they showed the estimated price response increases substantially. Guevara and Ben-Akiva (2006) applied the control function method to the endogeneity in residential location choice models. They assumed that dwelling unit's price is correlated with error terms. That is, the omitted variables are correlated with price. They use the control function method to test robustness to different error structures by using two Monte Carlo experiments, and showed that price endogeneity is significant in choice models of residential location. Guevara and Ben-Akiva (2012) pointed out that the parameters obtained from the control-function method are only valid up to a scale. They depicted the determinants of change of scale in the control-function method. They showed non-consideration of change of scale may lead to significant biases.

Like the BLP method, the control function method requires an instrumental variable to explain an endogenous relationship. However, if an omitted variable has many endogenous relationships with explanatory variables or many variables with endogeneity are omitted, it is sometimes difficult to obtain or define proper instrumental variables because these should be behaviorally related to the omitted variable. For example, it is very difficult to define and measure properly instrumental variables to represent endogeneity for mode comfort in transportation mode choice behavior.

3.3 Multiple Indicator Solution (MIS) approach

Very recently, Guevara and Polanco (2016) suggested a non-IV approach using the multiple indicator solution (MIS) method, proposed by Wooldridge (2010) for linear models. Instead of instrumental variables, this method only requires two indicators to explain any kind of endogeneity. They applied the MIS approach to an empirical case study, and showed the approach successfully addresses the bias caused by omitted relevant variables.

Assume the *Kth* variable is omitted in the choice set.

$$U_{in} = \sum_{k=1}^{K-1} \beta_k^{true} x_{ink}^{true} + (\beta_K^{true} x_{inK}^{true} + \varepsilon_{in}^{true}) \tag{27}$$

Instead of IVs for the endogenous variables x_k^{true}, assume we have two indicators $x_{k_1}^{true}$ and $x_{k_2}^{true}$ with the following conditions:

$$x_{K_1}^{true} = \gamma_{K_1} + \beta_{k_1} x_K + e_{K_1} \tag{28}$$

$$x_{K_2}^{true} = \gamma_{K_2} + \beta_{k_2} x_K + e_{K_2} \tag{29}$$

where,

$$\begin{aligned} Cov(x_K^{true}, e_{K_1}) &= Cov(x_k^{true}, e_{K_1}) = Cov(x_K^{true}, e_{K_2}) \\ &= Cov(x_k^{true}, e_{K_2}) = Cov(e_{K_1}, e_{K_2}) = 0 \end{aligned} \tag{30}$$

Then, x_{K_1} replaces x_K in equation 26 with the new error terms.

$$U_{in} = \sum_{k=1}^{K-1} \beta_k^{true} x_{ink}^{true} + \beta_K^{true} (\frac{x_{inK_1} - \gamma_{K_1} - e_{K_1}}{\beta_{K_1}}) + \varepsilon_{in}^{true}$$

$$= \sum_{k=1}^{K-1} \beta_k^{true} x_{ink}^{true} + \frac{\beta_K^{true}}{\beta_{K_1}} x_{inK_1} + (-\frac{\gamma_{K_1}}{\beta_{K_1}} - \frac{e_{K_1}}{\beta_{K_1}} + \varepsilon_{in}^{true}) \quad (31)$$

Now, the new error term $(-\frac{\gamma_{K_1}}{\beta_{K_1}} - \frac{e_{K_1}}{\beta_{K_1}} + \varepsilon_{in}^{true})$ is not correlated with the explanatory variables, and the variable x_{K_1} is the only endogenous variable. The indicator x_{K_2} becomes a proper IV for x_{K_2} using equations 28 and 29.

This MIS approach is different from the previous IV approach. First, if the omitted variable is correlated with many explanatory variables, the IV approach requires as many IVs as correlated explanatory variables. However, the MIS approach always requires two indicators regardless of the correlations. Second, IV approach assumes that the IVs are correlated with endogenous variables, but uncorrelated with the error terms. However, the assumption in the MIS approach is stricter. Two indicators are only correlated with the endogenous variable and fulfill the condition reflected in equation 29.

Even though the discussed three methods (BLP, control function, MIS) have successfully expressed empirical endogeneity, it can be only valid when satisfying the implied assumptions. Therefore, the suggested methods represent a specific type of endogeneity. Guevara (2015) classified multiple approaches (Proxys, Control Function method, Multiple Indicator Solution, Latent Variable, and Maximum-Likelihood) representing diverse types of endogeneity and formally showed how it can be represented. However, it is still necessary to be empirically applied.

4. TASTE VARIATION (PREFERENCE HETEROGENEITY)

Random utility models were originally estimated based on the assumption of homogeneous taste weights. However, the assumption of homogeneous taste parameters is behaviorally problematic: 1) the intrinsic bias due to individual factors such as income and gender 2) subjective evaluations of level-of-service attributes (Bhat, 2000). Homogeneous taste weights may lead to inconsistent model parameters estimates and severe inconsistent choice probability estimates (Chamberlain, 1980).

The most basic way of representing taste variation is to use observable socioeconomic variables such as income, age, and gender (Train and McFadden, 1978; Kitamura, 1981). However, researchers do not exactly know which and how many socioeconomic characteristics are related to the taste variation. Therefore, since decades, researchers have assumed parametric joint probability distributions to represent random taste variation in the error terms, and then derive choice probabilities. Due to the computational burden, early studies included only one or two dimensions of integration (Train et al., 1987; Chintagunta et al., 1991; Ben-Akiva et al., 1993; Gonul and Srinivasan, 1993; Postorino, 1993; Vanhonacker, 1998; Revelt and Train, 1998). Later, improvements in computer speed and simulation methods allowed a larger number of integrations. As a result, McFadden and Train (2000) proposed mixed multinomial logit models.

As discussed, the choice probability of the multinomial logit model is obtained using equation 6 based on the assumption that the taste weights (β_k) are fixed. If we assume the taste weight (β_k) is a continuous random variable with probability density $f(\beta_K \mid \boldsymbol{\theta}_\mathbf{K})$, where $\boldsymbol{\theta}_\mathbf{K}$ are the parameters of this distribution, such as the mean and variance. Therefore, taste variation can be represented by $\boldsymbol{\theta}_\mathbf{K}$, which is a vector containing information such as mean and variance of a certain distribution. Then, the unconditional choice probability would be:

$$P_{in} = \int_{k=K} \cdots \int_{k=1} \frac{\exp(\sum_{k=1}^{K} \beta_k x_{ink})}{\sum_j \exp(\sum_{k=1}^{K} \beta_k x_{jnk})} f(\beta_1 \mid \boldsymbol{\theta}_\mathbf{1}) \cdots f(\beta_K \mid \boldsymbol{\theta}_\mathbf{K}) \qquad (31)$$

Since the choice probability P_{in} is not expressed in closed form any more, simulation is required to obtain approximate values to ultimately estimate parameter β_k. That is, a certain number (R) of draws estimating parameter β_k is randomly sampled to obtain an approximate value of $\hat{P}_{in}$.

$$\hat{P}_{in} = \frac{1}{R}\sum_{r=1}^{R}\frac{\exp(\sum_{k=1}^{K}\beta_{kr}x_{ink})}{\sum_{j}\exp(\sum_{k=1}^{K}\beta_{kr}x_{jnk})} \tag{32}$$

Instead of the log likelihood function of equation 6, a simulated log likelihood function is used to obtain optimized values.

$$SLL = \sum_{n=1}^{N}[y_{in}\log\hat{P}_{in} + \cdots + y_{jn}\log\hat{P}_{jn}] \tag{33}$$

The mixed multinomial logit models have been applied to diverse choice problems to represent taste variation (Brownstone et al., 2000; Bhat, 2000; Cicia et al., 2002; Bhat and Castelar, 2002; Hensher and Green, 2003; Green et al., 2006; Green and Hensher, 2007; Hynes et al., 2008).

Despite the theoretical and computational advantages of mixed multinomial logit models, analysists still should specify the type of distribution of parameters. Any type of distribution is theoretically difficult to clearly define the taste variation.

An alternative approach applied in previous studies (Stopher, 1969; Lerman and Ben-Akiva, 1976; Burns and Golob, 1976; Nicolaidis et al., 1977), is based on the assumption that taste weights are heterogeneous across groups of decision makers. However, originally, the criteria for segmenting groups were arbitrary. Later, Heckman and Singer (1984) and Swait (1994) proposed to assign respondents to latent classes, with each class having different taste weights. This is the latent class model. If we assume the taste weights (β_k) are discrete random variables $(\beta_{k_s}; s = 1, \cdots, S)$ and each probability is $P_{ns}\ (s = 1, \cdots, S)$, where $0 \le P_{ns} \le 1$, then the choice probabilities of the latent class model can be derived as

$$P_{in} = \sum_{s=1}^{S} P_{ns}\frac{\exp(\sum_{k=1}^{K}\beta_{k_s}x_{ink})}{\sum_{j}\exp(\sum_{k=1}^{K}\beta_{k_s}x_{jnk})} \tag{34}$$

The probability to be included in latent class (P_{ns}) can be expressed using the latent membership likelihood function.

$$M_{ns} = \lambda_s \mathbf{z_n} + \xi_{ns} \tag{35}$$

where $\mathbf{z_n}$ are vector containing both the psychographic constructs and the sociodemographic characteristics of individual *n*, λ_s is/are parameter(s) to be estimated, and ξ_{ns} are identically and independently Gumbel distributed error terms.

$$P_{ns} = \frac{\exp(\lambda_s \mathbf{z_n})}{\sum_{s=1}^{S} \exp(\lambda_s \mathbf{z_n})} \tag{36}$$

Therefore, the choice probability in equation 31 can be expressed:

$$P_{in} = \sum_{s=1}^{S} \left(\frac{\exp(\lambda_s \mathbf{z_n})}{\sum_{s=1}^{S} \exp(\lambda_s \mathbf{z_n})}\right)\left(\frac{\exp(\sum_{k=1}^{K} \beta_{k_s} x_{ink})}{\sum_{j} \exp(\sum_{k=1}^{K} \beta_{k_s} x_{jnk})}\right) \tag{37}$$

Since the discrete values can be considered as a special type of distribution, some authors (e.g. Train, 2008) argue that the latent class model is a special case of the mixed multinomial logit model.

The latent class models have been applied to diverse choice problems to explore the degree of taste variation (Bhat, 1997; Boxall and Adamowicz, 2002; Provencher and Bishop, 2004; Scarpa and Thiene, 2005; Provencher and Moore, 2006; Birol et al., 2006; Wen and Lai, 2010; Arunotayanun and Polak, 2011; Breffle et al., 2011).

Since both the mixed multinomial logit model and the latent class model provide different perspectives on taste variation, several studies have compared the models. Green and Hensher (2003) compared the models in the context of road type choice behavior in New Zealand. Although their data provided statistical evidence of the superiority of the latent class model, they concluded that we cannot say which model is really superior. Later, Hynes et al. (2008) used location choice data based on perceived attribute values to compare the models. They found considerable differences between the models with respect to the values of welfare estimates. Shen (2009) compared the models using two stated preference data sets about mode choice behavior. They concluded that the latent class model shows consistently better performance than the mixed multinomial logit model in both data sets. Hess et al. (2011) argued that the latent class model outperforms the mixed multinomial logit model with respect to the representation of richer patterns of heterogeneity based on empirical results about stated route choice behavior in Denmark. They showed that even with a small number of classes, the latent class model shows similar or better performance, compared to the mixed multinomial logit model. Even though taste variation can be represented by different taste weights for each class, it still is a stricter assumption than taste weights being homogenous within each class. Therefore, Green and Hensher (2013) proposed the latent class mixed multinomial logit model, which can be viewed as a mixture of the mixed multinomial logit model and the latent class model. The taste weights are heterogeneous between classes and within classes. The proposed model outperforms conventional latent class models and mixed multinomial logit models in the context of stated freight route choice behavior in Australia.

5. NEW TYPE OF DISCRETE CHOICE MODEL: RANDOM REGRET MINIMIZATION MODEL

Recently, as an alternative to the traditional Recently, as an alternative to the traditional random utility maximization (RUM) model, random regret minimization (RRM) discrete choice models have been proposed in transportation research (Chorus et al., 2008). Based on regret theory (Bell, 1982; Loomes and Sugden, 1982, 1983, 1987; Quiggin, 1994) this new model has been applied to a variety of choice problems (De Moraes Ramos et al. 2011; Hess et al. 2012; Kaplan and Prato 2012; Thiene et al. 2012; de Bekker-Grob and Chorus 2013; Chorus et al. 2013; Prato 2014; Jang et al., 2016a; Rasouli and Timmermans, 2016).

Whereas random utility models assume that individuals evaluate alternatives using the concept of utility, and then choose the alternative that maximizes their utility, random regret minimization models assume that alternatives are evaluated in terms of regret and individuals choose the alternative that minimizes their regret. Similar to the utility function, the regret function is assumed to consist of a certain (measureable) and an uncertain (random) part.

$$RR_{in} = \mu_{in} R_{in} + \varepsilon_{in} \tag{38}$$

where RR_{in} is total regret for alternative i, R_{in} is deterministic regret, μ_{in} is scale factor, and ε_{in} is error terms.

While the linear-additive deterministic utility V_{in} in equation 2 is assumed to be derived by processing the attributes of each choice alternative independently and separately, the linear-additive deterministic regret R_{in} is assumed to be derived by comparing the attributes of each choice alternative.

$$R_{in} = f(x_{jnk} - x_{ink}) \quad \forall j \in C_n \tag{39}$$

Then, incorporating a semi-compensatory decision rule, regret is conceptualized as the emotion that is felt when one or more non-chosen alternatives perform better than the chosen one, in terms of one or more attributes (Chorus et al., 2008; Chorus, 2010; Chorus, 2012). If the chosen alternative outperforms (or equals) the non-chosen (foregone) alternative, regret is zero regardless of the attribute-level difference.

The definition of regret for multi-alternatives choice sets is an important issue in random regret models. Chorus et al. (2008) defined regret for the chosen alternative to depend only on the best non-chosen (foregone) alternative in multi-alternatives choice sets, following Quiggin's (1994) principle of *Irrelevance of Statewise Dominated Alternatives*.

$$R_{in} = \max_{j \neq i}[\sum_{k=1}^{K} \max\{0, \beta_k (x_{jnk} - x_{ink})\}] \tag{40}$$

Even though the regret function in equation 40 has a strong theoretical background, two max operators make the regret function non-differentiable. Later, Chorus (2010) therefore suggested an alternative regret function to avoid this technical problem. The first max operator is replaced by a summation, and the second max operator is replaced by a logarithmic approximation.

$$R_{in} = \sum_{j \neq i} \sum_{k=1}^{K} \ln[1 + \exp\{\beta_k (x_{jnk} - x_{ink})\}] \tag{41}$$

The probability of choosing alternative *i* can be obtained by minimizing regret:

$$
\begin{aligned}
P_{in} &= \text{Prob}(RR_{in} < RR_{jn}) \\
&= \text{Prob}(\mu_{in} R_{in} + \varepsilon_{in} < \mu_{jn} R_{jn} + \varepsilon_{jn}) \\
&= \text{Prob}(\varepsilon_{in} - \varepsilon_{jn} < \mu_{jn} R_{jn} - \mu_{in} R_{in}) \quad \forall j \in C_n
\end{aligned} \tag{42}
$$

To maintain computational advantages, the scale factors are normalized to one $(\mu_{in} = 1)$, and the error terms are assumed to be *negatively* identically and independently Gumbel distributed. Then, equation 42 can be easily transformed using an exponential function and the parameters can be estimated using a log likelihood function.

$$
P_{in} = \frac{\exp(-\mu_{in} R_{in})}{\sum_j \exp(-\mu_{jn} R_{jn})} \tag{43}
$$

Until very recently, the uncertainty problem has not been systematically investigated for random regret models. The focus of attention concerned the predictive performance of the model, relative to classic random utility maximizing models. Empirical studies suggest that generally the performance of the two models is similar. In some cases, the regret model outperformed the utility model; but there is also evidence on the contrary. Hence, it is fair to say that the assumptions about the error terms have been made for convenience. Chorus (2012) asserted that measurement errors cause negative correlation and omitted relevant variables lead to positive correlation. He assumed that these effects cancel out each other.

Therefore, the difference between RUM and RRM can be summarized as: 1) full compensatory decision rule in the RUM and the semi-compensatory decision rule in the RRM. 2) assessment of utility by processing the attributes of each choice alternative independently and separately in the RUM and assessment of regret by comparing alternatives. These theoretical differences raise the basic questions: 1) whether the sources of uncertainty composing error terms evenly affect RUM and RRM?

and 2) If not, how it affects the assumptions about error terms underlying both models.

As said, very few studies have examined the assumptions about the error terms in random regret models. Jang et al. (2016b) explored the effect of measurement error in RRM. They formally and empirically showed that while the measurement error homogeneously affects the RUM, it heterogeneously affects the RRM. Therefore, they casted doubt on the suitability of the assumption of IID error terms in random regret models.

Van Cranenburgh and Prato (2016) proposed to use ASCs in RRM to represent the average effect of the omitted relevant variables. Unlike the RUM, since regret is based on a comparison of alternatives, they insist that choice set composition ASCs are more suitable for the RRM, compared to general ASCs.

Taste variation has received more attention. Chorus et al. (2008) found taste variation to be statistically significant. Boeri and Masiero (2014) compared the mixed multinomial based RUM and RRM models in a freight transport context, and found a statistically significant difference with respect to mean elasticity and market shares. Hensher et al. (2016) also compared the mixed multinomial based RUM and RRM models using a mode choice data set. However, overall, they found only small differences between the empirical results.

6. CONCLUSIONS

Random utility discrete choice models have been the preferred modelling approach in transportation research and urban planning to replace the zone-based demand models. To represent the combined effect of unobservable/uncertain components and randomness of individuals, error terms were introduced in these models. The error terms in RUM are generally assumed to be identically and independently Gumbel distributed, simply for computational advantages. Because of the sources - measurement error, omitted relevant variables, and taste variation - composing the error terms, we can only obtain estimated parameters values, not their true values. If we are able to describe the size of the effect of the different sources of error, we may obtain the true parameters to explain choice behaviour, or at least approximate these values.

This paper reviewed studies on the effect of the various sources of uncertainty in discrete choice models. Because of the difficulty to quantify the effects, all studies have explored the effect of only one source of error. It would be interesting in future research to study the combined effect of multiple sources, which would provide insights in how to more accurately represent choice behavior. An important issue would be how the correlation of the effects of each source can be addressed. Moreover, previous studies have only focused on single choice behaviour. It would also be necessary to explore the effect in simultaneous choice behaviour, such as the combination of mode and route choices.

Finally, we discussed a new type of discrete choice model (RRM) and its behavioural differences with the RUM in evaluating choice alternatives. Our contention is that since regret models differ from random utility models in their evaluation of alternatives, the effect of each uncertain source may be different. Ultimately, this affects the assumptions about error terms. Unfortunately, the number of studies about the error construction in RRM is very limited. Therefore, more studies are necessary to figure out the effect.

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A pictorial approach to geodesign

A case study for the Lower Zambezi valley

Key words: Geodesign; Visualisation, Local knowledge; Participatory GIS; Lower Zambezi Valley

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Introduction

Geodesign tools can be used to support collaborative processes. Typical tools combine different methods, such as simulation models, spatial multi-criteria analysis, visualization, and optimization. User-friendly interfaces allow multiple users to provide input and generate real-time output to support negotiated spatial decisions (Geertman and Stillwell 2009; Eikelboom and Janssen, 2015a; 2015b).

Our presentation demonstrates how experiences with geodesign in data rich environments such as the Netherlands (Janssen et al 2014) and the UK (Alexander et al 2012) can be used to design an approach for interactive workshops in the Lower Zambezi valley, Mozambique. Instead of a model based application that provides real time response to proposed changes, a pictorial geodesign tool was developed that relied on a combination of drawing, use of icons and visualization to facilitate interaction with the participants. The approach required no calculation steps and relied heavily on input provided by the local stakeholders.

The geodesign tool

Geodesign tools provide the interface between stakeholders and spatial information Our tool is based on the concept of a value map. Valuation consists of transforming an attribute map layer into a standardised value map. A value map is a combination of the attributes of the region with a value function representing the value judgements of the stakeholders (See also Janssen et al 2014). The tool does not require a predefined spatial unit such as the land parcel above. This is important in studies where no clear spatial unit can be linked to the underlying attributes and the categories to be valued as is the case in our study of the Zambezi valley. At the heart of the tool is an extensive collection of map layers available from the project's WebGIS. A standard drawing tool is used to allow participants to draw the spatial units to be valued. In the Zambezi case these units represent the areas considered relevant for the developments of the various sectors. The next step is linking a value to each sector. As in standard value maps this value is derived from the underlying map layers. Participants can add or delete an icon or move them around on the map. Participants can assign a value by selecting green (high) yellow (medium) or low (red). Participants rank the sectors by moving the icons around on the screen (figure 1).

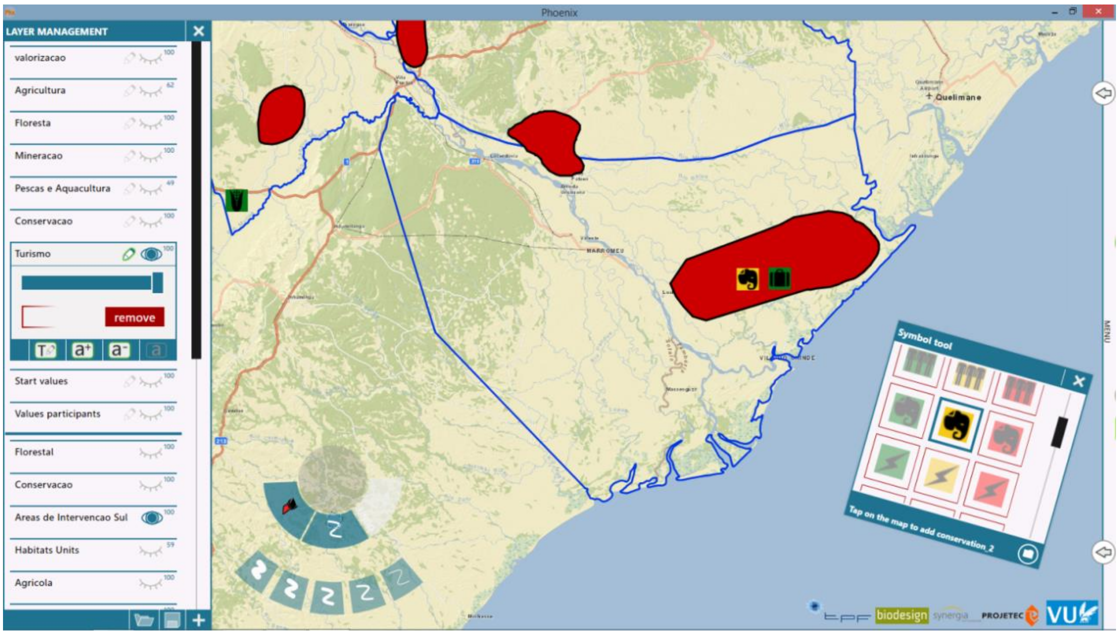

Figure 1 The interface of the geodesign tool

Results

After identifying the land claims for all sectors the sector layers were overlaid to identify overlapping claims. As an example Figure 2 shows the potential areas of conflict between mining (grey) and fisheries (blue). Figure 2a shows the values for mining, commercial and artisanal fisheries in the conflict area.

(a) (b)

Figure 2 Valuation (a) and ranking (b) of the sectoral claims in the overlapping regions.

Finally, participants rank the sectors by moving the icons around on the screen. Figure 2b shows fisheries ranked before mining. Even with mining as a high potential, the participants argued that artisanal fishing and subsistence farming are crucial for the local population so should be ranked first.

The tool requires use of a touch screen. For our study we used the Lenovo Horizon (27''). The tools are implemented in Phoenix, a software package developed by GEODAN to support visualization (http://www.geodan.com/products/phoenix/ last accessed 01-02-2016).

Conclusion

This approach required no calculation steps (the local stakeholders provided the input) and relied heavily on visualization, drawing and use of icons. This appealed to the participants and the absence of a quantitative model was not seen as a problem. Despite the simple strategy, the tool served its purpose well. It was interesting to observe that it was possible to use the principles of more sophisticated tools in an approach that was simpler but much more graphical as a means of promoting discussion and understanding.

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Mixed logit model of intended residential mobility in renovated historical blocks in China

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Key words: Residential mobility, residential satisfaction, mixed logit model, historical block renovation

Abstract: Using data from 8 historical blocks in China, the influence of social-demographic characteristics and residential satisfaction on intended residential mobility is analysed. The results of a mixed logit model indicate that higher residential satisfaction will lead to a lower intention to move house, and that housing satisfaction and satisfaction with the residential environment have a higher impact compared with satisfaction related to other life domains. Younger residents and residents who live in blocks during early or late renovation are more interested in relocating.

1. INTRODUCTION

Residential mobility has a long history of intensive study in urban planning and housing research. As mobility is significant in understanding residential preference and behaviour, the question how families move began to attract the interest of scholars since at least the middle 1950s. In the 1980s and 1990s, identifying variables that influence residential mobility was a popular topic of research. Even though recent years have witnessed a decrease in the analyses of residential mobility due to the shift of interest to international immigration (Coulter, Ham, Findlay and Coulter, 2013), residential mobility remains a significant topic to discuss, especially in developing countries.

Initially, Clark (1983) defined the housing, neighbourhood and accessibility as three main reasons for voluntary residential mobility. Boehm (1986) and Lee (1994) found that neighbourhood variables play an significant role in predicting mobility. Clark (2003, 2006a) checked the influence of neighbourhood satisfaction and stated that people who like their neighbourhood are less likely to move out. In another paper, Clark et al. (2006b), further addressed the trade up in housing and neighbourhood quality and found people often improve both. Kan (2007) used social capital to replace the nearby neighbourhood and found it has a negative effect on residential mobility.

Since Rossi (1955), tenure has always been included in analyses of residential mobility. It was found to have a salient effect on residential mobility as raised by Clark (2003), Van der Vlist (2002) and Lu (2002). Baker (2002) soon added that homeowners are more satisfied with their housing and community characteristics than tenants. Huang (2006) found that homeowners are less likely to move than renters. Besides tenure, length of stay has been subjected to analyses using months as an independent variable in residential mobility studies. Studies have found varying effects. McGinnis (1968) concluded that increasing length of stay will decrease the propensity to move. However, Ioannides (1987) asserted that length of stay will effect mobility jointly with tenure status. Onaka (1983) also found length of stay does not have a consistent effect on mobility. Only for young couples without children, a negative effect could be observed.

Residential mobility is also considered to be the function of lifecycle events. Different events happening in an individual’s life are potentially triggering the need of moving house. Rossi (1955) mentioned that life course is placed at the top of the list of reasons of residential mobility. Clark (1983) argued that life cycle is a more important determinant compared with cost, tenure, etc. Two years later, Courgeau (1985) applied a retrospective survey and found that the birth of the first child has a significant effect on increasing mobility rates. He also pointed out that divorce has a significant effect mainly for woman while the influence of marriage changes over time. Later Clark (2003), Feijten (2007) and Rabe (2010) confirmed the importance of lifecycle for couples in explaining residential mobility.

Change of job can also be regarded as a lifecycle event, which potentially leads to residential mobility. Many scholars already found the positive link between job change and moving house (van Ommeren et al., 2000; Clark and Davies Withers, 1999). By analysing job change, Böheim (2002) found that unemployed people are more likely to move than employees in the UK, while Diaz-Serrano (2010) argued that the influence of job change depends on the country where respondents live.

The relation between residential satisfaction and residential mobility also attracted lots of attention in housing research. A significant influence of residential satisfaction (or dissatisfaction) on the intention to move was found by many scholars (Clark and Onaka, 1983; Kearns and Parkes, 2003; Oh, 2003; Kwon and Beamish, 2013). Speare (1975) applied path analysis to study the influence of residential satisfaction on mobility. His model was confirmed by Landale (1985) and showed that satisfaction is a strong predictor of thought of moving and the thought of moving will influence the real move. Earhart (1996) and Oh (2003) argued that residential satisfaction influences the intention to move house by working together with other variable like feeling of home attachment and social bonding. Diaz-Serrano (2010) used panel data collected from 12 countries to find that residential satisfaction also triggers real moves. By studying the reverse causality between residential satisfaction and mobility, scholars also found that previous residential mobility will affect current residential satisfaction, in spite of the fact that those studies are based on different scales of relocation (Barcus, 2004; Lu, 2002; Posthumus et al., 2014).

Residential mobility has also interested an increasing number of Chinese scholars in the past decade (e.g.; Fang, 2006; Li and Song, 2009; He, 2015). However, Chinese findings are inconsistent with western results. Using data from Beijing, Fang (2006) found that in contrast to the Western literature, lower residential satisfaction causes a high intention to move house, but will not lead to more real moves. Li (2009) also found that life course, including marriage and childbirth, is not influential for residential mobility, which is different from findings in the Western world. Even for tenure status, Li (2003) and Wu (2006) found it does not necessarily drive residential mobility and migrant tenants are less likely to move. The main reason for this discrepancy may be that Chinese are faced with stronger constraints and hence have less opportunity to act on their preferences and intentions.

The influence of the special Chinese hukou system on mobility was analysed by Huang (2014). He found that it only has effects in more-developed municipalities. Huang and Deng (2006) found that changes in housing supply and housing qualification trigger residential mobility in Chinese cities while He (2015) asserted that the intention to move house is generated by a combined effect of various factors.

Although the number of studies in China has been increasing, the study of Chinese residential mobility is still at an early phase and systematic analysis of the influence of both residential satisfaction and social-demographic variables is still lacking.

The aim of this paper therefore is to analyse how social-demographic variables and residential satisfaction jointly influence residential mobility intentions. Consistent with the mainstream residential mobility studies that concentrated on the propensity to move (Kestens, 2004), our analysis will only consider the mobility intention rather than real moves. The specific focus of this study is on historical blocks in selected Chinese cities. These blocks are of great theoretical and applied interest because on the one hand various constraints may operate more strongly in these urban environments, but on the other hand, particularly the renovated blocks have gone through upgrading schemes. It is thus important to accumulate evidence of residential satisfaction and intentions to move house in such blocks. Although life course is always considered to be significant determinant, they are excluded in this analysis as it is hard to collect data associated with life course.

The remainder of this paper is structured as follows: the introduction section is followed by a description of the data collection. Then, the method of analysis will be presented and results will be discussed. Based on the results, some conclusions will be drawn in the last section.

2. DATA COLLECTION

Data used for this paper was collected from 8 historical blocks from two Chinese cites: Chongqing and Shanghai. Chongqing is located in the western part of China while Shanghai is located in the eastern part. Both cities are first-tier cities with a high GDP growth (> 7%). In order to protect their culture heritage from being engulfed in economic development, both cities established their own historical preservation areas. Considering the ratio of remaining protection areas (8 in Chongqing and 14 in Shanghai), 3 blocks from Chongqing and 5 from Shanghai were randomly selected. All these blocks experienced different degree of renovation.

In order to better understand the relations between residential satisfaction and mobility, our questionnaire measured satisfaction based on 7 dimensions in line with traditional mobility research (Clark, 1982, 1983), including housing, environment, historical atmosphere and tourism, neighbourhood relationship, family, work and economy. Every dimension contains 3 to 10 variables. Based on judgements of all these variables, overall satisfaction of each dimension was measured on a seven-point rating scale, ranging from ‘very unsatisfied’ to ‘very satisfied’. Finally, the intention to move was measured. After the survey, at least 3 interviews were taken in every blocks that over than 30 interviews were recorded in total.

The data was collected from April to June 2015. 400 questionnaires were distributed and 384 valid questionnaire were completed. Thus, the response rate equals 96 percent. Table 1 shows the collective results of the mobility choice. As data was collected in a detailed way to obtain more information, some categories were merged during analysis to reduce the number of estimated parameters. Table 2 gives descriptive information about the data. The percentage of women (51.3) is slightly higher than the percentage of men (48.7). Over half of the families does not need to support any child (56.8%) or elderly (63.3%). A large share of the sample (79.7%) has a lower level of education, compared with average citizens (75%[1]). Most respondents have the hukou from the same city (89.1%) while very few have it from other cities or villages (10.9%). 64.6% of the respondents have lived in the blocks for over 20 years. 52.4% of the families have a family income less than 5000 yuan (around 714 euros) and only 2.9% earns a family income over 20000 yuan (around 2857 euros) per month. As for the stage of renovation, 2 blocks (25.3% of respondents) are still at the early stage of renovation and only underwent a few rounds of small renovations before and might encounter more larger scale renovation soon; very few natives have moved out until now. 4 blocks (51.6% of the respondents) are during the middle stage of renovation, which means they have already experienced at least one around of large scale renovation. There are no immediate plans of further renovation; nothing will change much in the short run, but these blocks still have the potential of renewal again in the future. Another 2 blocks (23.2% of respondents) are already at a late stage of renovation. They have experienced several rounds of renovation and will not have huge scale renovation soon. A large percentage of local residents has already been replaced. Figure 1 displays the distribution of age showing that residents in historical blocks tend to be relatively old with 43.8% of the respondents being 60 or over and their average age is 55 years old.

Table 1. Description of mobility data

Variable	Category	Frequency(%) N=384
Residential Mobility	Move	44.3
	Stay	55.7

Table 2. Description of social-demographic data

Variable	Category	Frequency(%) N=384
Gender	Male	48.7
	Female	51.3
Family composition	live alone	12.2
	with partner	30.2

[1] http://www.stats.gov.cn/tjsj/pcsj/rkpc/6rp/indexce.htm

	with children/with parents/with others	24.0
	with partner+ children+ parents/ with partner+ children	33.6
Number of raising children	0	56.8
	1	37.8
	2 and over	5.5
Supporting elderly	Yes	36.7
	No	63.3
Education Level	Junior high school and under	45.1
	Senior high school	34.6
	Junior college and over	20.4
Hukou	This city	89.1
	Other city	6.3
	Village	4.7
Length of stay	20 years and under	35.4
	21-40 years	34.1
	41-60 years	20.1
	Over 60 years	10.4
Family Income	<2000 yuan	7.6
	2000-5000 yuan	44.8
	5000-20000 yuan	44.8
	>20000 yuan	2.9
Job	Yes	47.7
	No(including retired)	52.3
Renovation Stage	Early stage of renovation	25.3
	Middle stage of renovation	51.6
	Late stage of renovation	23.2

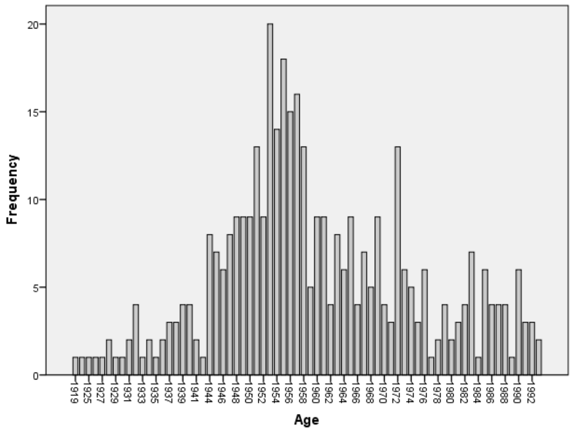

Figure 1. Age frequency

3. METHOD AND RESULTS

A mixed logit model was used to estimate the influence of residential satisfaction and social-demographic characteristics on residential mobility. By specifying the random parameters in the mixed logit model, unobserved heterogeneity between individuals can be captured. As different renovation stages changed the living environment for residents, they are assumed to affect residents' thoughts about housing individually and used as random parameters to estimate taste variation between residents in renovated historical blocks. Also, in order to check the influence of renovation stages on satisfaction, interactions between those two groups of variables were estimated. All the categorical attributes were effect coded and n-1 variables (every attribute has n categories) were involved in the estimation.

To show the effects of taste variation, the multinomial logit model was also estimated. The results of both models are listed in Table 3. Compared with the multinomial model (Rho squared= 0.239), the mixed logit model resulted in only a slightly better fit (Rho squared= 0.246). It suggests that the sample of respondents is rather homogeneous and that much of the taste variation is already captured by the observed socio-demographics, although as we will see soon, even most of the socio-demographic variables are not significant. Because by and large, the estimates of the models are consistent, only the results of mixed logit model will be interpreted in detail.

Table 3. Results of multinomial model and mixed logit model

Variables	Coefficient		z		Prob. |z|>Z*	
Constant	8.94366***	(8.94263***)	5.09	(5.1)	0.0000	(0.0000)
Renovation stage 1	0.19805**	(0.19848)	0.09	(0.09)	0.9273	(0.9271)
Renovation stage 2	-4.03464	(-4.03416**)	-2.25	(-2.25)	0.0243	(0.0242)
Job	-0.17192	(-0.17192)	-0.92	(-0.92)	0.3602	(0.3601)
Gender	0.08339	(0.08338)	0.61	(0.61)	0.5423	(0.5423)
Age	-.03731***	(-.03730***)	-2.60	(-2.60)	0.0094	(0.0094)
Family composition 1	-0.01848	(-0.01850)	-0.06	(-0.06)	0.9537	(0.9536)
Family composition 2	0.05844	(0.05844)	0.25	(0.25)	0.7995	(0.7994)
Family composition 3	-0.13178	(-0.13177)	-0.54	(-0.54)	0.5875	(0.5874)
Number of raising children 1	-0.06561	(-0.06559)	-0.25	(-0.25)	0.8051	(0.8051)
Number of raising children 2	-0.01001	(-0.01001)	-0.04	(-0.04)	0.9687	(0.9686)
Supporting elderly	0.09221	(0.09220)	0.63	(0.63)	0.5270	(0.5269)
Education level 1	0.15977	(0.15975)	0.77	(0.77)	0.4437	(0.4437)
Education level 2	0.06497	(0.06497)	0.34	(0.34)	0.7313	(0.7313)
Hukou 1	0.12905	(0.12901)	0.37	(0.37)	0.7082	(0.7083)
Hukou 2	-0.48253	(-0.48247)	-1.17	(-1.17)	0.2407	(0.2406)
Length of stay 1	-0.05601	(-0.05601)	-0.22	(-0.22)	0.8223	(0.8223)
Length of stay 2	0.22758	(0.22755)	1.04	(1.04)	0.2984	(0.2983)
Length of stay 3	0.02940	(0.02941)	0.11	(0.11)	0.9103	(0.9102)
Family income 1	0.58273	(0.58263)	1.32	(1.32)	0.1853	(0.1852)
Family income 2	-0.31055	(-0.31055)	-1.08	(-1.08)	0.2790	(0.2789)
Family income 3	-0.03360	(-0.03361)	-0.12	(-0.12)	0.9014	(0.9013)
Renovation stage 1 × Satisfaction of housing	-0.20850	(-0.20852)	-0.90	(-0.90)	0.3662	(0.3661)
Renovation stage 1 × Satisfaction of environment	-0.25650	(-0.25650)	-0.87	(-0.87)	0.3848	(0.3847)
Renovation stage 1 × Satisfaction of historical atmosphere and tourism	0.17001	(0.16998)	0.51	(0.51)	0.6099	(0.6099)
Renovation stage 1 × Satisfaction of neighbourhood	-.72426**	(-.72420**)	-2.01	(-2.01)	0.0445	(0.0445)
Renovation stage 1	.71956**	(.71948**)	2.16	(2.16)	0.0311	(0.0311)

× Satisfaction of family						
Renovation stage 1 × Satisfaction of economy	0.40245	(0.40241)	1.58	(1.58)	0.1151	(0.1151)
Renovation stage 2 × Satisfaction of housing	0.06790	(0.06792)	0.37	(0.37)	0.7101	(0.7100)
Renovation stage 2 × Satisfaction of environment	0.18126	(0.18126)	0.80	(0.80)	0.4233	(0.4232)
Renovation stage 2 × Satisfaction of historical atmosphere and tourism	0.14499	(0.14496)	0.56	(0.56)	0.5728	(0.5728)
Renovation stage 2 × Satisfaction of neighbourhood	.59712**	(.59706**)	2.16	(2.16)	0.0306	(0.0306)
Renovation stage 2 × Satisfaction of family	-0.15281	(-0.15282)	-0.58	(-0.58)	0.5618	(0.5617)
Renovation stage 2 × Satisfaction of economy	-0.03406	(-0.03407)	-0.17	(-0.17)	0.8647	(0.8647)
Satisfaction of housing	-.56477***	(-.56471***)	-3.81	(-3.81)	0.0001	(0.0001)
Satisfaction of environment	-.45233**	(-.45229**)	-2.30	(-2.30)	0.0215	(0.0214)
Satisfaction of historical atmosphere and tourism	0.05292	(0.05292)	0.24	(0.24)	0.8115	(0.8115)
Satisfaction of neighbourhood	-0.26670	(-0.26669)	-1.11	(-1.11)	0.2672	(0.2672)
Satisfaction of family	-0.28587	(-0.28581)	-1.26	(-1.26)	0.2062	(0.2061)
Satisfaction of job	-0.14946	(-0.14943)	-0.82	(-0.83)	0.4094	(0.4093)
Satisfaction of economy	0.05523	(0.05523)	0.30	(0.30)	0.7608	(0.7607)

Random parameters	Standard deviation	z	Prob. |z|>Z*
Constant	0.01764	0.01	0.9904
Renovation Stage 1	0.00116	0.00	0.9997
Renovation Stage 2	0.01868	0.01	0.9903

Note: 1 The numbers in the parentheses are results of multinomial model.
2 ***, **, * ==> Significance at 1%, 5%, 10% level.

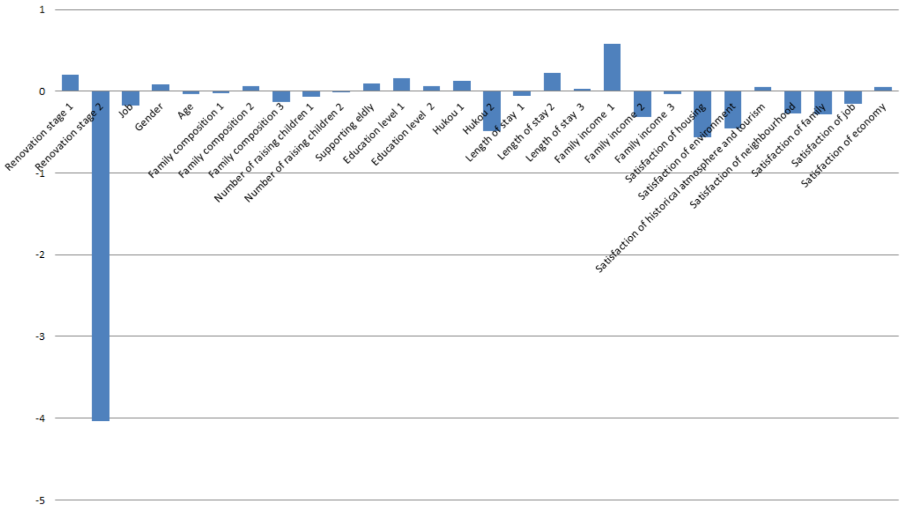

Figure 2. Utilities of main effect variables

An examination of Table 3 shows that the estimated constant is positive and significant. It illustrates that the propensity to move house is larger than the intention not to move. Results also indicate that stage 2 (middle renovation stage), age, interaction between renovation stages and satisfaction of neighbourhood and family, housing satisfaction and satisfaction with the environment are statistically significant at conventional levels (Figure 2). The middle stage of renovation is found to be influential variable for residential mobility (-4.034). Compared with people from other renovation stages, residents living in blocks during middle renovation are less likely to move. As the renovation continues, the intention to move increases in the early and late stages. This may suggest that renovation from government more or less changed both the tangible and intangible living environment. This quantitative result was confirmed during our qualitative interviews in which residents mentioned that after few rounds of renovation, they do find their living conditions improved. So they were happy about their houses and less interested in moving out. However, because the historical buildings were partly made from wood and always need repair, few rounds of small scale renovation cannot stop the trend of deterioration. Therefore, after some time, in spite of more rounds of renovation, residents were more inclined to move as they think the renovation cannot solve the fundamental problems, such as housing structure and house size. Age also significantly impacts the mobility intention (-0.037). Its negative sign shows that the older the residents, the lower the intention to move house.

As for the various satisfaction variables, housing satisfaction contributes significantly to the intention to move house (-0.564). Its negative impact suggests that lower housing satisfaction leads to a higher intention to move, which is consistent with previous research (Kearns and Parkes, 2003) (Oh, 2003). Housing satisfaction is also the most important variable influencing residential mobility compared with other satisfaction variables. Following housing, satisfaction with the environment also significantly influences the mobility intention (-0.452). The negative coefficient also indicates that the higher environmental satisfaction, the lower the propensity to move. Similarly, neighbourhood satisfaction, job satisfaction and satisfaction with family life have a negative sign, showing that the intention to move house decreased with increasing satisfaction with neighbourhood, job and family. In this context, it should be mentioned that job satisfaction includes a variable depicting the work commuting time. Historical and economic satisfaction show an unexpected positive sign; however none of them are statistically significant. Here economic satisfaction involves variables depicting rent increase, house price increase and family business. In this context, it should also be emphasised that all satisfaction variables are strongly intercorrelated. If we examine the single correlations, results indicate that historical satisfaction and economic satisfaction are negatively correlated with the intention to move house as we would assume. Thus, the negative signs in the logit model is likely due to the multicollinearity among the satisfaction variables.

Although renovation stages are assumed to display taste variation, the standard deviation of these random parameters are statistically insignificant. It means residents living in blocks of different renovation stages do not exhibit significant differences in their propensity to move house. However, estimates of interaction between renovation stage and satisfaction variables suggest that the neighbourhood and family satisfaction significantly interact with several renovation stages. Specifically, with same neighbourhood satisfaction, residents living in blocks of early renovation (-0.724) have a lower inclination to move compared with those from blocks of later renovation (0.597), which is different from results of renovation stage. A likely explanation is that social bonding was destroyed during renovation as more neighbours were replaced. The same trend is found in interaction with environmental satisfaction. In contrast, for residents with same family satisfaction level, those who live in blocks during early renovation stage are most likely to move, which is consistent with the main effect of stage. Then lower housing satisfaction is found may decrease the (base) preference of moving in early renovation stage. As historical and economic satisfaction exhibit unexpected signs, so their interactions will not be interpreted.

Regarding other social-demographic variables, although the results suggest that they are statistically insignificant maybe due to relatively small sample size, some trends can still be observed. The negative sign of having a job indicates that people who have a job are less likely to move out compared with those retired or having no job. It might be because people with a job are more stable than those without a job. Some respondents mentioned in the interviews that they cannot move because their work places are nearby and it would be inconvenient for their commuting if they would relocate. Gender positively influences residential mobility, which means that males have a higher intention to move compared with females. The changing signs of family composition indicate that residents who lives alone and live with children or parents or other relatives are less interested in moving compared with residents living with a partner or extended family. The result is consistent with researches focusing on life course that marriage will lead to higher moving intention (Clark and Huang, 2003; Feijten and van Ham, 2007; Rabe and Taylor, 2010). Parameters of the number of raised children demonstrate that families having more children are more likely to move compared with having less children, which is reasonable as more children need more space and families might consider moving. Similarly, supporting more elderly at home will also induce a higher mobility intention. In terms of length of stay, residents who live less than 20 years and longer than 60 years in the historical block are less likely to move. Although tenure has been studied intensively in residential mobility research, it is not involved in this analysis as the model indicated singular when tenure is included, which might be due to its high correlation with other variables.

Education level also displays a negative effect in the sense that residents with a higher education level have a lower inclination to relocate. Residents holding hukou of the current city and village have higher moving intention compared with those holding hukou of other cities, which is confirmed in the interviews that residents holding hukou from other cities are more reluctant to move as they have much less expectations about change. For family with lowest income, they are more interested in moving than families having other levels of income, which might be because some respondents with low family income mentioned that they intend to get high compensation from government from relocation to improve their economic situation.

4. CONCLUSIONS

The aim of this paper is to systematically understand residential satisfaction and social-demographic characteristics as determinants impact residential mobility. The results of mixed logit model indicate that residential satisfaction is an important impactor of residential mobility, which is consistent with previous researches (Kwon and Beamish, 2013). Renovation stage and age are also found to significantly influence mobility intention.

Most satisfaction variables have negative impact on residential mobility. It means when certain dimension of satisfaction increases, the intention to move decreases. Housing satisfaction is found to be the most influential variable compared with other satisfaction variables. As for social-demographic characteristics, length of stay is found not to affect mobility consistently, which is consistent with Onaka (1983), but because of distinct reasons. Another variable, age, negatively influences the intention to move, which confirms earlier findings (Earhart and Weber, 1996; Clark and Huang, 2003). Holding the special Chinese ID, hukou, of other city may also reduce the propensity to move compared with those having local hukou. Consistent with previous Western studies (Clark and Huang, 2003; Feijten and van Ham, 2007), people living with a partner or extended family are more likely to move compared with those living alone or with few relatives, which is, however, inconsistent with finding from urban areas in Shanghai (Li and Song, 2009). Therefore, different from most other Chinese findings, the residential preferences in renovated Chinese historical blocks are more similar with Western literatures.

The study also revealed that there is no difference in residents' taste regarding renovation stage. Residents living in blocks of the same renovation stages have similar preference contributing to the mobility intention. However, the joint effects of renovation stage and neighbourhood and family satisfaction are influential in the propensity to move. For residents having the same neighbourhood satisfaction, those who live in early renovation stage are less likely to move out, which might be because increasing number of local residents are replaced as the renovation continues. In contrast, under the same satisfaction level of family, residents living in the early stage are more inclined to move home. As renovation stage and its interaction with neighbourhood satisfaction influence residential mobility significantly and residents are more inclined to move in later stages, how to improve the renovation to create better living environment and reduce deterioration of social fabric is worthy consideration by policy makers. Although this study provides some insights into the influence of social-demographic characteristics and residential satisfaction on intended residential mobility, further investigation about the effect of more detailed attributes behind satisfaction variables on residential mobility still remains for further study.

5. ACKNOWLEDGEMENT

The author would like to thank Aloys Borgers (Tue) for his help in the improvement of this model.

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A Tool to Explore Community-based Activities Considering Mutual Assistance for Earthquake Disaster Mitigation Using a Multi-agent System and GIS

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Key words: Earthquake disaster, community-based activity, mutual assistance, MAS, GIS

Abstract: Japan is at great risk of being struck by earthquakes. In particular, the promotion of capabilities of self-help, public assistance, and mutual assistance for earthquake disaster mitigation as well as the technology for promoting the capability of mutual assistance among residents is required. To support the examination for community-based activities considering mutual assistance, this paper proposes the development of a tool utilizing a Multi-agent System and GIS based on the results of our previous study. Specifically, the tool consists of two sub-tools: 1) a GIS-based tool for evaluating the capability of mutual assistance, and 2) an MAS-based evacuation simulator in consideration of mutual assistance. This tool can reproduce various disaster situations and simulate evacuation behaviors with consideration towards mutual assistance under the situation. Through the analysis of results from demonstrations and the evaluation by administrative officers, the following findings were obtained. 1) It is possible to quantitatively evaluate and analyze the capability of mutual assistance by visual representation. 2) Users can change the condition of the simulator such as the speed of evacuation and the range to search for residents who cannot evacuate without some support on the control panel. For this, users confirm the results of simulation reflected by the opinions of residents during the workshop to examine community-based activities considering mutual assistance. This information may be able to sufficiently promote an understanding of the importance of mutual assistance for disaster mitigation.

1. INTRODUCTION

1.1 Background and objective

Japan is at great risk of being struck by earthquakes. The various measures for promoting the seismic safety of urban structures such as reconstruction and widening narrow roads as well as the response capabilities to deal with huge earthquakes are important. However, the improvement of urban structures requires a long time and huge costs. Therefore, the promotion of capabilities of self-help, public assistance, and mutual assistance for earthquake disaster mitigation as well as the technology for promoting the capability of mutual assistance among residents is required. To address this, technology possessing the following functions is considered to be important in community-based activities for disaster mitigation.

- To quantitatively evaluate and analyze the capability of mutual assistance by visual representation.
- To promote an understanding of the importance of mutual assistance among residents.
- To support the examination of community-based activities considering mutual assistance.

This paper proposes the development of a tool utilizing a Multi-agent System (MAS) and Geographic Information System (GIS) based on the results of our previous study.

Specifically, the tool consists of two sub-tools: 1) a GIS-based tool for evaluating the capability of mutual assistance, and 2) an MAS-based evacuation simulator in consideration of mutual assistance. Such tools can reproduce various disaster situations and simulate evacuation behaviors with consideration toward mutual assistance.

1.2 Study method

Initially, examination was conducted to organize the configuration and required functions of the tool. Based on the results, we developed two sub-tools as previously mentioned. Then, to confirm the functionality and the usability of the tool, experimental use was observed. To verify the usability of the tool, a hearing survey was administered to local government staff.

1.3 Related studies

Very few previous studies have used the evaluation method to explore mutual assistance for disaster mitigation. Akiyama et al. (2013) suggested the evaluation method to quantitatively estimate mutual assistance as the initial response ability during huge earthquake disasters. However, the estimate value transfers mesh data to analyze disasters at a large scale such as at the urban scale. In other words, there is no method to evaluate the capability of mutual assistance by neighborhood communities for community-based activities. Another related study approach is model development, which simulates human behaviors such as evacuation responses to natural disasters. One of the most popular methods is utilizing an MAS. For example, D'Orazio et al. (2014) proposed an innovative approach to earthquake evacuation, presenting an agent-based model to describe phases and rules of motion for pedestrians. Wagner and Agrawal (2014) presented a prototype of a computer simulation and decision support system that uses agent-based modeling to simulate crowd evacuation in the presence of a fire disaster, and provides testing of multiple disaster scenarios at virtually no cost.

Our previous study (Karashima et al., 2015) attempted to develop a simulator of evacuation activities considering mutual assistance under various earthquake disasters to support the exploration of the contents of community-based activities. However, the examination of using method and the required functions of the tool were not sufficient. In addition, there is no evaluation of the tool from experts. The current study therefore attempts to conduct these methods of analysis.

2. EXAMINATION OF CONFIGURATION OF THE TOOL

2.1 Examination of the required tool

To evaluate the capability of mutual assistance, the evaluation method considering the situational aspects such as scale, purpose, and users should be examined. First, extracting the area with low capability is necessary. Then, to promote the capability, exploring the contents of community-based activities considering mutual assistance is required. Therefore, this tool consists of two sub-tools according to the previously described examination: 1) a GIS-based tool for evaluating the capability of mutual assistance to extract the area showing low capability (GIS tool) and 2) an MAS-based evacuation simulator that explores community-based activities in relation to mutual assistance and illustrates the usability of the mutual assistance activities (MAS tool) (see Figure 1).

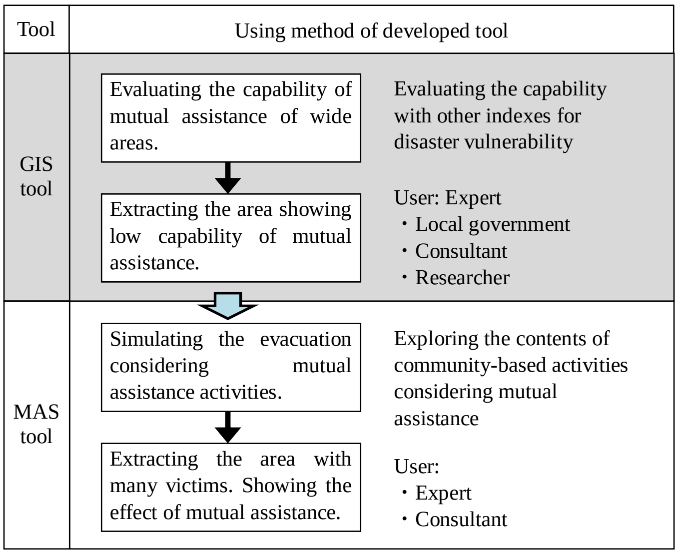

Figure 1. The process of evaluation of mutual assistance

Initially, experts such as individuals in local government, consultant staff, and researchers evaluate the capability of mutual assistance at the wide-range municipal level. Using this sub-tool, local government could extract the area showing low capability. Then, local government should promote the capability of the extracted area and should facilitate community-based activities to promote the capability. In addition, using this sub-tool, users could explore community-based activities considering mutual assistance and visualize the usability of mutual assistance activities.

2.2 Examination of the function

Comparing the previously described examination and previous studies, the required function of the tool was examined (see Table 1). Regarding the GIS tool, users could not evaluate the capability of mutual assistance considering structures that residents cannot across, such as railway tracks and rivers. In addition, the GIS tool was evaluated manually. Therefore, evaluating wide areas and extracting areas of low capability proved difficult.

Regarding the MAS tool, residents' perception range of locating individuals who could not evacuate was fixed. Therefore, the area characteristics such as vertical interval and low visibility caused by weather (cloudy, rainy) and hours (daytime or nighttime) could not be considered. To solve these issues, two sub-tools were developed.

Table 1. Issues of our previous study and current study measures

Purpose	Item	Measures
Promotion of usability	Setting detailed spatial situation	Considering structures that cannot be crossed by residents during evacuation.
	Manipulability	Calculating the capability of mutual assistance in the morning, noon, and night simultaneously.
Promotion of reality	Road blockage	Applying road width.
	Changing evacuation situation by time of day, climate, etc.	Adding a function to change perception range.
		Adding a function to change evacuation speed.
	Construction of roadways	Applying pathways from buildings to front roads.

3. GIS TOOL

3.1 Evaluation method

The evaluation method for the current study is the same as used for the previous study. We utilized the evaluation method suggested by Akiyama et al. (2013). First, the expected value for rescue of each person was calculated by referring to Table 1. The expected value for rescue is the numerical value showing the ability to rescue the victims (e.g., pulling a survivor from the wreckage) in accordance with gender, age, and strength. This table was organized based on the actual rescue activities conducted during the Great Hanshin-Awaji Earthquake in 1995 in Japan. For example, the expected value of a 40-year-old man is calculated by the following formula:

strength (0.93) * executing rate (0.298) * activity rate (0.72) = 0.1995

The strength value is calculated in accordance with age and gender on the basis of the strength value of a man in his teens through his twenties set at one. The value of executing rate is set in accordance with the condition of actual rescue activities conducted during the Great Hanshin-Awaji Earthquake. The activity rate value is the ratio of residents who can perform rescue activities considering the degree of daily activities.

The expected value Rrj of building j is calculated as the total of residents' expected value at building j. However, in this paper, elementary school students and junior high school students have no capability for rescue. Second, the expected value is weighted by distance based on the assumption that residents take some time to discover or recognize those persons who cannot evacuate without some assistance in accordance with the distance.

Therefore, the range limit in which residents can discover a person who cannot evacuate the building *i* is set at 100m. The resident's expected value is decreased with the increase of distance from building *i*. The weighted value *dwi* of building *j*, having *dj* [m] distance from building *i*, is calculated by formula (1). The evaluation unit of the mutual assistance capability is the building unit, based on the assumption that it is easy for residents to understand the capability.

$$dw_j = \frac{\log(1+X)+1}{2(\log(1+d_j)+1)} \quad (0 \geq j \geq X) \quad (1)$$

$$\text{The capavility of mutual assistance} = \frac{\Sigma Rrj \times dwj}{5} \quad (2)$$

Table 2. The expected value in accordance with age and gender

Age	**Men's strength**	**Women's strength**	**Executing rate**	**Men's activity rate**	**Women's activity rate**	**Men's expected value**	**Women's expected value**
10	1	0.85	0.228	0.76	0.24	0.1733	0.0465
20	1	0.76	0.228	0.76	0.24	0.1733	0.0416
30	0.96	0.76	0.229	0.72	0.28	0.1583	0.0487
40	0.93	0.73	0.298	0.72	0.28	0.1995	0.0609
50	0.9	0.72	0.228	0.63	0.37	0.1293	0.0607
60	0.84	0.7	0.191	0.74	0.26	0.1187	0.0348
70-	0.78	0.65	0.129	0.75	0.25	0.0755	0.021

3.2 Using method

The capability is calculated automatically. Users first set the calculating range, and then set the structure such as railway tracks and rivers. After executing the calculation, the capability of mutual assistance is shown by building unit (see Figure 2).

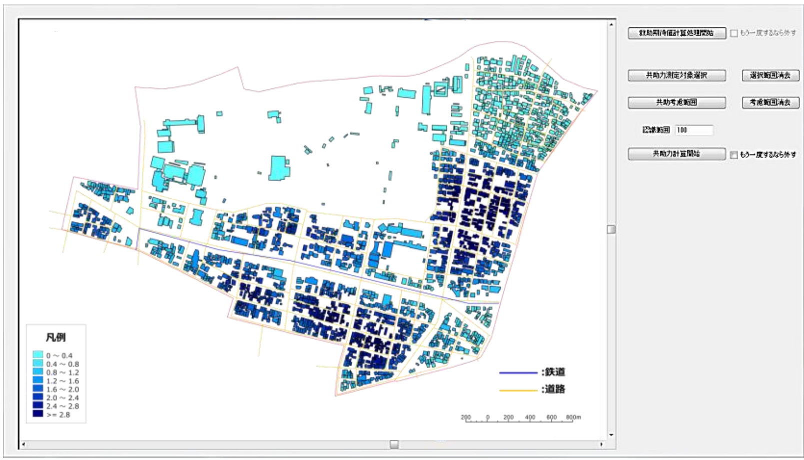

Figure 2. The GIS tool interface

4. MAS TOOL

4.1 Agent

The model was set to simulate a huge earthquake (intensity 6 upper). Collapsing buildings, road blockages, and fire spreads were generated. Under the situation, residents evacuated to the designated evacuation site. Therefore, the following agents as the components of a simplified virtual urban area were present: building agents, resident agents, point agents, link agents (see Figure 3).

Building agents have certain attributes such as structure, floor number, and built year. Resident agents are made up of attributes such as age and gender. Finally, point agents are set at each building agent, and resident agents are generated based on point agents.

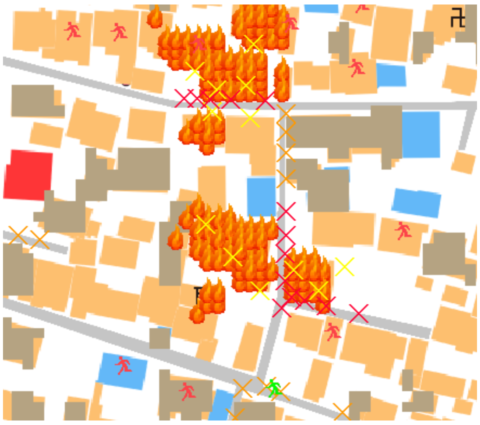

Figure 3. Example of the MAS tool

4.2 Structure of simulator

The developed simulator includes a road blockage model, fire spread model, and evacuation simulator. These were united in the structure of the previous simulator. For this simulator, users could not fix the situation of road blockages and fire spread. This means that each simulation result has different conditions, and it proved difficult for users to understand the effect of mutual assistance activities. To enable the simulations' fixed situations of road blockages and fire spread, a road blockage model and fire spread model were divided from the evacuation simulator. The simulator including both models was calculated before the evacuation simulator, and the results were then analyzed.

4.2.1 Road blockage model

The road blockage model utilized in the current study is nearly the same as that used in our previous study. The model proposed by Gohnai et al. (2007) was incorporated in the current study. After setting the probability of building collapse for each building based on structure, floor number, and year of construction, collapsed buildings were generated by using random numbers. When the rubble was spread on a road with a width under 0.6m, resident agents could not pass through the road. However, in our previous study, it was difficult to handle numerical values less than the cell size. In fact, the road measuring under 3m was recognized as 3m. In this study, the road width data was applied and the road blocked by rubble was judged by the outflow width (road width over -0.6m).

4.2.2 Fire spread model

The fire spread model is the same as that used in our previous study. The model proposed by Ohgai et al. (2007) was incorporated as the fire spread model. Fire origins were set by using random numbers. Users could set the wind velocity and wind direction. According to the condition, a fire spread simulation was conducted.

4.3 Behavior of agent

Each resident agent is defined as one person. Resident agents evacuated to the designated evacuation site with their families due to the fact that in reality, residents will not evacuate without his/her family. The resident agents performed the following six actions.

1) Evacuation: Each resident agent evacuated from each building to the designated evacuation site. In this model, high-class children above elementary school age (10 and older) could evacuate alone. Children less than 10 years old evacuated with his/her parent.
2) Waiting rescue: The resident agent who was buried under a collapsed building would wait for help. The resident agent who was in a burning building had no support from other resident agents because in the real world, it is difficult for residents to rescue someone who delays escape from a fire.
3) Rescue victims: When resident agents discovered a victim in need of help within the perception range (the range that residents can find a person who requires mutual assistance) during evacuation, he/she took part in the rescue activity. However, resident agents with children less than 10 years of age were_given priority in evacuation. When the total expected value of resident

agents participating in rescue activities exceeded 1, they could rescue a victim. When the total expected value was not greater than 1 after a lapse of 5 minutes from earthquake generation, the resident agent gave up rescue and restarted evacuation.
4) Those in need of evacuation support: The residents who cannot evacuate individually such as elderly people and disabled people wait for other resident's help.
5) Those supporting evacuation: When resident agents discovered a resident in need of evacuation support within the perception range of the evacuation site, he/she provided evacuation support. However, resident agents with children less than 10 years of age were given priority.
6) Awaiting public support: In the following three situations, resident agents could evacuate, even when performing mutual assistance activities. Therefore, when residents are in the following situations, they should wait on support from public institutions such as the local fire or rescue teams: 1) A resident agent in a burning building; 2) A resident agent who cannot be rescued by another in situations where the total expected value is not greater than 1; 3) A resident agent who cannot reach the designated evacuation site due to road blockage.

This simulator does not perform the initial firefighting during evacuation. In our previous study, all residents started evacuation together according to the specified evacuation start time. However, it is unlikely that residents will start evacuation all at once in reality. Therefore, in this study, residents do not start evacuation all at once; rather, they initiate evacuation at random.

4.4 Simulation flow

Figure 4 shows the simulation flow. First, the virtual space is constructed and resident agents are generated. Then, the result of the other simulator incorporating the road blockage mode and the fire spread model is read and expressed on the virtual space in each step. The resident agents then examine and judge the action considering his/her situation. The residents who judged evacuation go to the nearest evacuation site. While on their way to evacuation, if they notice a person who needs assistance, they try to rescue and support evacuation. The residents who judged waiting for rescue or support for evacuation stay the building. After receiving rescue or support from other residents, they may then evacuate.

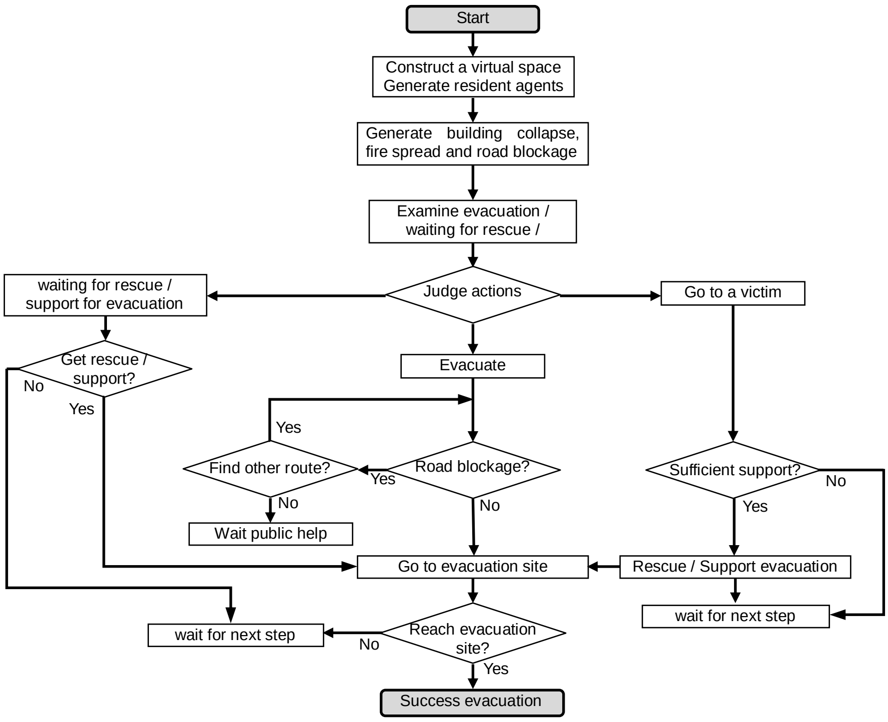

Figure 4. The flow of the MAS tool

4.5 Interface

Figure 5 shows the interface of the simulator. Using the interface, users can set the following parameters.

1) Evacuation start time: The time from earthquake generation to starting evacuation.
2) Perception range: The range of residents' capability to discover individuals who require mutual assistance.
3) Evacuation speed: The walking speed of resident in evacuation.
4) Ratio of resident agents who require evacuation assistance: The ratio of resident agents who require some evacuation assistance for each age group.
5) Mutual assistance setting for children aged 10 to 15: Whether or not the setting item performs the mutual assistance for children aged 10 to 15 years.
6) Road blockage setting: Item to be set to select whether the road is closed by an earthquake or fire.

For example, by changing parameters 1, 2, and 3 at the same time, the situation being considered can be changed according to factors such as weather changes and time of day.

Figure 5. The control pane of the MAS tool

5. EXPERIMENTAL USE

5.1 Outline

To verify the usability for exploring the contents of community-based activities, experimental use was conducted. The target district in Toyohashi City shows particular vulnerability to earthquake disasters. Therefore, the following two scenarios were set: 1) The presence or absence of mutual assistance activities during evacuation; 2) The capability of mutual assistance was changed according to the time of day caused by the commuting population. The cases in the morning and early evening were calculated, and the calculations reflecting the above scenarios were carried out ten times. The base parameters are illustrated in Table 5.

Table 5. Base parameters

Presence or absence of mutual assistance	1) With mutual assistance	2) Without mutual assistance	3) With mutual assistance
Change in time	morning	same	night
Wind speed [6]	5m/s	same	same
Wind direction [6]	northwest	same	same
Evacuation speed [7]	1.5m/s	same	1.0m/s
Perception range [1]	15m（5cells）	0m（0cell）	9m（3cells）
Ratio of residents who could not evacuate	60-69：0.1 70 & over：0.2 other：0.05	same	same
Road obstruction by rubble	yes	same	same
Road obstruction by fire	no	same	same
Agent can be out of the building at the time of the fire	no	same	same

5.2 Analysis of the results

The numerical value of simulation results reflected in scenario 1 is shown in Table 6. Focusing on the ratio of helped persons by mutual assistance, about 13% of those who require rescue and support from others were identified by comparing the presence or absence of mutual assistance. Users can easily understand the effect of mutual assistance during evacuation to residents. Understanding the importance of mutual assistance should be promoted.

The numerical value of simulation results reflected in scenario 2 is shown in Table 6. Users can change the perception range: in the morning, residents have a wide perception range compared to early evening. In this experimental use, the perception range in the morning was set at 15m, and the range in the early evening was set at 9m. In addition, the constitution of household members was changed: in the morning hours, all household members are in their respective buildings. The total population of 398 is the same as the actual total population.

In the early evening hours, almost all residents in the virtual space were stay-at-home wives, elderly persons, and students. The total population was assumed as 301 persons. Comparing the ratio of helped persons by mutual assistance of morning and evening, the value in the morning is higher than that of the evening. In this way, the capability of mutual assistance activities by neighborhood was changed in accordance with the timeframe. Users can thus understand the need for countermeasures such as the promotion of mutual assistance activities for timeframes when the capability is low.

Through displaying the results in map form, users can easily comprehend the number of persons who were helped by other residents. In addition, users can perceive the number of helped persons and the places where residents cannot receive rescue or support.

Table 6. The numerical value of simulation result

Case	Number of residents	Total number of successful evacuations	Evacuation success rate (%)	Number of people requiring mutual assistance	Total people receiving mutual assistance	Mutual assistance success rate (%)
1)	398	2915	73.24	1083	147	13.57
2)	398	2790	70.10	1107	0	0.00
3)	301	2172	72.16	801	43	5.37

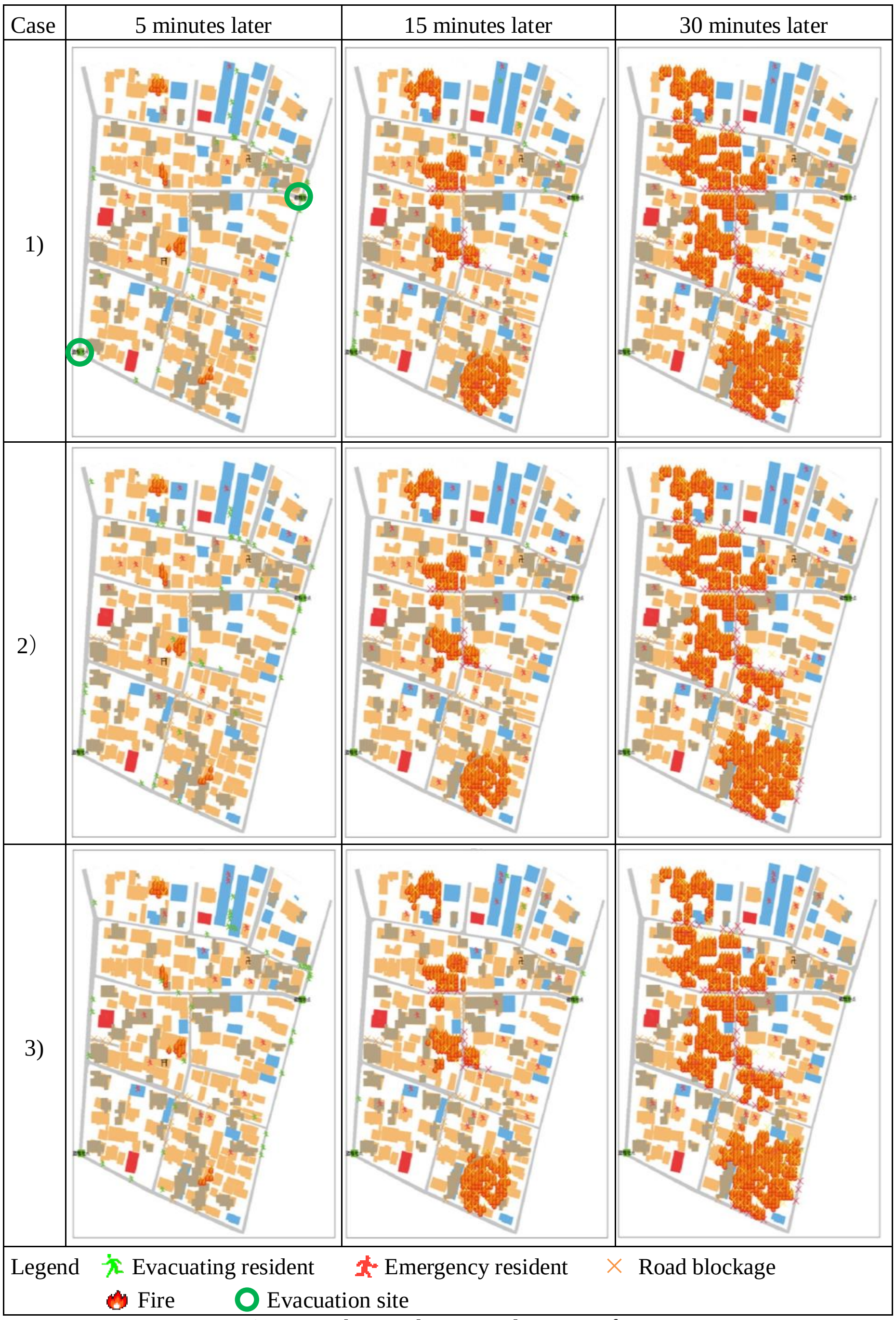

Figure 6. The simulation results in map form

6. EVALUATION

6.1 Outline of hearing-based survey

To verify the usability and issues of the developed tool, a hearing-based survey was administered to local government staff. An overview of the hearing-based survey is presented (see Table 7). By explaining the usage as previously mentioned in detail, an understanding of the evaluation method of the capability of mutual assistance, as well as the outline, function, and usability regarding the developed tool was promoted among participants. The comments from participants were then obtained (see Table 8).

Regarding the GIS sub-tool, the following usability characteristics were obtained.

Table 7. The process of evaluation of mutual assistance

Date	January 18, 2016
Participants	Disaster mitigation division staffs of Toyohashi City
	Urban planning division staffs of Toyokawa City
Items	・Usability of the developed tool
	・Issues of the tool
	・Necessary functions

Table 8. The process of evaluation of mutual assistance

Evaluation	Comments
Usability	GIS sub-tool
	・ Calculating wide range was sufficient. Extracting the area with low capability was simplified.
	・ This tool can display factories and offices where many people work (showing high mutual assistance).
	・ The capability of mutual assistance is visually shown. It is easy for residents to understand the areas showing low capability.
	MAS sub-tool
	・ The capability of mutual assistance is visually shown. It is easy for residents to understand the effect of mutual assistance.
	・ This tool can simulate a reflection of opinions obtained by exploring the contents of community-based activities.
	・ Understanding the importance of mutual assistance may be promoted.
Issues	・ When explaining the results of the tool to residents, clearer explanations will be required.
	・ Data collection is difficult.

・ Extracting the area showing low capability was simplified by calculating wide range.
・ The capability of mutual assistance is visually shown. It is easy for residents to understand the area showing low capability.

Regarding the MAS sub-tool, the following usability characteristics were obtained.
・ The capability of mutual assistance is visually shown. It is easy for residents to understand the effect of mutual assistance. Therefore, understanding the importance of mutual assistance should be promoted.
・ This tool can simulate a reflection of opinions obtained by exploring the contents of community-based activities.

In particular, evaluating the capability of mutual assistance and showing the effect of mutual assistance seem to be the strengths of this tool. This tool offers the opportunity for residents to explore the contents of community-based activities. However, the difficulty of data collection was identified. Our evaluation method of the capability of mutual assistance requires detailed personal data such as age, gender, and household members. Thus, it is necessary to understand the characteristics of residents in order to perform the simulation of real areas in the future.

7. CONCLUSION

This study developed two sub-tools based on our previous study to support the examination of community-based activities considering mutual assistance. The first is a GIS-based tool utilized to evaluate the capability of mutual assistance. The second sub-tool is an MAS-based tool used to simulate evacuation behaviors.

Using the GIS-based tool, evaluating the capability of mutual assistance for wide areas and extracting the areas showing low capability was simplified. To promote capability accuracy, structures that residents cannot cross during a disaster such as railway tracks and rivers were considered. Further, by utilizing the MAS-based tool, it is easy for residents to understand the effect of mutual assistance. In this way, understanding the importance of mutual assistance is promoted. Users can explore the contents of community-based activities using simulation results assuming various situations. In particular, using certain functions to change the perception range and evacuate speed is especially useful.

The usability of this tool was objectively proved. Obtaining evaluations and comments of the developed tool from experts is very important. Future works related to the topic of this study are important. Further, promoting the accurate portrayal of the capability of mutual assistance and revalidation are required for the proper use of this tool. In addition, the collection method of detailed data should be examined in the future.

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Analysis of Use Characteristic Change with Parking Fee Change by Utilizing Accounting Data

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Key words: Parking accounting data, Cluster, Big data-analysis, Parking management

Abstract: The accumulated parking accounting data is expected to utilize actively for setting an appropriate parking fee structure in accordance with characteristics of parking utilization. This research shows typical usage patterns of parking lot by using the accounting data. As our findings, a transition of cluster can understand as a change of parking usage pattern. The characteristics of parking usage is changed significantly by improvement of parking fee structure and also affects revenue.

1. INTRODUCTION

Due to advancements in information technology, big data analysis in transportation management field is expected to implement more efficient measures. For example, vehicles' counting data obtained from road sensors and location data from probe vehicles that can be analysed to mitigate traffic congestion. However, there is still room to analyse as utilizing POS (point-of-sales) data in supermarkets in marketing research field.

Accounting data of parking lots are also a big data in transportation field. Useful information such as parking demand forecasting and parking management policies should be derived.

Since parking on a street is generally prohibited in Japan, there are many parking management companies to be controlling their parking lots and facilities. They are often located within the vicinity of commercial sites or vacant lots. Online parking accounting systems have been installed in most of the parking lots to reduce the management cost, it is possible to open in 24-hour unmanned. In Japan, users can pay his/her parking fee by cash or coupons, as well as credit cards or public transportation IC cards.

Parking fee should be set based on characteristics of parking usage, like the demand on specific times of the day. Parking fee should also be customized to serve the specific needs of the users. Doing so, user convenience, improvement of parking service and increase revenue may be achieved.

Many studies have investigated parking price management. Asano et al. (2007) proposed the variability fee system by simulating the data in the parking lot of the prefectural hospital. Gillen (1978) built a parking choice model, and analysed the price sensitivity of own price, time price and total price.

In this study, we focus on the park utilization rate which calculate from accounting data, and find use characteristic change with cluster analysis. Moreover, we discuss an effect of improving the parking fee and propose a method to find a change of usage pattern to grasp how decision makers can decide the parking fee

2. PARKING DATA

The parking account data in this study is provided from Meitetsu Kyosho Co., Ltd. This company operates over 1,000 parking lots in the Nagoya metropolitan area and the total number of parking accounting data is approximately 40 million from August 1st, 2012 to July 31st, 2014. *Table 1* shows an overview of data used. Parking accounting data include enter and exit time which are recorded for each minute.

Parking lot data include parking code, location data, capacity, parking fee structure. In conjunction with the fee structure data, individual parking data is also used. The past of fee structure changes has also been recorded.

Table1. Parking Data

Parking accounting data	Parking code, Enter and exit time, Total fee, Length of parking, Payment method
Parking lot data	Parking code, Capacity, Latitude and Longitude, Parking fee per unit time and maximum charge

3. BASIC ANALYSIS OF PARKING ACCOUNTING DATA

The locational information of the parking lots which were subject analysis are shown in *Figure 1*.

Generally in Japan, parking management companies set two type of parking fee: one is a time unit charge, the other is a maximum charge which is a discount for a long-parking time users. From *Figure 2*, 92 % of parking lots in this company is set the maximum charge.

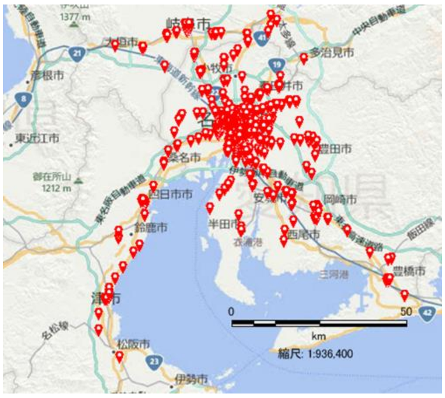

Figure 1. Distribution of Parking Lot

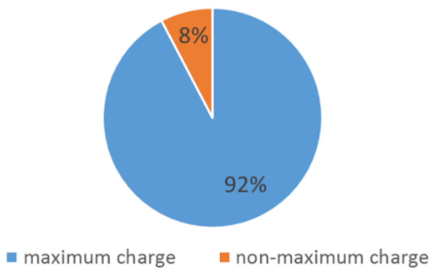

Figure 2. Share of setting Maximum charge

Figure 3 shows a parking time distribution in all subject parking lots. Most of users parked for less than one hour, and demand for longer time parking is relatively small. The second small peak around 600 minutes is due to setting the maximum charge for long-time user, which is an upper limited fee within one day.

Figure 4 shows hourly average of parking utilization rate on the day of the week. Parking rates are high during daytime (6:00- 18:00) and low during night time (18:00-6:00). In addition, the parking rates during Friday and Saturday nights (i.e. on weekend) are higher than that of the other nights on weekdays.

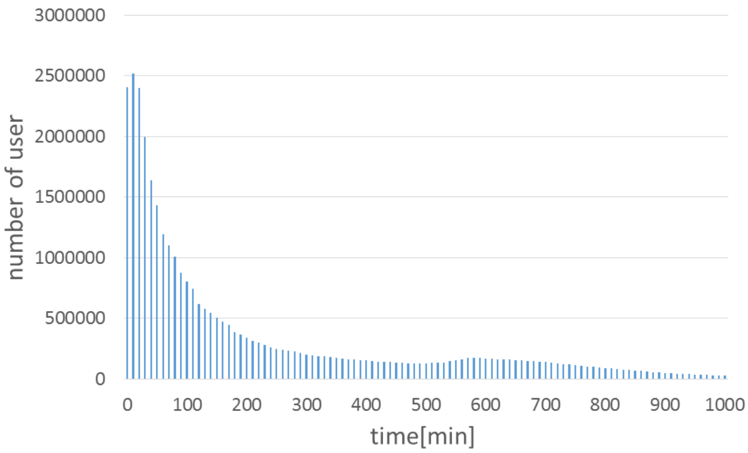

Figure 3. Parking Time Distribution in All Parking Lots

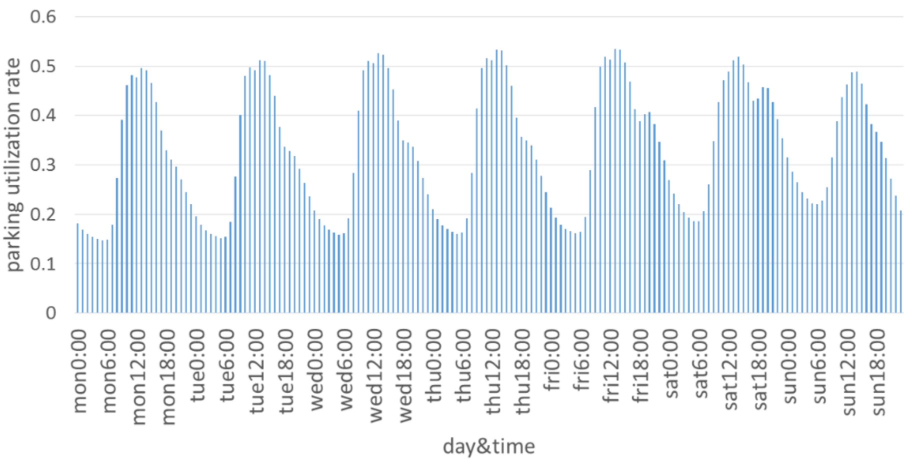

Figure 4. Hourly Parking Rate in All Parking Lots

4. ANALYSIS OF A CHANGE CHARACTERISTIC OF USE WITH THE PARKING FEE CHANGE

In this chapter, we considered the parking utilization rate as a characteristic of parking utilization. Firstly, the hourly parking utilization rate of each parking lot were calculated. Then cluster analysis was done by using 24 hours utilization rate patterns in order to understand the parking characteristics easily.

4.1 Definition of utilization rate

Parking rate is adopted as an index to grasp a usage characteristic of parking lot in this study. The parking rate is defined as the share of the car for the parking capacity, per unit time. *Figure 5* shows several cases how to calculate parking rate. If a user parked his car from 11:00 to 12:30, it will be considered to have occupied one parking space from 11:00 to 12:00, and be considered to have occupied 0.5 parking space from 12:00 to 13:00. If a user parked from 12:20 to 13:15, it will be considered to have occupied 0.66 (=20/60) parking space from 12:00 to 13:00, be considered to have occupied 0.25 (=15/60) parking space from 13:00 to 14:00.

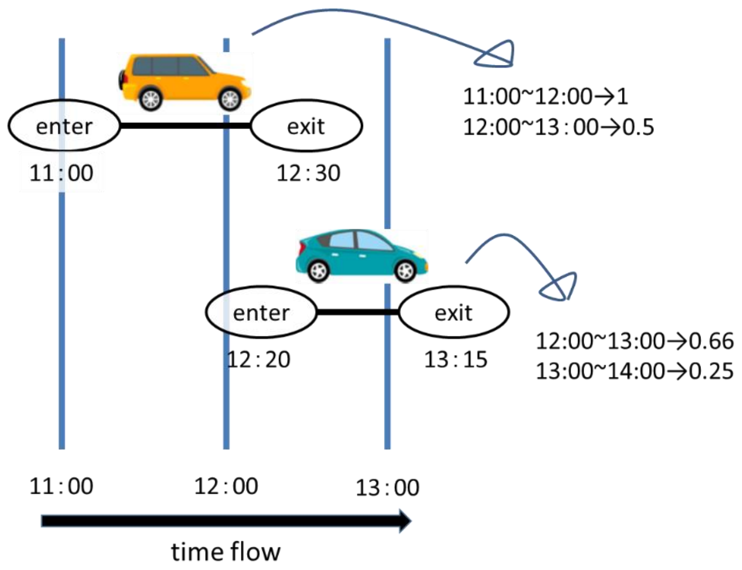

Figure 5. Definition of Parking Utilization Rate

4.2 k-means Method

Cluster analysis divide data into k by using means of the cluster k unit. K-means method is explained referred to the Text Book (Sato, 2009).

The k-means method passes through the following trips.

① As an initial condition, we give the center point of the cluster of the k unit at random.

② We calculate the center point of the cluster and the distance (often use Euclid distance) with target data and assign it to the nearest cluster.

③ We set a convergence condition and repeat a change of the center point of the cluster until it converges.

Various algorithm has been suggested for the k-means method. This study utilized Hartigan and Wong (1979) methodology and statistics were processed using R software.

4.3 Results of Cluster Analysis

Cluster analysis is introduced to understand a change of parking usage pattern in this study. Firstly, an hourly parking rate for each parking lot can be calculated as mention in 4.1, and the total number of hourly utilization rate is 17520 (= 2 years * 365 days * 24 hours). It is difficult to understand the change of hourly parking rate directly, thus we set hourly patterns within day for input data of cluster analysis. Since we prepare time-series data of hourly parking rate for each parking lot for two years, the total number of input data of cluster analysis is 759,200 (= 2 years * 365 days * 1,040 parking lots).

As a result of cluster analysis, the daily parking patterns of 1,040 parking lots for two years were classified into five clusters. We labelled from cluster one to five from the lowest of daytime parking rate. *Figure 6* shows the average of hourly utilization rate in each cluster. Cluster 1 has the lowest utilization rate in the whole day. In the cluster 2, the utilization rate in nighttime is higher than that in the daytime. Its peak time is 9 p.m. and 10 p.m. In the cluster 3 and 5, their daytime parking rate is higher than the nighttime. Total utilization rate of cluster 5 is higher than cluster 3, i.e., the hourly changes of utilization rate of cluster 5 is higher. The hourly utilization rate of cluster 4 is about 50%, and the change between daytime and nighttime is small.

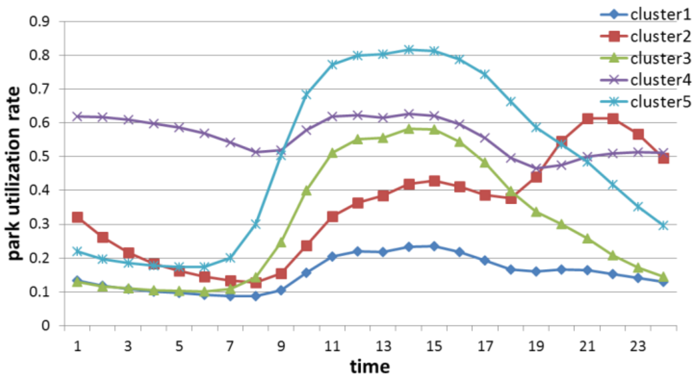

Figure 6. Average of Hourly Park Utilization Rate in Each Cluster

4.4 Use Characteristic Change with Parking Fee Structure Change

We compared a parking fee revision with the results of the cluster analysis, and analysed its effects.

In *Figure 7*, the daily change of the utilization rate of one parking lot is demonstrated. For first 80 days, this parking lot is classified as cluster 1 which means its park utilization rate is very small. *Table 2* shows that the parking fee structure was changed from 200 yen per hour to 100 yen per hour, and a maximum charge for 24 hours was also changed from 600 yen to 400 yen after the 72nd day. After the improvement of parking fee structure, the utilization rate gradually rose, and cluster label was also transitioned to cluster 3 and cluster 5. It is easy to understand an effects of change of parking fee structure by our proposed method. Moreover, *Figure 8* shows the daily parking revenue around the improvement of parking fee structure. The green line in the figure represents the improvement day. From this figure, daily parking revenue of this parking lot was also gradually increased after the improvement. Therefore this improvement of parking fee structure is succeeded.

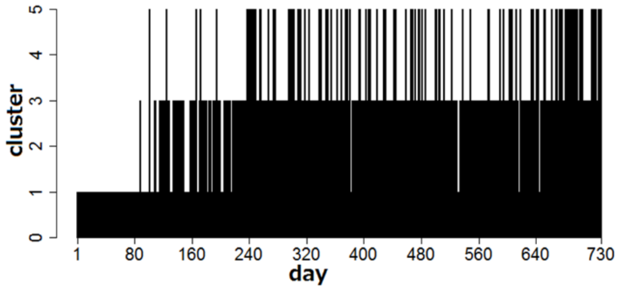

Figure 7. Daily Change of Cluster No. of Park Utilization Rate

Table 2. Fee Structure Change

0:00～24:00 ¥200 per hour Maximum charge ¥600 within 24 hours	72nd day →	0:00～24:00 ¥100 per hour Maximum charge ¥500 within 24 hours

Figure 8. Daily Change of Revenue

On the other hand, there are several examples of failure of fee change. From here, we show the example of the parking lot which a utilization rate decrease by a parking fee structure change. In *Figure 9*, the daily change of the utilization rate of one parking lot is demonstrated. For first 480 days, the utilization rate of this parking lot was high because cluster 5 or cluster 3 were labelled. *Table 3* shows that parking fee structure was changed from 100 yen per hour to 100 yen per hour from 15:00 to 7:00, and 100 yen per 10 minutes from 7:00 to 15:00 after the 479th day. *Figure 9* shows the utilization rate decrease after the raise of parking fee, and cluster label was also transitioned to cluster 3, cluster 2 and cluster 1.

Figure 10 is a graph which shows the daily parking revenue before and after fee change. The revenue just after improvement of parking fee was as same level as before, but the revenue decreases as time passed. The reason include that regularly users continued to use for some days and average fee per customer increased. This case is also easy to find the effect of fee structure change by our proposed method. We understand there are another reason for decreasing this park utilization rate (e.g. a new parking lot is opened near this parking lot or a competitor improve its strategy, and so on.)

Therefore, it is important to evaluate every improvement of parking fee structure, and to store the objective results. However, it is difficult to analyse with the data collected by only one management company, because several competition companies manage their parks in same area.

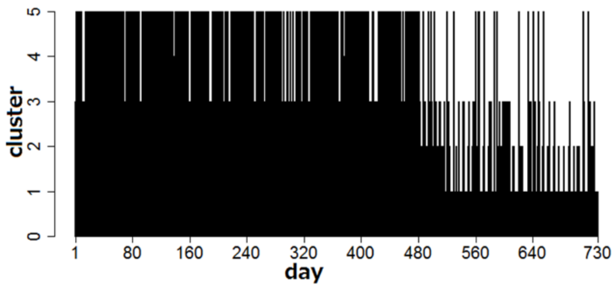

Figure 9. Daily Change of Cluster No. of Park Utilization Rate

Table 3. Fee Structure Change

0:00～24:00 ¥100 per hour Non-maximum charge	479th day →	15:00～7:00 ¥100 per hour 7:00～15:00 ¥100 per 10 min Non-maximum charge

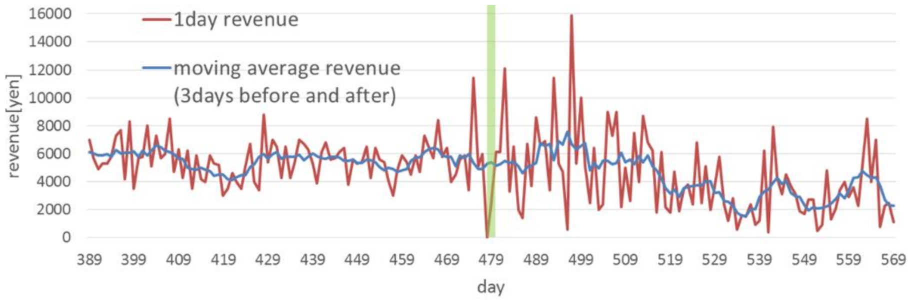

Figure 10. Daily Change of Revenue

5. CONCLUSIONS AND FUTURE WORK

In this study, a large amount of parking accounting data is analysed to evaluate an effects of the improvement of parking fee structure. We conducted clustering analysis to understand the change of characteristics of parking utilization, and confirmed that our approach may reveal the effects of improvement of parking fee. Parking utilization rates are influenced by fee revision, such that changes in parking fee may increase or decrease the revenue of parking lots.

As future work, we should analyse the sensitivity of how much revision should be done to gain more revenue. Also we try to analyse and identify other factors that might cause increase or decrease in parking revenue, such as distance from a main street, and presence of trip attractors like a commercial complex. In addition, we should develop a model considering the users' parking behaviours (e.g., parking lot choice and parking duration and so on).

ACKNOWLEDGMENT

The authors sincerely acknowledged Meitetsu Kyosho Co., Ltd. for providing the parking data used in this study.

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Periodicity analysis of charging behavior of electric car drivers: Latent class hazard models

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Key words: Hazard-based duration model, Inter-charging time, Latent segmentation

Abstract: The importance of public charging infrastructure has been recognised recently as it represents a key factor in the promotion of plug-in electric vehicles (PEV). Given that a large initial investment from the public sector is essential for its widespread adoption, many studies have focused on the issue how the charging infrastructure should be planned and located. Although it is of critical importance to understand PEV users' charging behavior for improving public charging infrastructure, relatively few number of PEVs makes it difficult to analyze charging behavior of large sample of PEV users. This study uses a Dutch four-year comprehensive charging transaction dataset. Given that electric vehicle users likely exhibit heterogeneous charging behavior in terms of both charging frequency (time interval between successive charging events) and charging regularity (regular charging versus ad-hoc charging), this study applies a heterogeneous hazard-based duration model to examine how often PEV users charge their car at public charging stations and to distinguish the difference characteristics of random (erratic) users and regular (routine) users. The results show that 67 per cent of PEV users charge their car at irregular intervals, while 33 per cent charge regularly. It is also shown that regular users charge their PEV more often and are more likely to have a battery electric vehicle (BEV) compared to random users. Moreover, clear differences exist between the two groups in terms of vehicle and charging characteristics.

1. INTRODUCTION

Several governments have stimulated marketing campaigns and offered tax cuts to encourage people to adopt electric vehicles (EV) as an efficient and sustainable alternative to the internal combustion engine vehicle (ICEV). Although the absolute market size for electric vehicle is still insignificant and consumer purchasing behavior seems to stagnate until further improvement in technology and more competitive prices have become a reality (e.g., Rasouli and Timmermans, 2016), the market penetration of plug-in electric vehicle (PEV) raises issues about the availability of public charging infrastructure and its performance. Adequate availability of charging stations seems a sine qua non for the further acceptance and market penetration of electric cars.

The situation in the Netherlands can serve as an example. Tax reduction measures resulted in the selling of an increasing number of electric cars. Political parties have expressed the target of a substantially larger market share of electric cars by 2020. The Netherlands has been one of the leading countries with respect to the number of public charging stations (Appels, 2012). However, the absence of charging infrastructure and the restricted driving range of EVs are still major barriers to large adoption (Franke and Krems, 2013a). Consumers may hesitate buying an EV if not enough charging stations are readily available, whereas charging infrastructure providers are not willing to build new charging stations until there is a sufficient large developed EV market. This problem has been characterized in terms of the so-called chicken-and-egg allegory (Kitamura and Sperling, 1987; Nicholas et al., 2004; Kang and Recker, 2014).

To solve this problem, the commonly made assumption in EV charging station location-allocation analysis is that activity-travel patterns of EV users will not change when they switch from ICEV to EV. For example, Chen et al. (2013) optimized the location of charging stations based on the assumption that conventional gasoline vehicle parking demand is a strong proxy for EV charging demands. Similarly, Dong et al. (2014) used longitudinal GPS travel data collected from conventional gasoline vehicles to solve electric vehicle charger location problems in the greater Seattle metropolitan area. More recently, Shahraki et al. (2015) used the GPS trajectories of taxis to capture public charging demand, and located the public charging stations by maximizing the amount of vehicle-miles-traveled (VMT) being electrified. However, it has been shown that driving patterns of EV users are clearly different from those of ICEV users. The main reasons for this difference relate to limited range (Franke and Krems, 2013b), absence of charging infrastructure (Speidel and Bräunl, 2014), and refueling patterns (Kuby et al., 2013). Moreover, EV owners are not homogeneous, but rather differ in terms of their usage pattern of charging stations (Frank and Krems, 2013b). Since charging an electric vehicle generally takes longer than refueling a gasoline vehicle, even with fast charging, users may adapt their charging decision based on the various constraints they face, such as their daily activity schedule and battery size.

Charging station location studies have also been based on the assumption is that EV users maximize their utility by charging their EV as much as possible. Frank and Krems (2013c), however, found the presence of individual differences in charging behavior in terms of the utilization of limited energy resources. For example, some drivers (e.g., risk-takers) charge in an opportunistic way, while others (e.g., risk-avoiders) have a planned charging scheme with a preferred charging station at a relatively fixed interval. Thus, examining the usage pattern of public charging stations will give useful insights into how EV users cope with the space-time constraints, set by their daily activity schedule and the state of the battery.

Further empirical studies are therefore warranted to enhance our understanding of charging behavior in the context of daily activity-travel patterns to enhance our modeling efforts and improve the solutions offered to entice people to purchase more environmentally-friendly vehicles. Unfortunately, limited market penetration of EV makes it hard to observe real-world charging behavior (Zoepf et al., 2013). Although various attempts have been made in the past few years to examine the mobility pattern of EV drivers, as well as their charging behavior, most existing knowledge about charging behavior is based on a (very) small samples (Khan and Kockelman, 2012). Franke and Krems (2013b), for example, investigated the charging patterns of 79 drivers in a 6-month EV trial in Berlin and identified the underlying psychological factors related to the battery state. Speidel and Braunl (2014) examined the charging behavior of 11 vehicles and the usage patterns of 23 charging stations based on a 3 year Western Australian Electric Vehicle Trial. In the Victorian EV Trial, Khoo et al. (2014) conducted statistical analysis of the empirical relationships between vehicle/participant types and attributes of the charging events including charge duration, daily charging frequency, energy consumed, start charging hour, and time to next charging event. More recently, The Japan Automobile Research Institute (JARI) collected the probe data from a larger sample of 483 BEVs over two years from 2011 to 2013 (Sun et al., 2015). The probe installed in the vehicle provides rich information about charging behavior as well as vehicle information such as vehicle trajectory and state of charge (SOC). However, based on this data set it is hard to grasp the full picture of the usage of public charging infrastructure because the probes are only installed in BEVs. Additional research is therefore required. Still little is known about how often EV users charge their cars at public charging stations, how many of them charge randomly or regularly, and which charging-related and vehicle characteristics motivate them to behave differently.

The aim of the study is to reduce this gap in our knowledge. Given that EV users exhibit heterogeneous charging behavior in terms of charging frequency and charging regularity (regular charging versus random charging), we applied a parametric hazard model of inter-charging times to examine the regularity and frequency of charging events at public charging stations. This study takes an in-depth look at the EV users' inter-charging times to understand their charging patterns using four-year longitudinal charging transaction data. Our empirical results enable us to segment EV users into two groups in terms of charging regularity. We explore a new way of looking at longitudinal charging transaction data, segment EV users into two broad groups with respect to charging regularity, and show that regular users are clearly different from random users regarding several charging behavioral and vehicle variables.

The remainder of this paper is structured as follows. The following section reviews previous literature on inter-episode duration analysis. Section 3 describes the theoretical basis of the hazard-based duration models and their specification used to model inter-charging times. Section 4 describes the data used in this analysis. Then, the results of the model estimation are discussed. The final section summarizes the main conclusions, implications of this study and plans for future research.

2. LITERATURE REVIEW OF INTER-EPISODE DURATION ANALYSIS

Prior inter-episode duration analysis can be classified into two broad groups according to its purpose and the data used. The first group of inter-episode duration analyses uses shopping trip data to examine how marketing variables affect the consumers' decision to go shopping. Kahn and Schmittlein (1989) found evidence of weekly cycles in shopping trips by observing inter-shopping times using IRI (Information Resources, Inc.) shopping trip data, and classified shopping trips into major and fill-in trips based on the amount of money spent on the corresponding shopping trip. In the context of examining trip regularity, they provided insightful results by classifying consumers into two segments: those who made more fill-in trips than regular trips (i.e., Quicks) and those who made more regular trips than quick trips (i.e., Regulars). This study, however, differentiates the two groups only by treating shopper's trip regularity as an exogenous variable. By taking duration dependence and heterogeneity in purchase rates across consumers into account, as well as covariate effects for modeling inter-purchase times of ground coffee with scanner panel data, Gupta (1991) developed four stochastic models of inter-purchase timing and compared these models. Results indicated that the model with duration dependence and heterogeneity in purchase rates improved model fit. Kim and Park (1997) developed a parametric hazard model of inter-shopping times using IRI shopping trip data, which incorporated heterogeneity in shopping trip regularity as well as shopping rates. Based on the parameter estimates, they endogenously segmented shoppers into random and regular groups by taking into consideration the pattern of shopping trip intervals (i.e., inter-shopping times). They noted that the exponential and Erlang-2 distributions were suited for explaining the frequency distribution of inter-shopping times of random shoppers and regular shoppers, respectively. Heterogeneity in shopping trip frequency was taken into account by introducing a gamma distribution, while heterogeneity in shopping trip regularity was modeled with the mixture of the exponential and Erlang-2 distributions. This study provided a useful approach to distinguish between random shoppers and regular shoppers in terms of shopping regularity. In recent years, Kim (2013) compared the pattern of online purchase timing with the corresponding patterns in the offline market. The results support the hypothesis that shopping time regularity collapses in the online market.

Secondly, a growing body of research recently focused on examining multi-day or multi-week longitudinal activity diary data (Yang and Timmermans, 2015). Recognizing the limitations of the existing activity-based approach to travel demand modeling in that most studies have relied on cross-sectional data (Rasouli and Timmermans, 2014), previous research has stressed the necessity of a deeper insight into temporal patterns of daily activity and travel characteristics which vary across days or weeks (Axhausen et al., 2002; Bhat et al., 2005; Arentze and Timmermans, 2009). Previous researchers have applied inter-episode duration analysis for this problem. For example, Schönfelder and Axhausen (2001) used six-week travel diary data of 361 individuals from 162 households, located in the German cities of Halle/Saale and Karlsruhe, to analyze the rhythmic patterns of "daily shopping" and "active sports" activities. They estimated the Cox proportional hazard model and Weibull parametric hazard model for the inter-episode duration distribution, which allows not only to incorporate observed inter-episode durations for the probability of event occurrence, but also to treat duration-independent determinants such as socio-demographics or personal constraints. Bhat et al. (2004) used the same dataset to examine the regularity and frequency of shopping behavior. Moreover, they expanded the hazard-based formulation, which accommodates a non-parametric baseline hazard and unobserved heterogeneity across individuals in inter-shopping durations, and included a latent segmentation scheme to classify shoppers into regular and erratic shoppers. In addition, Bhat et al. (2005) extended the previous analysis to five activity purposes, and found inherent weekly rhythms for participating in those activities. The results showed a stronger rhythmic pattern in the participation in the non-shopping activities (i.e., social, recreation, and personal business activities) than in the shopping activities (i.e., maintenance shopping and other shopping activities).

This paper deals with periodicity in charging behavior, which has been widely neglected, and segments EV users into two broad groups according to their charging regularity (i.e., random and regular group). Several hazard-based duration models will be formulated to examine inter-charging times of EV users using a Dutch four-year charging transaction data set. The model results provide information to private and public sector actors for the future development of charging infrastructure related to the understanding of the dynamic structure of space-time charging behavior. From a methodological standpoint, the estimated models can be considered an extension of Kim and Park's work (1997).

3. MODEL STRUCTURE AND SPECIFICATION

This section describes the hazard-based duration model used to examine inter-charging times. Given the assumption that heterogeneity exists in charging frequency and charging regularity, a gamma mixing distribution and a mixture of the exponential and Erlang-2 distribution are used to examine charging frequency heterogeneity and heterogeneity in charging regularity, respectively. We endogenously divide EV owners into random and regular users using a latent segmentation approach. It is assumed that charging regularity is treated as a latent variable, which cannot be observed by researchers. In this study, the posterior membership probability of each user is obtained from the estimated parameters in order to segment EV users into two groups according their charging regularity.

Similar to previous studies, it is assumed that the exponential distribution is suitable to model inter-charging times of random users, while the Erlang-2 distribution is reasonable for regular users (Gupta, 1991). These properties can be easily illustrated by inspecting the hazard rate of these distributions. The probability density function $f_i^E(x)$ and survival function $s_i^E(x)$ of the exponential distribution are equal to

$$f_i^E(x) = \lambda_i^E \exp(-\lambda_i^E x) \tag{1}$$

and

$$s_i^E(x) = \exp(-\lambda_i^E x) \tag{2}$$

where λ_i^E is the inter-charging hazard rate of user *i*.

The hazard function for exponential inter-charging times thus becomes $\lambda_i^E(x) = f_i^E(x)/s_i^E(x) = \lambda_i^E$, which is constant over time. Thus, this model represents random charging behavior of users.

Similarly, the probability density function $f_i^R(x)$ and survival function $s_i^R(x)$ of Erlang-2 can be written as

$$f_i^R(x) = (\lambda_i^R)^2 x \exp(-\lambda_i^R x) \tag{3}$$

$$s_i^R(x) = (1 + \lambda_i^R x) \exp(-\lambda_i^R x) \tag{4}$$

Thus, the hazard function of the Erlang-2 model is $\lambda_i^E(x) = f_i^R(x)/s_i^R(x) = (\lambda_i^R)^2 x/(1 + \lambda_i^R x)$. This equation shows that it is a monotonically increasing hazard over time and thus reflects duration dependence. Therefore, this model can be used to represent regular charging behavior.

Given that the charging transaction dataset is right-censored, the conditional likelihood function for random user *i* becomes

$$\begin{aligned} L_i^E(x|\lambda_i^E) &= \left[\prod_{j=1}^{n(i)-1} f_i^E(x_{ij})\right] s_i^E\left(x_{in(i)}\right) \\ &= \left[\prod_{j=1}^{n(i)-1} \lambda_i^E \exp\left(-\lambda_i^E x_{ij}\right)\right] \exp\left(-\lambda_i^E x_{in(i)}\right) \end{aligned} \tag{5}$$

where x_{ij} is the j^{th} inter-charging time of user i, $n(i)$ is the last observation of user *i* (i.e., censored inter-charging time). It is assumed that the hazard rate is constant here and identical for all users (i.e., $\lambda_i^E = \lambda^E \ for\ all\ i$). However, it is not appropriate to assume that all EV users have the same charging rate. Therefore, heterogeneity in inter-charging rates across EV users can be incorporated by introducing a gamma distribution. With the gamma heterogeneity, the likelihood function of user *i* can be rewritten as

$$\begin{aligned} L_i^E(x|\alpha,\gamma) &= \int_0^\infty L_i^E(x|\lambda_i^E) g(\lambda_i^E|\alpha,\gamma)\, d\lambda_i^E \\ &= \frac{\alpha^\gamma \prod_{j=0}^{(n(i)-1)-1}(\gamma+j)}{\left[\alpha+\sum_{j=1}^{n(i)-1} x_{ij}+x_{in(i)}\right]^{n(i)-1+\gamma}} \end{aligned} \tag{6}$$

where $g\left(\lambda_i^E|\alpha,\gamma\right)$ is the density function of the gamma mixing distribution with scale parameter α and shape parameter γ. Then, the log-likelihood of the *N* users in the sample becomes

$$LL = \sum_{i=1}^{N}\left[\gamma \log\alpha + \sum_{j=0}^{(n(i)-1)-1} \log(\gamma + j) - (n(i) - 1 + \gamma) \log\left(\alpha + \sum_{j=1}^{n(i)-1} x_{ij} + x_{in(i)}\right)\right] \quad (7)$$

As indicated, the Erlang-2 model is duration dependent, and therefore suitable for describing the charging behavior of regular users. This model is based on the assumption that the elapsed time since the last charging may affect the next charging time. Traditionally, the Erlang-2 distribution has been used by many marketing researchers to examine regular purchasing behavior (e.g., Jeuland et al., 1980; Gupta, 1991; Kim and Park, 1997). Thus, the inventory effect can be taken into consideration, which also exists in charging behavior related to the state of charge (SOC).

The conditional likelihood function of user *i* given that he or she is regular user can be written as

$$L_i^R(x|\lambda_i^R) = \left[\prod_{j=1}^{n(i)-1} f_i^R\left(x_{ij}\right)\right] s_i^R\left(x_{in(i)}\right)$$
$$= \left[\prod_{j=1}^{n(i)-1} (\lambda_i^R)^2 x \exp(-\lambda_i^R x_{ij})\right]\left(1 + \lambda_i^R x_{in(i)}\right)\exp(-\lambda_i^R x_{in(i)}) \quad (8)$$

Similar to the equation (6), it is assumed that λ_i^Rs are gamma distributed across EV users. The likelihood function of user *i* can be rewritten as

$$L_i^E(x|\alpha,\gamma) = \int_0^\infty L_i^R(x|\lambda_i^R) g(\lambda_i^R|\beta,\delta)\, d\lambda_i^R$$
$$= \frac{\beta^\delta\left[\prod_{j=1}^{n(i)-1} x_{ij}\right]\left[\prod_{j=1}^{2(n(i)-1)}(\delta+j)\right]\left[1+\frac{(2(n(i)-1)+\delta)x_{in(i)}}{\beta+\sum_{j=1}^{n(i)-1} x_{ij}}\right]}{\left[\beta+\sum_{j=1}^{n(i)-1} x_{ij}+x_{in(i)}\right]^{2n(i)+\delta}} \quad (9)$$

where $g\left(\lambda_i^R|\beta,\delta\right)$ is a density function of gamma mixing distribution with scale parameter β and shape parameter δ. Again, the log-likelihood of the entire N sample becomes

$$LL = \sum_{i=1}^{N}\left[\delta \log\beta + \log\prod_{j=1}^{n(i)-1} x_{ij} + \sum_{j=0}^{2(n(i)-1)-1} \log(\delta + j) + \log\left(1 + \frac{(2(n(i)-1)+\delta)}{\beta+\sum_{j=1}^{n(i)-1} x_{ij}+x_{in(i)}}\right) - (2(n(i) - 1) + \delta) \log\left(\beta + \sum_{j=1}^{n(i)-1} x_{ij} + x_{in(i)}\right)\right] \quad (10)$$

We have expressed the likelihood function corresponding to random and regular users in equation (6) and equation (9), respectively. However, there is no information on the charging regularity as it is considered to be a latent variable, which cannot be observed. In this paper, the propensity to belong to a segment (e.g., random user vs. regular user) is calculated using the posterior segment membership probability of user i. The final unconditional likelihood function of user i can be obtained by integrating the two likelihood functions, conditional on the user being a random user or a regular user, weighted by φ and $1 - \varphi$.

$$\begin{aligned} LL &= \sum_{i=1}^{N} L_i(x|\varphi, \alpha, \gamma, \beta, \delta) \\ &= \sum_{i=1}^{N} \log\left[\varphi L_i^E(x|\alpha, \gamma) + (1 - \varphi) L_i^E(x|\beta, \delta)\right] \end{aligned} \tag{11}$$

This log-likelihood can be maximized to estimate the following parameters: (a) scale parameter α and shape parameter γ for the random user segment, (b) scale parameter β and shape parameter δ for the regular user segment, and (c) weight φ. The log-likelihood functions were maximized using *optimx* in R statistical software (Nash and Varadhan, 2011; R core team, 2015). Once parameter values are obtained, each individual can be assigned to the segments. The posterior membership probability of user i being a random user can be calculated as $\varphi L_i^E / L_i$, while the corresponding probability to be a regular user equals $(1 - \varphi) L_i^R / L_i$. If EV users' posterior membership probability of being in the exponential segment is greater than that of being in the Erlang-2 segment, he or she is seen as a random user, and vice versa for those in Erlang-2 segment.

4. CHARGING TRANSACTION DATA

The proposed approach is applied to the charging transaction panel data. The analysis of this data has the following challenges. First, the data contains not only ordinary charging transactions, but also charging transactions which can be seen testing. It is observed that some charging transactions occur too many times a day (e.g., dozens of times of charging a day), and are largely associated with specific individuals. We considered these data are not relevant for our purpose, and deleted 12 individuals who charged more than 20 times a day. Second, in order to obtain stable model results, very light users (i.e., users who do not charge at least five times) were also eliminated. Third, some inter-charging times were too large (e.g., 1263 days), which may occur for many reasons. Despite the E-laad data covers a significant number of charging stations in the Netherlands, there are charging stations that do not belong to the E-laad network. We assumed that all EV users in the data do not use a charging station outside the sample. It is also possible that users may be out of town for a long time. These extremely long inter-charging times, which are higher or equal to 30 days are considered as outliers, and were eliminated from the analysis. The upper bound was used here due to the small number of inter-charging times exceeding this duration length (about 7% of the observations). Thus, the sample used in this study consists of the inter-charging times of 9,528 EV users. *Table 1* shows the summary statistics of the data used. The number of inter-charging duration spells varies between 1 to 931 spells across individuals, with an average of 41.08 spells. The average inter-charging time of all individuals is 3.01 days.

Table 1. Summary of the charging transaction dataset

Time span	8/20/2010 – 8/29/2014
Total number of users	9,528
Total number of inter-charging times	453,884
Number of inter-charging times per person	Min = 1, Max = 931, Mean = 41.08
Length of inter-charging time	Min = 1, Max = 29.49, Mean = 3.01

One way to capture the details of inter-charging times is to examine their frequency distribution. The left section of *Figure 1* represents the frequency distribution of inter-charging times at an aggregate level, and resembles an exponential distribution. It may suggest that the EV users' propensity to charge at time t is independent of the elapsed time since the last charging event. It seems that charging occurs randomly rather than regularly at first. However, the right section of the figure provides clear visual evidence of rhythmic patterns in charging activity.

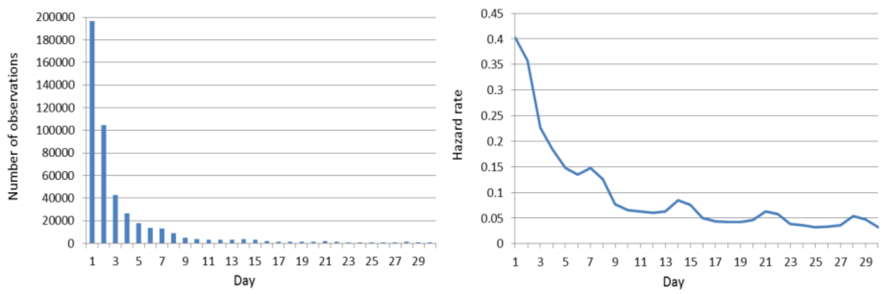

Figure 1. Frequency distribution of inter-charging times and sample hazard

The sample hazard was calculated using the Kaplan-Meier method with an upper bound of 30 days. It is a reasonable inference that several peaks at weekly intervals are related to the charging patterns of regular users. Kahn and Schmittlein (1989) also noted that weekly patterns in shopping frequency were the by-product of individuals' regular behavior. On the other hand, the high hazard at the first 6 days is monotonically decreasing indicating a negative duration dependence, which represents the inter-charging times of random users. In the next section, random users and regular users are separated out and compared.

5. EMPIRICAL RESULTS

Table 2 shows the estimation results for the different model specifications. First, the models with and without heterogeneity in charging frequency are compared. As we noted earlier, the charging rate (λ) is assumed to be Gamma distributed across individuals to represent heterogeneity in charging frequency. It is clearly shown that the inclusion of heterogeneity improves model fit in all cases. Given that the magnitude of the shape parameter indicates the degree of heterogeneity in the sample, the low value of the shape parameter indicates that substantial heterogeneity exists among individuals.

Second, we assess the impact of including duration dependence in the model by comparing the exponential with Erlang-2 models and exponential/gamma with Erlang-2/gamma models. The model without duration dependence fits the data much better. In other words, the model with the memoryless property of the exponential distribution describes the charging behavior of the entire set of observations well, which implies that EV users tend to charge their cars more at random. Contrarily to the results of previous inter-purchase and inter-shopping time studies (Gupta, 1991; Bhat et al., 2004), these results suggest that charging behavior has a different underlying structure than shopping behavior in terms of regularity. In addition, as Gupta (1991) noted, the interpretation of the shape parameter provides useful insight in the understanding of the intra- and interpersonal variations in charging rates. When comparing exponential/gamma with Erlang-2/gamma models, the results show that the shape parameter for the latter is less than that of the former. This result has an intuitive interpretation based on the assumption that the total variance in EV users' inter-charging times consists of within-individual variance (i.e., intrapersonal variability) and between-individual variance (i.e., interpersonal variability). As we noted earlier, the Erlang-2/gamma model assumes an Erlang-2 distribution for inter-charging times of individuals. This assumption implies that charging occurs more regularly than in the exponential model, which can be interpreted as the Erlang-2 model (or Erlang-2/gamma) having a smaller within-individual variance than the exponential model (or exponential/gamma). Thus, given the same amount of total variance in inter-charging times, an Erlang-2 model may represent larger between-individual variance than the exponential model. Therefore, in general, the shape parameter of Erlang-2 model is less than that of exponential model.

Thirdly, heterogeneity in charging regularity is taken into consideration by introducing a mixture of the exponential and Erlang-2 distribution into the model. It is shown that the inclusion of heterogeneity of charging regularity significantly improves model fit, as is evident from the lowest BIC (Bayesian Information Criterion) value. As we noticed in Section 3, the posterior membership probabilities of each individual being in the random users segment or in the regular users segment were calculated. The parameter estimates of φ indicate the proportion of the random users segment. The results suggest that about 67% of the entire sample of EV users is more likely to charge their car at random intervals, while 33% charges regularly.

Table 2. Model estimation results

	Exponential	Erlang-2	Exponential /gamma	Erlang-2 /gamma	Mixed
λ	0.315	0.633	-	-	-
Exponential parameters					
Shape (γ)	-	-	2.626	-	7.745
Scale (α)	-	-	9.489	-	45.56
Erlang-2 parameters					
Shape (δ)	-	-	-	2.477	7.211
Scale (β)	-	-	-	4.391	7.095
Size of Exponential (φ)	-	-	-	-	0.671
Log-likelihood	-977,778	-1,032,236	-900,036	-864,511	-848,839
Total number of individuals	9,528	9,528	9,528	9,528	9,528
Total number of observations	453,884	453,884	453,884	453,884	453,884
BIC	1,955,569	2,064,485	1,800,098	1,729,048	1,697,743

Note: BIC = -2*log(maximum likelihood) + (number of estimated parameters)*log(number of observations). The model with the lowest BIC is preferred. For heterogeneity concerns, it is assumed that inter-charging time rates (λ_i) are to be distributed as gamma with a shape parameter and a scale parameter. (Mean = γ/α, Variance= γ/α^2)

To get a better understanding of the reasons why people behave differently in the context of charging regularity, we take a look at the charging-related and vehicle characteristics of each segment. Two sets of variables were considered: charging-related and vehicle characteristics (see *Table 3* for descriptions of selected variables). Although demographic characteristics may also explain why heterogeneity in charging regularity arises, their effects could not be estimated because socio-demographic variables were not available due to confidentiality of the data. However, we have attempted to include any variables that were considered in other inter-episode duration studies. We considered six charging behavioral variables and two vehicle variables, as shown in *Table 3*. Charging behavioral characteristics included the average charging interval, charging duration, and charging frequency and the percentage of weekend charging. Moreover, we considered the charging station loyalty of each user, which can be calculated by $\sum_{i=1}^{N} s_i^2$, where s_i is the frequency of visiting charging station i divided by the total number of N visited charging stations, Charging station loyalty can be used as a measure to identify whether regular users charge at a relatively fixed location than random user. Vehicle characteristics considered dummy variables for two EV types (BEV and PHEV).

Table 3. Description of variables

Variables	Description
	Charging behavioral characteristics
Charging interval	Average charging interval in days
Charging duration	Average charging duration in hours (the elapsed hours between plug-in and plug-off time)
Number of charging	Average number of charging transaction
Weekend charging	Percentage of charging that occurred on Saturday and Sunday.
Charging station loyalty	Concentration ratio
	Vehicle characteristics
EV type	
BEV	1 if the user has a battery electric vehicle. 0 otherwise.
PHEV	1 if the user has a plug-in hybrid vehicle. 0 otherwise.

Based on the results of the mixed model, 6,273 EV owners are classified into the random users group while 3,255 are classified into the regular users group. *Table 4* provides the mean values, the standard deviations of the selected variables for each segment, and the corresponding p-values for mean differences. All selected variables are statistically significant at the 5 per cent level. In terms of the vehicle characteristics, regular users are more represented by BEV owners. This result corresponds to our expectation that BEV owners are more likely to stick with charging infrastructure in that electricity is the sole source of energy for BEV even with limited driving range. For charging behavioral characteristics, on average, regular users charge at public (or semi-public) stations almost every 2 days while random users charge every 1 week. Also it is interesting to observe that regular users tend to charge longer time once they plug-in their EV, compared to random users. Weekend charging is more significant in the random user group, that is to say, regular users tend to charge more at weekdays. Moreover, regular users exhibit a stronger charging station loyalty than random users. This is an intuitive and reasonable result. In conclusion, the results indicate that regular users show distinct characteristics from random users for both charging behavioral and vehicle variables.

Table 4. Characteristic of random and regular users

Variables	Random users (n=6273)	Regular users (n=3255)	*p* value
	Charging behavioral characteristics		
Charging interval	7.001 (2.949)	2.133 (1.055)	0.000
Charging duration	4.751 (12.558)	7.378 (5.404)	0.007
Weekend charging	0.298 (0.234)	0.222 (0.148)	0.000
Total number of charging	25.279 (29.169)	94.817 (117.547)	0.000
Charging station loyalty	0.218	0.621	0.000
	Vehicle characteristics		
EV type			
BEV	0.201 (0.401)	0.221 (0.414)	0.035
PHEV	0.782 (0.414)	0.759 (0.428)	0.019

6. CONCLUSIONS

This study has examined EV users' inter-charging times to understand their charging patterns with longitudinal charging transaction data covering more than 4 years. Given that EV users exhibit heterogeneous charging behavior in terms of charging frequency (time interval between successive charging events) and charging regularity (regular charging versus ad-hoc charging), this study applied a parametric hazard model to examine how often EV user charge their car, and to distinguish the distinct characteristics of random (erratic) users and regular (routine) users. The results show that 67 per cent of EV users charge their car at random, while 33 per cent of them charge regularly. It is shown that regular users charge their EV more often than random users and have a battery electric vehicle (BEV). Also, it is found that differences exist between the two user groups in terms of charging characteristics, such as charging intervasssl, charging duration, loyalty to charging station and total number of charging episodes.

Our results can be associated with quantifiable information about the periodicity of everyday charging activity. Such information is directly relevant to energy providers and to better manage smart grids. It provides the input to decide on the optimal location patterns of charging stations. It would be of interest in future research to incorporate models of dynamic charging behavior into computational process models of activity-travel behavior or into scheduling tools to derive essential information concerning the temporal allocation of recurrent behavioral activity-travel patterns. Both researchers and practitioners can gain new insights to better understand the periodic and repetitive nature of charging at public charging station.

An interesting future research topic is to examine the effects of covariates on hazard rates. In this study, we endogenously segmented EV users into two groups by considering only the patterns of charging intervals. Given that charging activity is chained with daily activity schedule and the state of charge (SOC), it would be a valuable to examine how those variables affect charging regularity and charging frequency.

ACKNOWLEDGEMENT

The authors would like to thank Auke Hoekstra at the Stichting E-laad for making the charging transaction data available for this research.

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Development of an Extended Model for a Disabled Person Support System in Welfare Towns

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Key words: Wheelchair user, Disabled Person Support System, Work shops

Abstract: The authors are working on the development of a "disabled person support system" so that even persons with disability can safely and comfortably enjoy activities in urban centers. One of the functions of this system is the "wheelchair navigation system," which defines its users as self-propelled wheelchair users. In this study, we proposed a method for developing an extended model to enhance the versatility of a wheelchair navigation system, performed the street evaluation experiments using application software and verified its usefulness through workshops.

1. INTRODUCTION

Recently, in Japanese provincial cities, the construction of large-scale shopping malls and condominiums has been underway. Citizens live in the suburbs and frequently visit these suburban shopping malls, using cars as traffic tools. However, the Japanese population is currently declining while the number of old people is increasing. Therefore, the Japanese government has been working on a compact city policy whereby city expansion is controlled and city functions are integrated into urban cities. Re-development projects enhance the convenience of urban life and a supply of condominiums is required so that many residents can live in urban centers and enjoy shopping and recreation there. Not only is there a requirement for such hardware, but also for software, such as support systems that allow children and old people to enjoy activities. The authors are working, in particular, on the development of a “disabled person support system” so that even persons with disability can safely and comfortably enjoy activities in urban centers. One of the functions of this system is the “wheelchair navigation system,” which defines its users as self-propelled wheelchair users. When a user moves around an urban center, this system provides them with information regarding suitable routes from their current location to their destination, such as the shortest route or the routes with lowest muscle burden, lowest vibration, etc. The usefulness of this system was verified by holding workshops in which we discussed the system with users. However, one of the problems of the system is its versatility for practical use. It is difficult to extend the target area or to apply this system to other areas due to the large amount of time and labor required. The final goal of this study is to propose a development method for easily extending the target area and to verify its practicality through experimentation.

2. RELATED WORK

The authors developed a test model of the “disabled person support system” to support wheelchair users. This support system for persons with physical disability has two functions: One is the “wheelchair navigation system” that searches for the optimum route from the current location to the destination, which is a software function for wheelchair user mobility support; the other function, in support of welfare town planning reviews, is the “downtown development review support function,” a hardware function that simulates the degree to which the physical burden on wheelchair users can be eased by constructing appropriate sidewalks(Koga M et al., 2014, Inada et al., 2014a).

With regard to the “wheelchair navigation system,” a more precise and detailed model was developed by searching for the route with lowest muscle burden and then verifying this with wheelchair users in a workshop setting (Koga M et al., 2015b, Yoshioka D et al., 2015c, Izumi S et al., 2015d, 2015e). In this study, an extended model was developed to enhance the versatility of the “wheelchair navigation system”.

Eguchi-Yairi et al. developed a mobility support tool that calculates and presents a safe and optimum route from the starting location to the destination using a geographic information service (Eguchi-Yairi et al., 2005f). Their tool considers traffic volume, i.e., both of vehicles and pedestrians, as well as factors that may narrow sidewalk width (e.g., roadside trees and utility poles), in order to calculate a safe optimum route. However, the physical burden imposed on persons with disability was not considered in their route calculation. Even if a street is wide, persons with disability may be subjected to a significant burden if the street surface has not been properly maintained or the cross slope is steep. This study has developed a tool that calculates the physical burden on persons with disability and presents an optimum route with the least possible physical burden.

3. RESEARCH METHODS

The methods for this study are as follows: 1. A method to develop an extended model of the wheelchair navigation system was proposed. 2. Application software for the “street evaluation” used in this method was developed. 3. The wheelchair navigation system was improved: the VR and interface were improved and a new route-search function was added. 4. Using the application software for evaluation, evaluation experiments were individually conducted by both able and disabled persons. 5. The results of the above experiments were reflected in improvements to the wheelchair navigation system. 6. Workshops were held to verify the extended model, in which the usefulness was verified through discussion of the system and the results of the street evaluation.

4. PROPOSAL FOR EXTENDED MODEL

The purpose of developing this wheelchair navigation system was to support wheelchair users to safely move around in urban centers and to provide users with a system for searching and informing on the shortest route or the route with the lowest muscle burden from a current location to a destination. In the development process for searching routes with the lowest muscle burden, investigators measured muscle burden by wearing muscle burden measuring meters on both arms and moving around all target streets. This time-consuming and laborious process was necessary to develop an extended area model or another town model. In this study, we propose a development method for an extended model as a conventional technique to extend the target area.

The navigation route in this extended model was calculated using “evaluation by wheelchair users.” This “evaluation by wheelchair users” on target streets in which wheelchair users actually move considers the maintenance conditions of the street, safety, and the feelings of wheelchair users regarding whether or not they wished to use this route. This evaluation was conducted using “street evaluation” application software on smartphones. The evaluated data were accumulated on a server and used to calculate suitable navigation routes based on the evaluation results. Furthermore, the final goal of this study was to obtain a result whereby an abled person performing “street evaluation” as a disabled person may provide the same evaluation as actual disabled persons (Fig. 1).

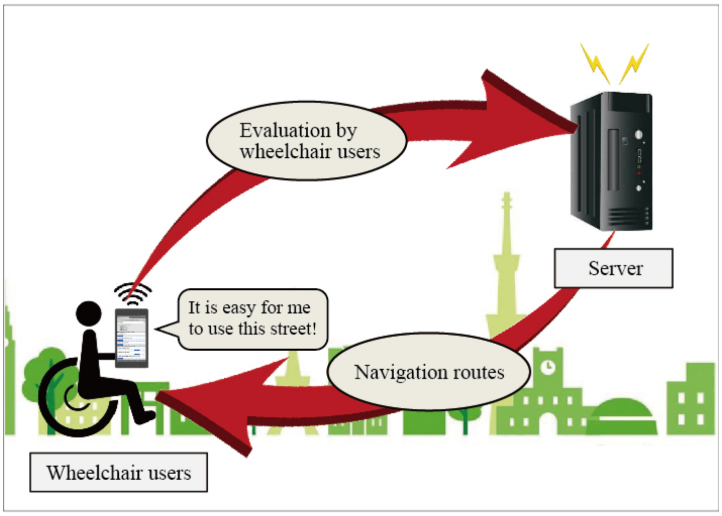


Figure 1. Proposal for extended model

5. DEVELOPMENT OF APPLICATION SOFTWARE FOR STREET EVALUATION

There are two types of “application software for street evaluation,” both of which were developed using JavaScript. This application software is used on a smartphone tablet through touch-input. The operation flow is as follows: 1. Switch on the application software, and input ID and password. 2. Display a map selection picture, and select the current location. 3. Ten questions are displayed on the screen, eleven questions in the case of an abled person. Answer these questions by selecting a number from 1 to 5. The questions are as follows: ① Do you frequently use this street? ② Can you pass through without getting wet in the rain? ③ Do you want to pass through the street? ④ Is the street width adequate to pass through? ⑤ Do you mind the rough surface of the street? ⑥ Is there a cross slope? ⑦ Is there a suitable sidewalk? ⑧ Is there a bump? ⑨ Is it difficult for wheelchairs to pass each other? ⑩ Are there obstacles? For the answer form, the “Likert scale” was adopted, as follows: 1, Strongly Disagree; 2, Disagree; 3, Undecided; 4, Agree; 5, Strongly Agree.

6. STREET EVALUATION EXPERIMENT BY ABLED AND DISABLED PERSONS

Evaluation experiments were performed by five wheelchair users on 93 streets of the target town on November 3, 2015, using the “application software for street evaluation” we had developed. The evaluation experiments were conducted by eight abled persons on November 1, 2015. Each average value of the street evaluation performed on Question 3 (Do you want to pass through?) by abled and disabled persons are shown in Fig. 2. Value 5 is the highest evaluation, and value 1 the lowest (Fig. 2).

The evaluations performed by abled persons and wheelchair users were almost identical on the highly evaluated streets, whereas the evaluations of

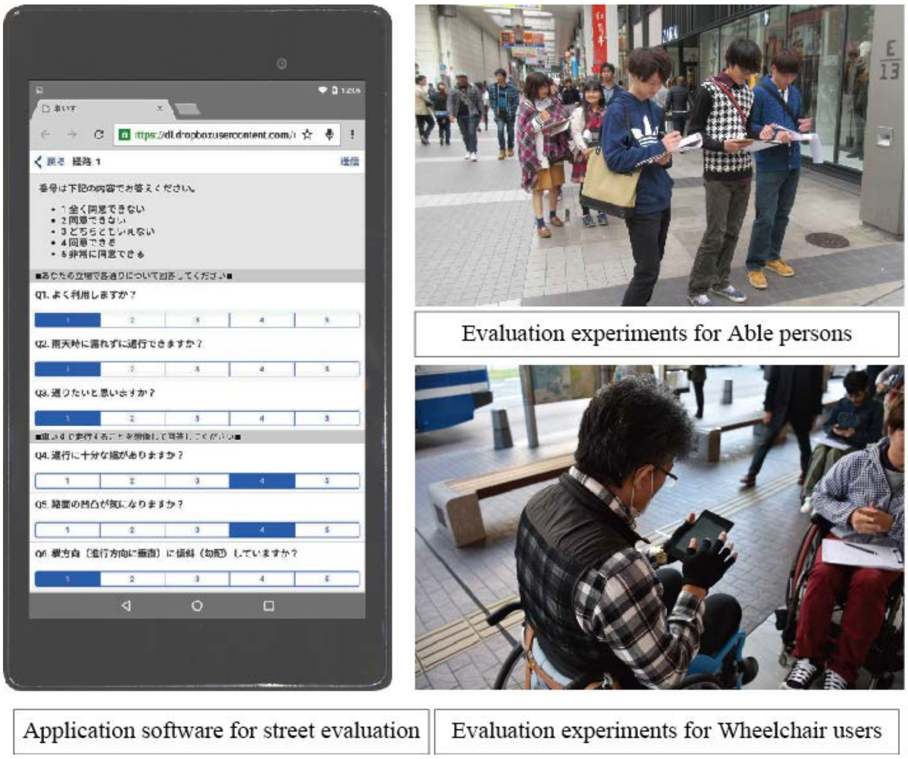


Figure 2. Application software for street evaluation and evaluation

disabled persons such as 1 to 1.2 were lower than those of abled persons on low evaluated streets. On the streets in Area A shown in Fig. 3, for example, the wheelchair users' evaluations were lower than those of abled persons.

This was because wheelchairs could hardly move due to a badly maintained road surface and the possible danger of contact with moving cars. Furthermore, it was difficult for wheelchair users to pass through the streets

Figure 3. Evaluation experiments Question 3 (Do you want to pass through?)

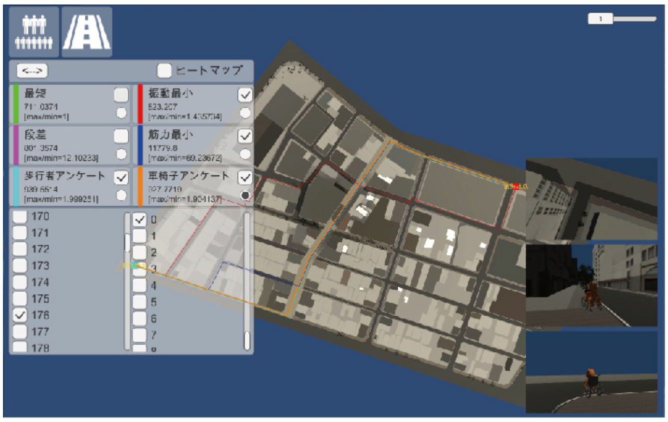
in Area B due to narrow and badly maintained sidewalks, although abled persons had no problem. Therefore, wheelchair users had to move to neighboring roadways. On the other hand, Areas C and D, which feature arcades, were highly evaluated by both wheelchair users and abled persons. These streets are wide and well maintained and there is no concern about getting wet in the rain. The experimental results of street evaluation by both wheelchair users and abled persons were input into the wheelchair navigation system, and the extended model was then developed.

7. OUTLINE OF NAVIGATION SYSTEM

The wheelchair navigation system aims to support self-propelled wheelchair users to engage in urban activities by offering information regarding navigation from their current location to a destination. The interface of the improved wheelchair navigation system is shown in Fig. 4. The points of improvement are as follows: 1. Modeling textures such as buildings, sidewalks, street trees, etc., in the target area were added and modified. 2. Navigation routes that were highly evaluated by both abled persons and wheelchair users were added. This system includes six search routes as follows: 1. Shortest route, 2. Route with least number of steps, 3. Route with least number of steps, 4. Route with lowest muscle burden, 5. Route highly evaluated by abled persons, 6. Route highly evaluated by wheelchair users. The calculation method for the route search using “Street evaluation” is shown in Fig. 5. A route is identified from amongst all possible routes from a starting location to a destination using the Distra method so that DL, the sum of logical distance (Dl), becomes the shortest distance. Logical distance (Dl) is the product of a value adding 1 to Aquest and actual distance. For example, in a case where the street evaluation has the highest value of 5, Aquest becomes 0, resulting in the logical distance being equal to physical distance. On the other hand, in a case where the street evaluation had the lowest value of 1, Aquest becomes 1, resulting in the logical distance being two times longer than the physical distance.

8. VERIFICATION OF SYSTEM

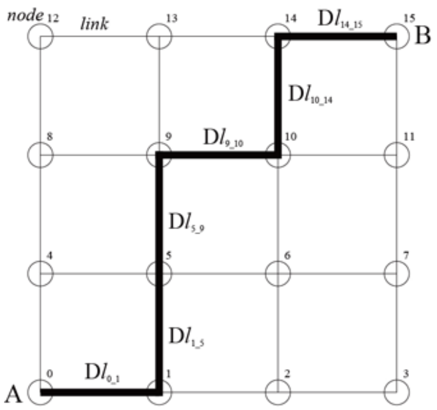
In order to verify the wheelchair navigation system and the result of street evaluation, workshops were held in Kumamoto city on November 21, 2015 and January 17, 2016. The view of the workshop is shown in Fig. 6. In this workshop, we verified four scenarios on individual routes from the starting



Input place of departure and destination

Navigation by character

Figure 4. Image of wheelchair navigation system



$$DL = \sum_{k}^{l} Dl_k \quad \text{-----------------} \quad (1)$$

$$Dl = (A_{quest} + 1)\,Dp \quad \text{-------} \quad (2)$$

$$A_{quest} = 1 - (Q_n - 1)/4 \quad \text{-----} \quad (3)$$

DL:Total logical distance
Dl: Logical distance
Dp : Physical distance
A_{quest} : Influence of the questionnaire result
Q_n : Questionnaire result

Figure 5. Calculation method for route search using “Street evaluation”

location to the destination. One of these search results with reference to the six above-mentioned items is shown in Fig. 7.

Figure 6. Workshops (Left side: first, Right side: second)

For the shortest route, the subject headed directly west on a main street with tramways, entered into arcade streets, proceeded south, and then turned west once more. Although Street A shown in the figure is for pedestrians only and is therefore safe for wheelchair users, the physical burden on wheelchair users was high due to high wheelchair vibration on the brick pavement. With regard to Street B, the sidewalk surface was poorly maintained, with many cases of cars driving along the sidewalk, so that Street B was evaluated as dangerous. For routes with the highest vibration and the least number of steps, Street C, which included both of these routes, was very dangerous for wheelchair users because trucks often parked on the sidewalk facing the back entrance of a department store. Street D was also dangerous due to its steep slope and crowded street during holidays. As for the route with lowest muscle burden, the subject went west, entered the arcade town, and turned west again just before the end of the arcade. The subject avoided Street E because its road surface was paved with tiles designed with ginkgo leaves, which placed a physical burden on wheelchair users moving over them. In this scenario, the street evaluation results performed by both abled persons and wheelchair users were the same. The subject went straight west, entered the arcade town, proceeded through the arcade town to the end, and then turned right to head west. This route was very highly evaluated for the following reasons: The road surfaces were well maintained. Wheelchairs could easily move due to the wide road and without anxiety of getting wet, even in rain, due to the arcade covering.

The opinions of workshop participants are shown in Table 1. With regard to wheelchair navigation, wheelchair users evaluated the route search and improved visualization highly. The shortest route was not highly evaluated because wheelchairs could hardly pass through due to dumps, etc. It was noted that opinions regarding safe routes and routes with few physical

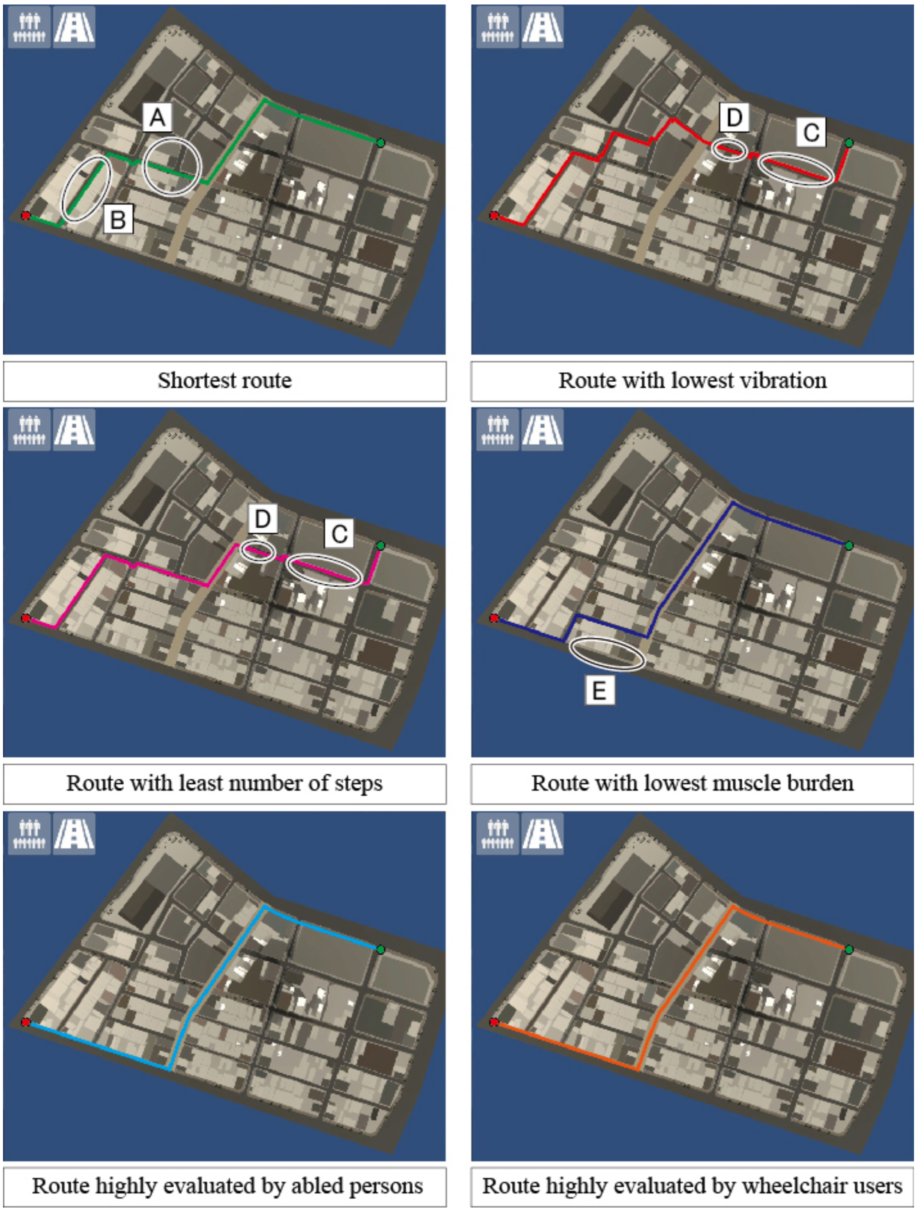


Figure 7. One of the search results from the six above-mentioned items

burdens were prioritized over the shortest route. With regard to the lowest vibration route, participants felt that the indicated route was too complicated for wheelchair users, despite the preference for streets with low vibration. The route with least number of steps was highly evaluated. However, some wheelchair users were anxious about the steep downward slope on this route, resulting in a low evaluation. With regard to the route with lowest muscle burden, the opinion that wheelchair users do not usually use this route despite its convenience was noted. With regard to the route highly evaluated by abled persons, these included routes that wheelchair users might not select. With regard to the route highly evaluated by wheelchair users, in all scenarios, they selected routes that included the arcade town. This route was highly evaluated because it was almost identical to that selected by wheelchair users participating in the workshop. Furthermore, wheelchair users felt that this route was safe and comfortable. As to the request for additional functions in this system, wheelchair users wanted additional functions to present information regarding wide parking areas for wheelchair users and restaurants with barrier free maintenance. They also requested further information, such as the remaining distance to the destination, and a function to allow users to update the town information.

9. SUMMARY

In this study, we proposed a method for developing an extended model to enhance the versatility of a wheelchair navigation system, performed the street evaluation experiments using application software and verified its usefulness through workshops. The following knowledge was obtained:

1) To develop an extended model of the wheelchair navigation system, we proposed a method to calculate navigation routes using street evaluation by wheelchair users using the “street evaluation software.” With regard to the route selected, streets that were highly evaluated by wheelchair users were preferentially selected. From the proposal for this development method, we could work towards solving problems of time and labor cost to extend the target area.

2) We developed “street evaluation application software,” and evaluated all routes in a model target area using a tablet terminal. Using these evaluated results, we could conduct “route research” reflecting the results of street evaluation performed by wheelchair users. Although the operational ability of the application software was highly evaluated, a problem whereby the tablet terminal hindered wheelchair mobility was reported. Hereafter, we will improve the application software to respond to different types of disability and to differentiate types of wheelchair such as electric wheelchair or self-propelled wheelchair.

3) We held workshops in which wheelchair users participated, and verified the usefulness of the extended model for the wheelchair navigation system. As a result, the improved interface was highly evaluated because the 3D-display of downtown was understandable. With regard to searching routes

according to “wheelchair evaluation”, we were able to indicate the evaluation of wheelchair users for each route and identify new problems. The shortest route was not highly evaluated because wheelchair users prefer a safe route rather than the shortest route even if this requires a detour. As to the routes with lowest vibration and least number of steps, some of these routes included dangerous streets in which cars often drove on the sidewalk. On the other hand, the routes selected by wheelchair users were most highly evaluated.

4) Wheelchair users made the following requests for additional functions of the wheelchair navigation system: indication of level difference, additional information about facility names and parking areas. In addition to increasing the accuracy of route research, hereafter we will present the downtown information requested by wheelchair users and develop the practicality of the wheelchair navigation system.

ACKNOWLEDGEMENT: This work was supported by JSPS KAKENHI Grant Number 26350031 and and the Mitsubishi Foundation

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Table 1. Opinions of workshop participants

Evaluation of wheelchair navigation system		・It was understandable due to the representation of textures.
		・Since wheelchair users were satisfied with the route presented, it was highly evaluated.
		・Since location and facility names were not shown, there were unrecognized places.
Opinions regarding evaluation of route search	Shortest route	・I felt it was difficult to move due to many dumps, etc., along the route.
		・I selected safe routes and those without burden rather than the shortest route.
	Route with lowest vibration	・As a wheelchair user, I liked it, since it was difficult for the wheelchair to move on tiles and bricks of sidewalk surfaces with high vibration.
		・I did not mind the vibration.
		・I did not move on the narrow sidewalk although the vibration was low.
	Route with least number of steps	・I noticed I did not use streets with bumps or physical burden.
		・I selected a route with fewer bumps although it was detour.
		・Since bumps increase the physical burden, I avoided streets with bumps.
	Route with lowest muscle burden	・I felt this route was convenient since wheelchairs can move except when climbing.
		・I did not usually use this route.
	Route highly evaluated by abled persons	・I felt wheelchair users could not pass through.
		・I felt the scenario resulting in both wheelchair users and pedestrians selecting the same route was interesting.
	Route highly evaluated by wheelchair users	・I thought the subjects selected routes with fewer bumps and uncrowded places.
		・I understood that routes that included the arcade were most often selected.
		・We need to consider physical conditions and whether a carer is present.
		・The result was almost the same as mine, and it is a useful, safe, and comfortable route.
		・I felt it is becoming similar to the route used by wheelchair users.
Request for information and function		・Information about parking areas with space for physically disabled persons.
		・Information about restaurants with or without barrier free entrances and toilet.
		・Function that allows users to update town information.
		・Information on upslope and downslope, and the possibility of moving without getting wet in the rain.
		・Information on elevators installed in facilities.
		・Display of the remaining distance to the destination.

Methodologies for requirement checking on building models

A technology overview

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Key words: Building Information Modelling, data management, code compliance, automation, model checking

Abstract: The use of Building Information Modelling (BIM) has increased in the Architectural and Urban domain. Stakeholders within distinct disciplines collaborate and exchange such information models digitally. In order to strive for an interoperable use of the models, requirement documents are being written by stakeholders, standardisation bodies and governments. Such documents pose additional requirements to the exchange of building model definitions and limit the scope of information to something that is relevant to the disciplines the exchange pertains to, the phase of the construction project and the level of development of the project. For effective collaboration processes, checking these requirements in an automated and unambiguous way is of crucial importance. Yet, requirement definitions often comprise natural language texts and academic and commercial tools being developed in this regard are fragmented and heterogeneous. Furthermore, the models being checked are of uncertain quality because the semantics of the schema are not rigorously formalized and enforced and models contain redundancies that affect their reliability. This paper urges for more developed schema semantics and illustrates how the body of technical means, such as classification system, concept libraries, query languages, reasoners and model view definitions are related to one another and to the concept of automated rule checking.

1. INTRODUCTION

1.1 Current practice

In recent years the use of Building Information Modelling (BIM) has increased in the Architectural and Urban domain. BIM has become an umbrella term for many recent innovations and insights based on data, but primarily signifies the transition from 2D CAD drawings to semantically rich information models in the building industry. Novel use cases have been enabled by virtue of the added semantic information.

In order to guarantee an interoperable use of these models, requirement documents are being written that make statements on the validity or appropriateness of (parts of) building model definitions. These use cases range from checking the conformance to rules set out by (local) governments to in-house guidelines and Level Of Development (LOD) specifications. In a similar fashion, the compliance to building codes needs to be checked in order to obtain permits. Several terms have been coined to name such requirements, such as “BIM norms”, “BIM employers requirements” and “BIM protocols”. They govern the requirements that people, organisations and government pose on the data or edifice that is delivered to them. Being able to check these requirements in an automated way is highly desirable for effective data exchange and high quality end-results.

On a technical level, various approaches are being researched to assess these requirements on actual models. These approaches allow for different levels of expressivity and extents to which they allow for automation, modularity and reuse. This paper will give an overview of available technical solutions to automate data requirements checking. It will state characteristics, advantages and limitations pertaining to these technologies. The technologies included in this overview are the IFC schema and its implementers agreements, Model View Definitions (mvdXML), classification systems and concept libraries, query languages, reasoners and proprietary software solutions.

1.2 State of the art

Various model checking platforms exist and are described in literature or are commercially available. A platform used in practice is *Solibri Model Checker (SMC)*. It is a JAVA-based executable that reads an IFC model and provides proprietary processing routines to facilitate the rule checking on common operations in the Architecture Engineering and Construction

(AEC) industry. This includes checking for the existence of attributes (so called pre-checking), and more advanced fire exit and evacuation checking and comparisons against the schedules and design briefs. SMC is a proprietary application that implements rule by means of hard-coding them in program code, therefore, other than adjusting specifically targeted parameters, this program is not extensible to add new types of rules.

Jotne EDModelChecker (EDM) is a commercial library that separates the definition of rules from the program code. Rules are defined in the EXPRESS modelling language, an ISO certified open standard, in which the IFC schema is conceived as well (Eastman, et al., 2009).

FORNAX is among the first large government-involved effort towards automated rule checking in the building industry. It is part of the Singapore CORENET platform, developed as an automated system to regulate building permits. It is implemented on top of the EDM Model Checker (Khemiani, 2005).

An attempt to aid the formalization process of rule definitions is provided by *SMARTcodes*, which presents methods of converting codes and standards from textual natural language definitions into computer code. This is accomplished by means of semantically structured domain knowledge (Nawari, 2012).

Automated approaches to validate the conformance of a model to a Model View Definition (MVD) are described in (Zhang, et al., 2013). But as described in (Solihin, et al., 2015), what constitutes a valid, meaningful and unambiguous exchange is broader than what currently can be expressed in such a MVD and includes in addition aspects such as geometrical and topological correctness, for example that spaces are correctly bounded and that the faces that constitute this boundary conform to their (typically planar) underlying surface geometry.

Disambiguation is a crucial part of the formalization of rule definitions. For this purpose the use of multilingual concept libraries is crucial as it allows to unambiguously point to a well understood concept from within diverse national classification systems and different languages (Palos et al., 2014). In the AEC industry initiatives are being undertaken to implement such concept libraries specific to the industry, such as the buildingSMART Data Dictionaries (bsDD). In addition, well established ontologies with a broader scope are available, for example (Navigli and Ponzetto, 2012) and (Miller, 1995).

An orthogonal line of research is initiated by (Krijnen and Tamke, 2015) that tries to employ machine learning concepts, such as anomaly detection to enable model checking without the à priori definition of formal rules, but instead deduce a norm to which most building elements conform to and flag the elements that deviate from this norm.

(Eastman, et al., 2009) describes a variety of rules and discusses the implementation of them in various of the available rule checking platforms. Often these rule sets are a mixture of safety or programmatic requirements. This work identifies major issues, such as a lack of extensibility of some of the platforms and resonates the finding that none of the platforms address the entire scope of rule checking. This entails the process of converting rules from natural languages into formal definitions, pre-checking the suitability of the model for more rigorous checking, executing the checks that often need geometrical and topological functionality to abstract building models into spatial structures suitable for e.g. fire exit checking and finally reporting the results.

1.3 Problem statement

The authors observe that on the one hand there is a wide variety of rules being developed, predominantly in natural languages within government bodies and standardization institutes. Yet, there is no easily apprehensible overview of the implications on computational complexity and decidability for such rules in the context of automated rule checking. On the other hand there is a wide variety of technical research directions undertaken that try to solve the notion of automated rule checking on top of various platforms with different levels of expressivity and with different requirements and prerequisites for the definition of rules. Often these technical ventures are focussed on isolated parts and not on the overall process. A general overview that connects and harmonizes the various approaches in this field seems to be lacking and is trying to be created in this paper. For that purpose an allegorical example of a rule is approached from various technical means. From this analysis the complimentary nature of these technical means can be seen.

2. DEFINITION OF A RULE

As an allegorical example of a rule, to be used throughout this paper, a seemingly simple example has been chosen that touches on and interconnects the relevant technical means of rule checking described in this paper. The rule is given below in Listing 1.

Listing 1. Rule introduced in this paper

```
A blind wall should not be longer than 3 meters
```

2.1 Relevance of concept libraries

In the particular case of the rule in Listing 1 three concepts can be identified: “length”, “meter” and, most interestingly, “blind wall”. Ontologies such as the Getty Architecture and Art Thesaurus (AAT) readily contain an identifiable concept that can be used for this purpose (Krijnen and Beetz, 2016), while there is no explicit semantics in the IFC schema to annotate walls of this type. In general, requirements, like the example above, are provided in natural language and the process of reinterpreting them into something formally understood, and to include the implicitly available domain knowledge, is a significant part of coming to an automated approach to checking such rules (Sohilin and Eastman, 2015). After understanding the formal implications of the rule, the process of rule checking relies on disambiguating terms in the equation by means of classification systems or concept libraries (Eastman et al., 2009). For a “blind wall” in AAT the following definition is given provided in Listing 2.

Listing 2. Definition of a blind wall in the Getty Architecture and Art Thesaurus

Walls whose whole surfaces are unbroken by windows, doors, or other openings.

With this definition the rule can be formalized as given in Listing 3, which is to say that a valid wall implies that either its length is less than or equal to three meters or no openings are associated to the wall element.

Listing 3. Formalization using predicate logic of the rule in Listing 1.

$\textbf{valid\_wall}(\mathcal{W}) \rightarrow (\textbf{length}(\mathcal{W}) \leq 3\text{m}) \vee (\exists \mathcal{O}\text{: } \textbf{opening}(\mathcal{W}, \mathcal{O}))$

2.2 Relevance of query languages

After the formalization, the rule can be encoded as a query. For the purpose of reporting issues with model, that is to say, return elements within a model that violate the rule, the query in Listing 4 has been negated. Only the second part of the conjunction is included initially. In this particular case the SPARQL query language has been used. This necessitates that the building model definition in IFC has to be converted to a linked data representation, for example as defined by (Pauwels and Terkaj, 2016). The query returns unique identifiers for walls to which no IfcRelVoidsElements are related. This is the objectified relationship in the IFC schema that connects elements to openings, which in turn are connected to windows and doors.

Listing 4. SPARQL query to return walls without openings

```
PREFIX ifcowl: <http://www.buildingsmart-tech.org/ifcOWL#>

SELECT ?wall_guid_value
WHERE
{
   ?wall a ifcowl:IfcWallStandardCase ;
      ifcowl:GlobalId ?wall_guid .

   ?wall_guid ifcowl:has_string ?wall_guid_value .

   FILTER NOT EXISTS {
      ?rel a ifcowl:IfcRelVoidsElement ;
         ifcowl:RelatingBuildingElement_of_IfcRelVoidsElement ?wall .
   }
}
```

However, when the results of such a query on a commonly used example model[1] are then visualized, the set of elements returned consists of several unexpected elements. Elements identified by this query do not conform what would be typically understood as a wall. As has also been noted in (Krijnen and Tamke, 2015) models might contain flaws pertaining to misclassifications into element categories.

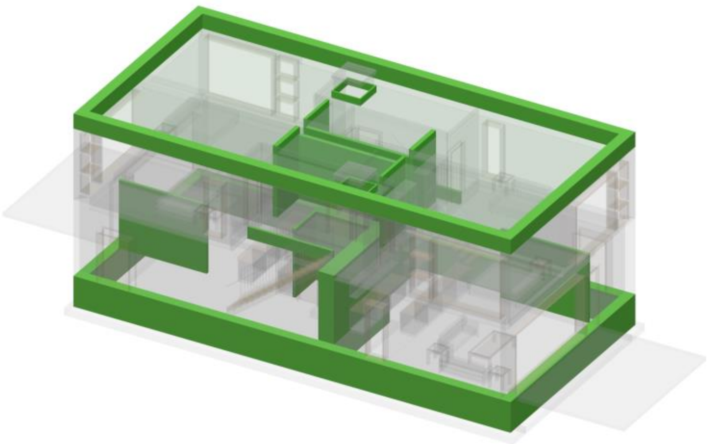

Figure 1. Elements returned by the query in Listing 1 include elements not typically considered as walls. Elements that are matched by the query are printed in solid green. Unmatched elements are printed transparently.

[1] http://www.nibs.org/?page=bsa_commonbimfiles

2.3 Relevance of schema semantics

As illustrated in Figure 1, many of the elements returned by the query to retrieve blind walls, while they indeed do not contain openings, also do not appear to match the common idea of a wall. According to the IFC standard, which draws from ISO 6707-1 for most of its terminology, a wall is a “vertical construction usually in masonry or in concrete which bounds or subdivides a construction works”. However, as has been noted by (Amor, 2015), with the IFC schema expanding its size and domain coverage, the body of codified and formal where rules is not growing along. The only semantic constraint to a wall (IfcWallStandardCase) is that there should be a single material layer set defined that depicts the distribution of material over its cross section. There is no formal apprehension in place of the fact that elements, which do not function as a wall in the model, should not be classified as such.

An additional issue with the body of formal rules defined in the IFC standard is that these rules are defined in the EXPRESS language, which is a relatively old specification for which little support is available in terms of its rule language. This calls for mapping such rules to other formal languages, for example as implemented in (Terkaj and Šojić, 2015).

2.4 Relevance of Model View Definitions

Model View Definitions specify additional constraints on the validity of an exchange of information. Such an MVD then describes the subsets of the schema that supports the needs of a particular data exchange (Lee et al., 2016). The language to describe such MVDs, mvdXML, is not as expressive as other rule languages, making it relatively easy to implement in software and making the definition of such rules straightforward. On the other hand it necessitates that if higher levels of expressiveness are required, other languages need to be incorporated, for example SWRL in (Lee et al., 2016). In addition, by specifying what information is relevant, they also define where is to be found in the model.

The left-hand side of the conjunction in the query in Listing 3 constraints the maximum length of a blind wall. IFC allows the definition of key-value pairs by means of its IfcPropertySets and IfcElementQuantities. They form an extensible means to encode information that is not directly prescribed in the IFC schema. The extensibility stems from the usage of free-form strings as the keys of the pairs, which is the sole constituent that defines the meaning. This is also why additional conventions are needed to guarantee an interoperable interpretation of the information conveyed in these key-value pairs. MVDs are a way of enforcing that for relevant building elements such information is present and defines how it is encoded. In that sense MVDs are a very relevant component of the pre-checking phase (Eastman et al., 2009) of the model checking workflow in which basic availability of information is asserted. With such assertions in place, the query from listing 4 can be appended with a triple pattern to retrieve and filter on the wall length.

Listing 5. Addition to the SPARQL query to retrieve wall lengths in explicitly stored quantities

```
?rel_prop a ifcowl:IfcRelDefinesByProperties ;
  ifcowl:RelatedObjects_of_IfcRelDefines ?wall ;
  ifcowl:RelatingPropertyDefinition ?prop .

?prop a ifcowl:IfcElementQuantity ;
  ifcowl:Quantities ?quantity .

?quantity a ifcowl:IfcQuantityLength ;
  ifcowl:LengthValue ?length .

?length ifcowl:has_double ?length_value .
```

2.5 Relevance of reasoners

As described in the previous section, MVDs can be seen as a form of contract between the exporting and the importing party of the exchange. On the other hand, it might not always be feasible for exporting parties to be able to comply to all MVDs. Development iterations of exporting software are sometimes lagging behind or views on information are simply not always available in the authoring software. In such cases the importing party may need to infer the information using reasoners. Using reasoners and inference engines, a bottom-up higher-order apprehension of a model can be obtained by inferring new knowledge from explicitly available information and inference rules.

In the case of the rule in Listing 3 and without the explicitly encoded quantity information for wall lengths, which is queried in Listing 5, the length can be obtained by means of a conventional query (Listing 6). This is mainly provided to illustrate the relative infeasibility of this approach.

Listing 6. Addition to the SPARQL query to retrieve wall lengths from geometrical data

```
?wall ifcowl:Representation ?shape .
?shape ifcowl:Representations ?list .
?list ifcowl:isFollowedBy*/ifcowl:hasListContent ?rep .
?rep ifcowl:RepresentationIdentifier ?label .
?label ifcowl:has_string "Axis" .

?rep ifcowl:Items ?rep_item .
?rep_item a ifcowl:IfcPolyline ;
  ifcowl:Points ?point_list .

?point_list ifcowl:hasListContent ?point1 .
?point_list ifcowl:isFollowedBy/ifcowl:hasListContent ?point2 .

?point1 ifcowl:Coordinates_of_IfcCartesianPoint ?p1xy .
?point2 ifcowl:Coordinates_of_IfcCartesianPoint ?p2xy .

?p1xy ifcowl:hasListContent/ifcowl:has_double ?p1x .
?p1xy ifcowl:isFollowedBy/ifcowl:hasListContent/ifcowl:has_double ?p1y .

?p2xy ifcowl:hasListContent/ifcowl:has_double ?p2x .
?p2xy ifcowl:isFollowedBy/ifcowl:hasListContent/ifcowl:has_double ?p2y .

BIND (afn:sqrt((?p2x - ?p1x) * (?p2x - ?p1x) + (?p2y - ?p1y) * (?p2y - ?p1y)) as ?length)

FILTER (?length > 3.0)
```

There is a large amount of complexity involved with querying seemingly trivial information from building models in IFC. This stems from the standard being permissive as it allows geometry to defined in my ways. In addition, complexity is introduced by the objectified relationships that introduce additional indirection to get to relevant information. By introducing shortcuts to such data, the model can be made more idiomatic to common linked data ontologies (Farias et al., 2015). Such shortcuts is also something part of specific-purpose query language for IFC building models, such as presented in (Mazairac and Beetz, 2013).

To summarize, there are three complicating factors illustrated here: 1) the inference of a wall length in this case depends on the availability of an ‘axis’ geometry, which might not be defined, although dictated to exist in textual form 2) for such a representation geometry may be defined in different ways 3) ordered aggregates difficult are difficult to inspect and query in SPARQL as they have to modelled as a tree structure in RDF (Pauwels et al., 2015). Therefore the query in Listing 6 is only able to return a wall length for the simple cases. As such, due to the combinatorial complexity of these complications, a bottom-up approach to infer new information is more suitable.

3. CONCLUSIONS

In order to come to an efficient automated rule checking workflow, the technical aspects discussed in this paper need studied holistically and not in isolation. By exploiting their complementary nature, rules can be encoded formally, succinctly and expressively.

A crucial foundation for rule checking are the semantics introduced on the schema level: in order to prevent false positives and negatives, elements need to be classified correctly. Currently there are no or very limited provisions in the IFC schema that actually guarantee this formally. As a consequence elements are misclassified, or classified in overly broad or meaningless categories, such as IfcBuildingElementProxy. Elements that are misclassified result either in false negatives, as certain relevant checks are not performed, or in false positives (as illustrated in the case of Figure 1), because irrelevant checks are performed. Both are detrimental to the quality of the rule checking process and therefore to the delivered artefact. For this purpose, a large body of the documentation of the IFC standard, which consists of hundreds of pages, needs to be translated into formal and decidable statements.

Secondly, formal notations of explicitly encoded quantities are necessary in order to guarantee that the available quantities are accurate. IFC is a highly redundant data format: the length of a wall will typically be reflected in many places within the schema, including space boundary geometries, explicitly calculated quantities and different representations for the body and axis of elements. The quality of a data schema can be described by means of a minimal redundancy and maximum reliability (McLeod, 1995). Without formalized connections between the different apprehensions of attributes like the wall length, the amount of redundancy induces an increased risk of errors when parts of a model get updated.

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A 5-metric methodology for selecting a shading system control strategy

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Key words: Control strategy, shading systems, daylighting

Abstract: When selecting the type of control strategy for the shading system of a building, the end decision is sometimes based on the cost of the system itself. Another approach could be to balance the cost of the various control strategies of the shading system and the potential benefits induced by each of the control strategies. The potential benefits could be energy savings as well as productivity gains, improved health and wellbeing of the building occupants or even increased rental value of the building. The proposed paper investigates a methodology that helps the choice of the most appropriate control strategy for the shading system of a building based on its performance assessed by various metrics. In order to assist design teams and developers in their choice of shading systems control strategies, we developed a 5-metric methodology based on lighting and energy calculations.

1. INTRODUCTION

Daylight deserves a specific attention during the design process of a building. It deserves a specific attention because building occupants enjoy it and prefer it to electric lighting. A recent study shows that daylight is the ambiance parameter that is sought by 42% of office workers (Cooper, 2015).

Statistics show that nowadays, people living in occidental countries spend up to 90% indoors. When considering daylighting in buildings, there is much more at stake than the savings that can be done on electric lighting and heating / air conditioning. The impacts of daylight on health, comfort and wellbeing are as important as its impacts on energy, if not more.

Those impacts could be massive. Jin (Jin, 2012) reports that improved lighting and thermal comfort conditions in buildings caused better productivity in office workers that may have generated between 20 and 160 billion dollars in the USA in 1996 (Fisk, 2000).

Lighting control technologies are a key element when it comes to managing and optimizing natural and electric lighting in buildings. For lighting conditions to be optimal, those technologies need to be associated with efficient control strategies. Without appropriate controls and management, lighting systems can yield to glare, overheating, energy overconsumption or users dissatisfaction.

In the presented study, we focus on the impact that various control strategies of shading systems can have on glare, electric lighting use, health and comfort as well as overheating. We developed a 5-metric methodology based on the performance of various shading systems control strategies on those five parameters.

2. THE BENEFITS OF DAYLIGHTING

The study of the benefits of daylight on people and buildings has been a hot research topic for the past fifty years. Recent research suggests that the impacts of daylight on people may be, on a wider scale, much bigger than those on energy. For example, operational costs of an office building are shared as follows: 1% for energy costs, 9% for rental and operational costs and 90% for occupants salaries (WGBC, 2014). These figures show that measures that aim at improving lighting conditions of office workers hence their wellbeing hence their productivity will potentially have a bigger payback than investing in energy saving light bulbs.

Additionally, the biophilia hypothesis suggests there is an instinctive bond between human beings and other living systems[1] (Wilson, 1984). Therefore, any contact with nature in the indoor working environment particularly through the view to the outside may have positive effects on wellbeing, mood and motivation that could induce an improved productivity.

[1] https://en.wikipedia.org/wiki/Biophilia_hypothesis

These figures and emerging theories yield to new ways of thinking. In the 21st century, it seems more and more obvious that all measures that improve employees wellbeing are clever investments that could have favourable effects on the prosperity of the companies they work for. In some cases, those investments may prove to be much more profitable than those concerning the building only (i.e. energy efficient lighting).

It is now established that the benefits of daylighting in buildings go much further than energy considerations. Research shows that the benefits of daylight have nowadays a much wider impact. Those impacts can be directly and indirectly monetized, they concern either the building, the occupants or the various stakeholders.

2.1 Building-scale benefits of daylight

The way that daylighting is designed will have multiple impacts on a building. Those impacts can affect the property value, the rental value, its construction costs as well as costs associated with its usage and maintenance.

It is an accepted fact that a bright dwelling or office that has a pleasant view to the outside will be slightly more expensive to purchase or rent than the same space without a nice view. According to a survey broadcasted by BFM TV in France on 19 September 2014, 53% of the French state that the brightness of a dwelling is one of its most attractive characteristics. This survey also reveals that potential buyers would be ready to add 5 to 10% to their budget for a dwelling offering good access to natural light (LUX, 2014).

Evidence of the correlation between property or rental value of a building and its access to natural light are not easy to obtain. However, literature gives some information related to this topic:

- The presence of windows and access to daylight in an office has an impact on its rental value. Statistics show that where windowless and dark offices have a rental of 80 to120 € /m², offices with windows and access to daylight have a rental value of 100 to 140 €/m², i.e. an average rental value 20% superior for offices with windows (Boyce, 2005).
- It is a known fact that nowadays, buildings labelled with an environmental certification (LEED-US, BREEAM-UK, HQE-

FR, for instance) will have a higher rental value than the same building without an environmental label. An American research indicates that a building an environmental label will have a rental value increased by 3% and a property value increased by 16% (Eicholtz, 2009). Unfortunately, there are no statistics concerning daylighting and rental value exclusively.
- An increase in sales of 40% has been observed following the installation of rooflighting windows in a commercial building (Leslie, 2003).

Research also shows that the associated cost of a year of electric lighting for an employee corresponds to one hour of their wage (Leslie, 2003). This goes to show that if optimized daylighting was to reduce the use of electric lighting in a building, the savings would only be extremely small compared to the employees salaries.

It seems fair to say that the most important benefits of daylight in buildings occur on occupants rather than the building itself. Let's now examine the impact of daylight on people.

2.2 Occupants-scale benefits of daylight

Daylight can influence an individual's performances in three different ways (Boyce, 2004):

- Through the visual system : the amount of light received or produced by an object has a direct impact on our ability to see it.
- Through the circadian system : the spectral composition of light as well as the day/night cycle have multiple effects on our health, biological clock and the quality of our sleep.
- Through the cognitive system : information transported by daylight impacts our perception of a space and the psychological sensations, pleasant or not, that will be generated. This information could be for example the quality of the view to the outside, the colour of the light, the presence of direct sunlight or the global luminous ambiance. Lighting is not the only parameter to influence our perception of a space.

The belief that good access to daylight – in terms of quantity and quality, through the view to the outside for instance – improves productivity in an office space is spreading rapidly in the building sector. The quest for evidence of this hypothesis has officially begun. Researchers work on bringing elements of answer to this belief. The task is difficult.

In order to understand how daylight influences productivity, let’s see what parameters influence productivity. An individual is productive at work when:

- They have optimal visibility of the task they are doing. There is a proven correlation between the quantity of light and the reduction of errors at work. If an individual cannot see properly the task they are doing, many errors can occur.
- They are attentive. In order to be attentive, one needs to be focused. Focus is maximal when one can use all their intellectual capacities. Those capacities are optimal when our brain is alert and rested. When properly stimulated, the circadian system helps our body create these optimal conditions.
- They are motivated. Motivation of an individual is a complex parameter to analyze. Parameters that create motivation can be the interest of the task that is carried out, the responsibilities given to the worker, the absence of stress in the workplace as well as the actual design of the workspace.
- They are healthy. A person who is not healthy will not be able to use all their physicial and intellectual abilities in order to work in good conditions, their productivity will be impaired.

Most importantly, a happy worker is a productive worker. Good daylighting can participate in people’s happiness and wellbeing.

One of the main questions that can be raised about the link between daylighting and productivity is : « How much are developers and building owners willing to invest to improve people’s working conditions with optimized daylighting? ».

3. A 5-METRIC METHODOLOGY FOR SELECTING A SHADING SYSTEM CONTROL STRATEGY

In order to investigate how various stakeholders will be impacted by daylight in building, we decided to focus on the effects that various control strategies of shading systems can have.

When not controlled properly, daylight can have negative effects such as glare or overheating. A thoughtfully designed sunlight control strategy can help prevent those negative effects.

There are three ways to control moveable shading systems in a building :

- Mechanical system with manual control: Blinds are activated mechanically with manual controls such as strings or rotating handles.
- Motorized system with manual control: Blinds are fitted with motors and activated manually with a remote control or a switch.
- Motorized system with automated control: Blinds are motorized and activated automatically when the signal coming from sensors exceeds a set threshold value.

Literature gives some insight on the various impacts of shading systems control strategies:

- Motorized blinds with manual control are used three times more often than manually controlled mechanic blinds in offices (Sutter, 2006)
- In an office space, 45% of the movements of motorized blinds with automated control are rejected and corrected by users (Reinhart, 2001)
- It has been observed that 60% of the occupants of an office building never use their manually controlled mechanic blinds (Inoue, 1998)
- A study realized in several office buildings during one year showed that nearly half of the occupants actionned their manually controlled mechanic blinds blinds less than once a week (Paule, 2014)

3.1 Detail of the methodology

In order to quantify the impacts of various shading systems control strategies and to test our hypothesis, we developed a methodology that will allow the global assessment of the luminous ambiance inside an office space using five daylighting metrics:

- 1st metric : Daylight autonomy : this will assess the number of hours a level of 300 lux is achieved by daylight only during one selected overcast day (H_{300lux}), which represents the worst case scenario.

Daylight autonomy is calculated using the Radiance lighting simulation software at selected occupants positions. In an office space with several occupants, it is calculated at the furthest work station from the window in order to assess the least daylit position.

Three levels of performance are proposed in order to assess the efficiency of the assessed blind control strategy to offer good lighting levels under natural light

Level 1	**Level 2**	**Level 3**
$H_{300lux} > 2h$	$2h \geq H_{300lux} > 1h$	$H_{300lux} \leq 1h$

- 2nd metric: Glare: the probability of glare in natural light will be assessed by the Daylight Glare Probability (DGP) index. We assess the number of hours DGP is greater than 0,4 during a selected sunny day (HDGP>0,4) which corresponds to the limit of a glary situation (Wienold, 2009).

DGP is calculated using the simplified formula (Wienold, 2009):

DGP = 6,22.10-5 x Ev + 0,184

Ev is the vertical illuminance at eye level, it is calculated with the Radiance lighting simulation software at the occupants position. In a space with several work positions, DGP is calculated at the workstation that is the closest to the window which corresponds to the glariest position.

Three levels of performance are proposed in order to assess the potential of the assessed blind control strategy to prevent glary situations under natural light

Level 1	**Level 2**	**Level 3**
$H_{DGP>0,4} < 30$ min	30 min $\leq H_{DGP>0,4} < 1h$	$H_{DGP>0,4} \geq 1h$

- 3rd metric : Access to the view to the outside : the percentage of the window area that is visible and not covered by blinds from a specific point in a room (%view) on a selected sunny day (when blinds are most likely to be down and block the view to the outside).

The percentage of the visible window area is estimated geometrically from a specific point of view in a room.

Three levels of performance are proposed in order to assess the potential of the assessed blind control strategy to offer a view to the outside.

Level 1	**Level 2**	**Level 3**
$80\% < \%_{view} \leq 100\%$	$60\% < \%_{view} \leq 80\%$	$\%_{view} \leq 60\%$

- 4th metric : Circadian stimulation : the health potential of the daylighting conditions offered by the various shading system control strategies will be assessed using the Equivalent Melanopic Lux (EML) metric.

The EML metric proposed by the WELL environmental scheme[2] assesses the potential of the quantity of light received by an individual during a day to stimulate the circadian system. The human circadian system, also known as the “biological clock”, controls many vital body functions such as the sleep / wake cycle. Research recent found that short wavelength light helps entertain and sync the circadian system (Boyce, 2014)

The threshold of 250 circadian lux (corresponding to 275 lux of natural light) vertical at eye level during 4 hours a day as a threshold for circadian stimulation is proposed by WELL.

In our methodology, we are calculating the number of hours during a selected overcast day (worst case scenario) when the vertical illuminance value at eye level exceeds 250 circadian lux ($H_{250\ c\text{-}lux}$) to assess the potential of the various shading systems control strategies to stimulate the circadian system and the associated health benefits.

We chose to evaluate the performance under overcast sky conditions to consider the worst case scenario. The WELL threshold of 4 hours for EML being hard to achieve on an overcast day, we suggest to consider a value of 2 hours. EML is calculated with the vertical illuminance at eye level using Radiance.

[2] https://www.wellcertified.com/

Three levels of performance are proposed in order to assess the potential of the assessed blind control strategy to stimulate the circadian system.

Level 1	Level 2	Level 3
$H_{250\ c\text{-}lux} \geq 2$ h	1 h $\leq H_{250\ c\text{-}lux} < 2$ h	$H_{250\ c\text{-}lux} < 1$ h

- 5th metric : Solar gains : the potential for overheating will be evaluated by the solar gains penetrating the room for the various control strategies of the shading system.

The overheating metric used in this methodology is the amount of solar radiation penetrating the space, for the various control strategies of the shading system, per square meter on a selected sunny day.

Solar gains are calculated using the « Solar exposure » module available in the Ecotect building simulation software.

It is not possible to suggest performance levels for this metric based on the value of solar gains as thermal comfort depends on other parameters such as thermal mass, ventilation, internal gains, etc. Solar gains alone cannot predict thermal comfort condition. This metric will however be used to compare solar gains for the various shading systems control strategies considered as follows:

Level 1	Level 2	Level 3
Lowest solar gains	Medium solar gains	Highest solar gains

3.2 Impacts on the various stakeholders

Additionally to the assessment of these five metrics, we also suggest to think about how the shading systems control strategies impact the various stakeholders (i.e. the building owner, the occupant, the users and the facilities manager).

A detailed example on how to use this methodology is detailed in the following section.

3.3 A case study

For this case study, we consider a company that moves into a new office located in Paris, France. The office is composed of four individual offices and one open plan office (see Figure 1)

Windows do not have moveable solar shading devices. The office occupant wants to put external venetian blinds on the windows but is hesitant regarding the control strategy to implement: mechanical / manual, motorized / manual or motorized / automated. We are using the methodology we developed to assist the office occupant in selecting a shading system control strategy. In this paper, we limit our study to the open plan office.

Firstly, we evaluate the cost of the three options for the blinds control systems with Batiprix[3].

- Mechanical blinds with manual control: Blinds are activated mechanically with manual controls such as strings or rotating handles. Cost: 14,8 k€
- Motorized blinds with manual control: Blinds are fitted with motors and activated manually with a remote control or a switch. Cost: 25,7 k€
- Motorized blinds with automated control: Blinds are motorized and activated automatically when the signal coming from sensors exceeds a set threshold value. The control algorithm used in this system is a “suntracking” algorithm: blinds are activated automatically when direct sunlight hits the façade. Cost: 29,5 k€

Secondly, we model the office space and the external obstructions and consider three occupants positions in the open plan office (see Figure 1). We then calculate the five daylighting metrics according to the rules proposed in the methodology.

[3] http://www.batiprix.com/

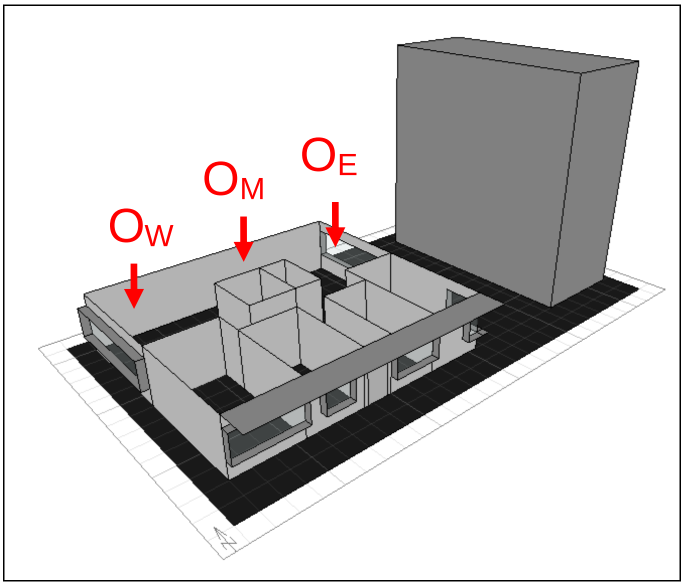
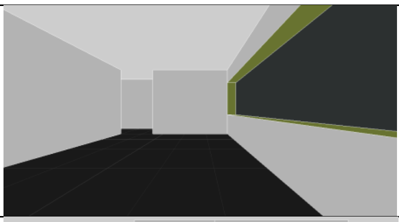
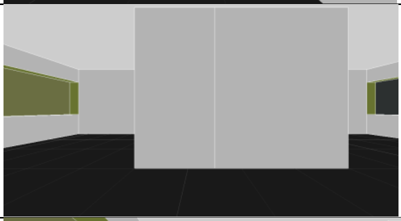
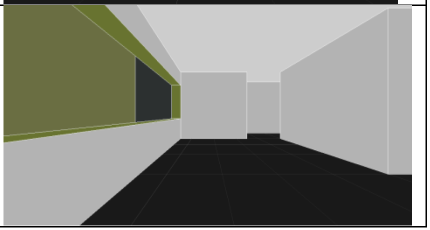


Figure 1: 3D view of the case study office & position of the three occupants in the open plan office

Table 1: Occupants descriptions and field of view

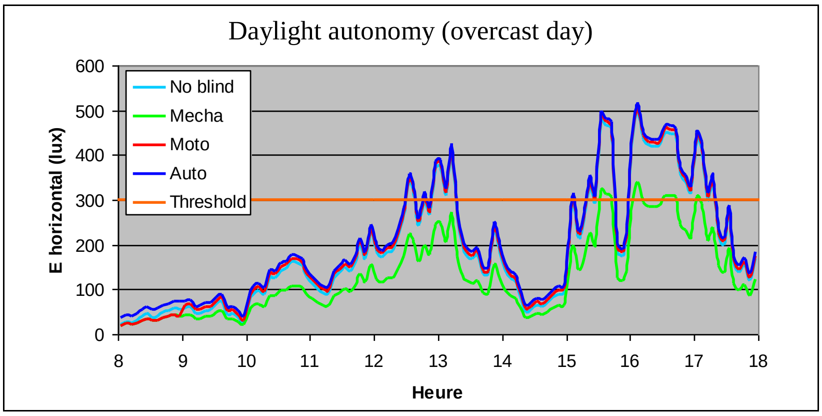
Occupant	Description	View
O_W	Located near the West façade of the open plan office, facing South, no obstruction outside the window	
O_M	Located in the middle of the open plan office, facing South, distant windows on each side	
O_E	Located near the East façade of the open plan office, facing South, one obstruction outside the window	

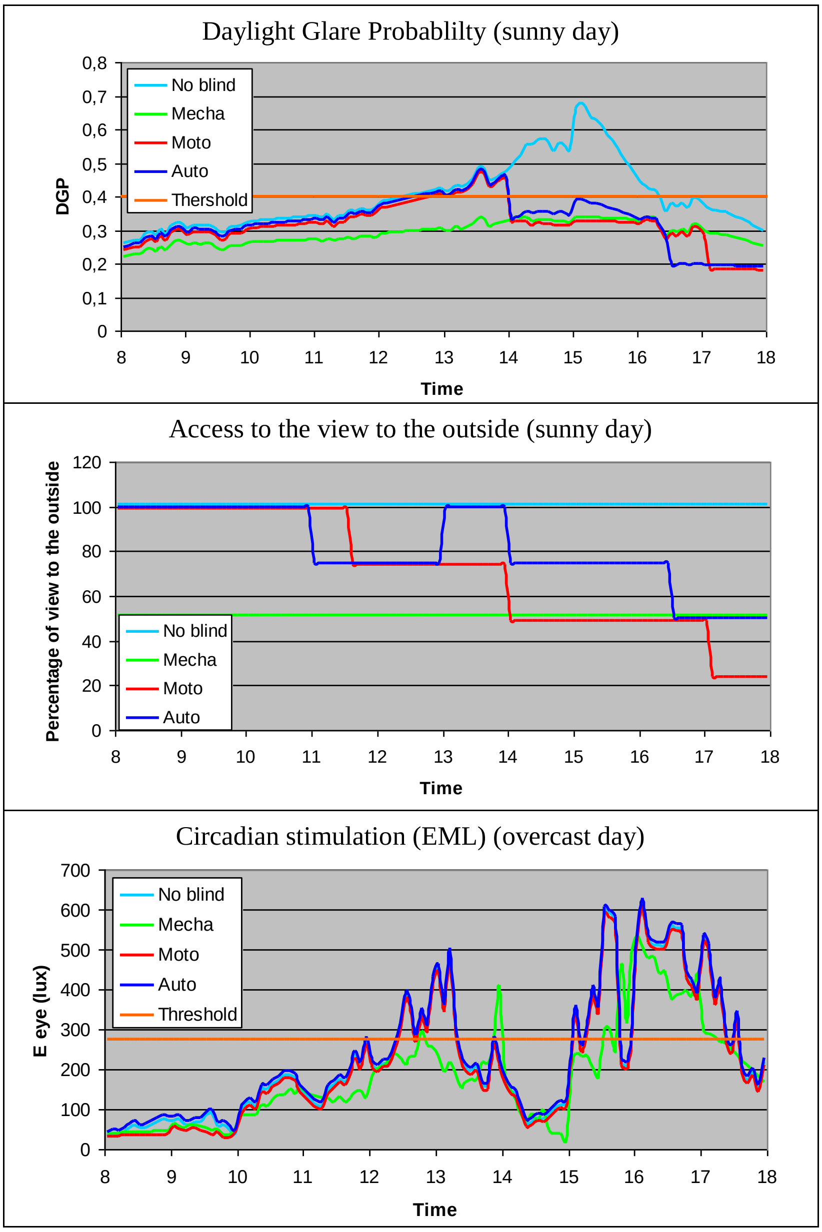
Thirdly, we establish some hypotheses, based on literature, about how blinds may be used for each of the three control strategies for the venetian blinds.

- Mechanical blinds with manual control: literature shows that in this situation, office occupants rarely action their blinds. We are considering the worst case scenario hypotheses: venetian blinds are always down with slats in the horizontal position.
- Motorized blinds with manual control: in this case, we can suggest that blinds may be actionned once or twice a day as soon as direct sunlight causes glare to the occupant. Slats will they be tilted in order to block direct sunlight.
- Motorized blinds with automated control: the suntracking algorithm considered here will position the slats of the blinds in order to block direct sunlight when it occurs.

Fourthly, we run the simulations to calculate the five metrics of the methodology. Calculations are carried out for a bright sunny day in June (Meteonorm weather file) and for an overcast summer day in June (Meteonorm weather file).

For these specific days and the occupants positions according to the methodology, each metric varies as follows for each control strategy of the venetian blinds. The no-blind option is also presented.




Daylight Glare Probablilty (sunny day)
DGP
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
8 9 10 11 12 13 14 15 16 17 18
Time
No blind
Mecha
Moto
Auto
Thershold
Access to the view to the outside (sunny day)
Percentage of view to the outside
120
100
80
60
40
20
0
8 9 10 11 12 13 14 15 16 17 18
Time
No blind
Mecha
Moto
Auto
Circadian stimulation (EML) (overcast day)
E eye (lux)
700
600
500
400
300
200
100
0
8 9 10 11 12 13 14 15 16 17 18
Time
No blind
Mecha
Moto
Auto
Threshold

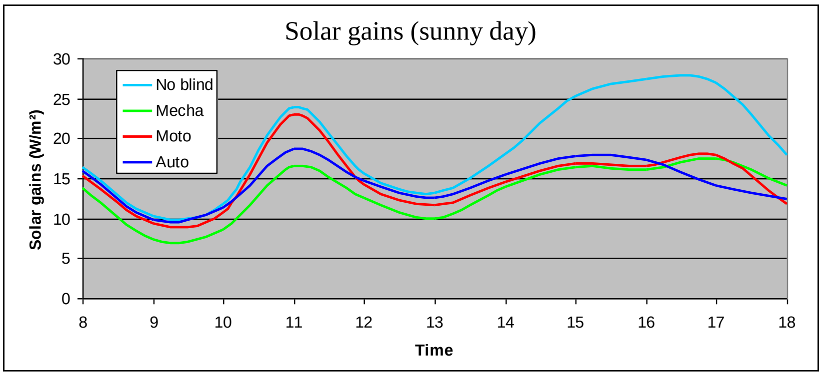


Figure 3: Performance diagrams for the five metrics and the various shading systems control strategies

NB : to facilitate the readability of the diagrams, the data was slightly shifted when there was overlapping

A summary of the performances for each control strategy is presented in Table 2.

Table 2: Summary of the performances for each blind control strategy

	Autonomy	DGP	EML	View	Solar gains
No blind	2h20	3h40	3h00	100%	1,96 kWh/m²
Mechanical / Manual	0h40	0h	1h50	50%	1,52 kWh/m²
Motorized / Manual	2h20	1h10	3h00	72%	1,62 kWh/m²
Motorized / Automated	2h20	1h10	3h00	81%	1,54 kWh/m²

Several observations can made from these performance diagrams :

- No blind : Daylight autonomy, circadian stimulation and the view to the outside perform very well (as expected). Glare and solar gains are the worst compared to the other scenarios (also as expected).
- Mechanical / Manual : This option is the worst of all three control scenarios. Performances in daylight autonomy, circadian stimulation and view to the outside are mediocre. Glare and solar gains performances are optimal but this is due to the hypothesis that blinds are down all the time with this control strategy which is not a good option.
- Motorized / Manual : Daylight autonomy and circadian stimulation are optimal but some glare persists, the view to the outside is acceptable but not optimal.

- Motorized / Automated : All metrics perform well with the scenario except glare. This could be explained by the fact that the action threshold of the blinds for this suntracking algorithm could be optimized.

The last step consists in a qualitative analysis of the gains (monetizable and non-monetizable) for the various stakeholders (building owner, occupant, users and facilities manager) associated with the three blinds control strategies. This analysis is presented in Table 3.

Table 3: Potential gains of the three blinds control strategies

	Mechanical / Manual	Motorized / Manual	Motorized / Automated
Building owner	No monetizable impact	Increases the property value	Increases the property value
Occupant	Air conditioning costs are lower	Lower air conditioning and electric lighting costs	Lower air conditioning and electric lighting costs
Users	Performance and productivity may be impaired due to glare and overheating	Better thermal comfort but glare and limited view out may impair performance and mood.	View out is maintained which may improve mood but glare potential might lower performance. An automated control for blinds can sometimes be rejected by users if not properly programmed which can lower productivity
Facilities manager	Small maintenance cost.	Standard maintenance costs are to be expected	Higher maintenance costs are to be expected

Based on the performance detailed in Table 1, the analysis of the potential gains in Table 2 and the budget allocated, the building occupant decided to select the Motorized / Manual option for controlling the blinds.

4. CONCLUSIONS

The proposed methodology represents a way of selecting a shading system control strategy based on a 5 daylighting metrics analysis. The qualitative analysis of the impacts for the various stakeholders also gives an insight of the anticipated financial and non-financial effects of each control strategy. The Efficacity Institute is currently investigating ways to monetize these effects. These monetized effect coupled with the methodology presented in this paper give a broad view of the impacts of a shading system control strategy and can help in the selection of the appropriate strategy for a project.

The methodology still requires some fine tuning but the multi-impact approach is a good way to select a control strategy for a shading system taking into account all parameters of a luminous ambiance in daylight and the impacts it has on the stakeholders.

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Spatial Analysis for Equitable Accessibility in Social Infrastructure Planning

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Key words: Inequality, Accessibility, Data, Spatial Analysis, Planning

Abstract: Equitable access can be taken as an indicator of good social infrastructure planning. Due to the inevitable spatial separation between demand and supply, inequality in accessibility has an inherently spatial dimension. An innovative approach has been developed and tested in this study. The proposed approach is less computationally intensive and overcomes some of the disadvantages of conventional approaches. It is based on the average distance of residents to the nearest service / facility by small area geography. It will support rapid assessments of inequalities and 'what-if' analyses in a planning context.

1. Introduction

Social infrastructure in the UK generally includes: healthcare, education, community facilities, emergency and other essential services. In order to ensure that social services are delivered effectively and comprehensively, social infrastructure should be well planned for new developments, regeneration and in rationalising the efficient use of available resources. In social infrastructure planning, there is always a challenge to match the service supplies and the local demands. In recent years, increasing difficulties are raised from both supply-side and demand-side because of rapid demographic changes in many areas of UK. Considerable effort has been made to improve social infrastructure planning.

The quantitative analysis and modelling of networks along with spatial cognition and navigation / wayfinding are important research topics in GIScience (e.g. Duckham et al. 2003, Heywood et al. 2011). Spatial accessibility here commonly refers to the ease with which something or somebody can be reached, which from a spatial perspective also implies nearness (distance) or ease of travel. In this study, carried out in the context of social infrastructure planning in the UK, equitable access to services / facilities across a region shows a consistent match between supply and demand and can be taken as an indicator of good planning (Rosero-Bixby 2004, HUDU 2007). Due to the inevitable spatial separation between demand and supply, inequality in accessibility has an inherently spatial dimension. Spatial accessibility therefore plays an important role in equal access to social services, together with service availability, demographic variety and other social-economic factors.

Measures of spatial accessibility are an effective means of analysing inequalities within the organisation of social services (Rouse & Serban 2014). Spatial accessibility analyses are normally associated with large amount of data, a range of variables, intensive computation and arbitrate assumptions. To efficiently capture accessibility by small area geography as an input to analyses of inequalities and to inform social infrastructure planning, a novel approach has been developed and tested which is less computationally intensive and overcomes some of the disadvantages of conventional approaches.

2. Spatial Accessibility to Social Infrastructure Facilities

2.1 Supply-side view and the demand-side view of spatial accessibility

There are two broad aspects (or stages) of social infrastructure planning: demand and supply. As summarised in Figure 1, demand includes needy population, demographical structure and prevalence whilst supply includes models, estates and workforce. In term of planning and management, spatial accessibility is seen as the mediation (or bridge) of supply and demand for social services. Inequality in accessibility is normally suggested as a practical or operable indicator of inequality in social services (Waters 2000).

Within a planning area, inequality in local social services is relative, as it is caused by imbalances in supply and demand across space. Correspondingly, relative spatial accessibility needs to be measured rather than in absolute terms. Relative spatial accessibility could be represented by relative distance, ranked travel cost or classified geography. Meanwhile, social infrastructure planning in UK is mainly carried out at a local scale, for example by local councils, NHS Trusts / GP consortia, or local education authorities. Details of spatial accessibility in relation to relevant social-economic variables are thus desirable by small area geography.

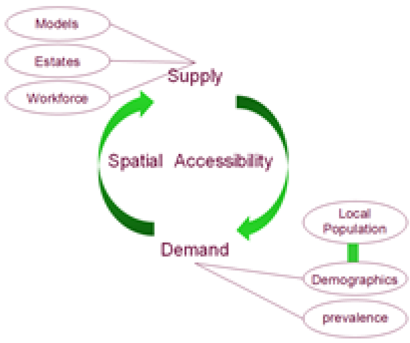

Figure 1. Demand and supply of social infrastructure

From the spatial accessibility perspective, there are two groups of approaches based on the supply-side view and the demand-side view respectively. Conventional approaches to accessibility normally include concentric buffers and polygons of network drive/walk times around individual or groups of facilities. This puts the point of origin for any accessibility at the facility being accessed and is therefore a supply-side view. One problem with such approaches is transforming the zones thus produced into a variable that can be attached to administrative units for further analysis. A demand-side view starts with where people live and estimates the distance required to access their nearest facilities. Substantial effort have been made on travel cost calculation in order to achieve accurate and comprehensive measures, which at the same time lead to more complex and less compatible approaches.

2.2 Techniques of spatial accessibility measurement

Approaches based on supply-side and the demand-side views can be seen in various techniques of spatial accessibility measurement (Guagliardo 2004, Liu & Zhu 2004). This paper broadly classifies spatial accessibility measures in social infrastructure planning into 3 categories: catchment profile, travel impedance and gravity model.

Catchment profile is normally based on provider-to-population ratio where the catchments can be administrative areas or specified zones (such as buffer zones or driving zones). Catchment profile is typically supply-side view based. Recent researches are trying to incorporate demand-side view into catchment profile, such as the two step floating catchment area method (McGrail, 2012).

Travel impedance is often referred as travel cost, which can be Euclidean distance (straight-line distance), road network distance, or travel time or travel cost in general. The distances can be the nearest distances from origins to destinations, and can be summed or averaged in different ways. Travel costs can be calculated by car driving, walk or bus. Travel impedance sometimes also refers as opportunity-based measures or opportunity models, as it looks at opportunities (or destinations) available within a certain distance from an origin. Travel impedance is mostly demand-side view based.

Over decades, details of travel cost have been thoroughly studied to take into account as many factors as possible. Diverse travel modes (rail, underground or ambulance), variable congestion levels (peak and off-peak speeds, road conditions, weather), and schedules/time budgets could be further taken into account (O'Sullivan, 2000; Ford et al., 2015; Ertugay & Duzgun, 2015). The difference between distance measures (e.g. Euclidean, network and travel time) has been discussed, for example the noteworthy impact from network type, network design and transit facility (Gutierrez & Garcia-Palomares, 2008). The strong correlation of different distance measures has also been initially explored by LSOA in the context of accessibility to UK hospital outpatient departments (Dusheiko et al., 2009). Distance or derived variables of distance are accepted as important criteria to support decision-making in term of spatial accessibility to social facilities (Ohta et al., 2009, Munoz & Kallestal, 2012).

Gravity model attempts to reflect the spatial interaction between supply and demand by travel impedance. It suggests that the attractiveness of supply and demand is related to their sizes and the travel impedance between them. Gravity model sometimes also refers as potential model, as it is related to demand potential, such as needy population or prevalence.

Gravity modelling has attracted scores of attentions, might be because it takes into account both supply-side and demand-side views. Moreover, it normally doesn't require detailed calculation of distance. The principle of gravity-type measures is based on Newton's Law of Gravitation. A variety of gravity-type methods have been developed to improve the spatial accessibility measurement. For example, the Gaussian kernel density method is developed to create a continuous surface with ratio values of provider density to population density across the study area, which intends to represent the estimated spatial accessibility (Schuurman et al., 2010).

2.2 Challenges

Spatial accessibility measurement has been improved significantly with increasing complex methods and growing amount of detailed information. On the other hand, there are more restriction and limitation associated with these advance measures because of sensitivity and assumption introduced.

The design of catchment may be sensitive to geographic scale, boundary system and uneven population distribution. It brings difficulties to achieve accurate measurement of spatial accessibility. The use of transport networks requires assumptions to be made not only of appropriate travel speeds, but of the mode of travel as the available network will differ. Some inappropriate assumptions might result in a poor understanding of local accessibility. For example, a study of accessibility to health services in Liverpool was based on the public transport network, but a survey showed that only 19% respondents took public transport to visit a GP.

Demographic data could be quickly outdated due to (i)migration, regeneration, dramatic financial situations and new government policies. Furthermore, there is often professional data involved in many advance measures of spatial accessibility, such as road network, transport and remote sensing. Many of these data may not be available in public domain while detailed data preparation may be outside the skill set of planers of social infrastructure. Associated with large volume of data and complex method, there is also a heavy computational burden in measuring local spatial accessibility. Finally, the complexity of such advance measures may not provide an intuitive result that can be readily understood, interpreted and further analysed alongside other variables such as deprivation. These drawbacks are likely to constrain the use of accessibility measurement and the advantages that it offers to local social infrastructure planning.

Challenges remain to establish robust and flexible approaches for various applications. Issues of sensitivity and assumption deserve more attentions, because these issues may have knock-on effect on the quality of accessibility measurement. Problems of data availability and computation load need to be deal with in order to increase practical feasibility. Straightforward and rapid 'what-if' analyses are also expected for local planning.

3. The Approach of Average Weighted Distance

In this study, a novel approach is developed to measure the inequalities in relative spatial accessibility to local social services / facilities from the perspective of where people live. As this study intend to reduce the complexity of accessibility measurement, major factors will be identified rather than exhausting every detail. The proposed approach therefore leads to higher compatibility and less computational burden than complex / comprehensive methods whilst correlates well with them. Meanwhile, by using updated time series data available in public domain, local organisations are able to monitor and analyse spatial accessibility locally in a timely manner.

The proposed approach is based an innovative variable, called average weighted distance (AWD), which was initially deigned in our previous study. AWD is derived from the average distance of residents to a nearest facility by small area geography and further weighted by population distribution. No assumption is made for this variable in term of travel cost.

OA (Output Area – the standard geography in UK census statistics) is chosen as the basic geographic unit, because it is a very small area geography and can be associated with many demographic and socio-economic variables. It could then support in-depth analysis of inequality for social infrastructure planning. Moreover, the proposed approach can be applied on different geographic scales (such as LSOA and MSOA in UK census statistics, or Ward in UK administrative boundaries).

3.1 Distributed population

Population distribution can exert significant influence on spatial accessibility measurement (Langford et al. 2008). However there is a lack of up-to-date inter-census information about population distribution by small area geography. There are some alternative data which have been used in relevant research (Eicher & Brewer, 2001; Landford, 2004), such as aerial image or cartographic maps. However local organisations are not likely to have expertise on image processing / interoperation or map query / operation. These data may also have large data volume and expensive cost. More importantly, both aerial images and cartographic maps don’t have information about how many people residing in these buildings.

For each postcode unit, OS (Ordnance Survey) CodePoint provides a geographic delivery centroid as well as the number of domestic deliveries. This is used as a proxy of population distribution within an OA or LSOA. As the up-to-date population data are only available on LSOA scale, screening tests have been carried out by LSOA to check the correlation between domestic delivery and residential population. Test results show strong correlation for most districts between delivery and population. For example in the case study areas of this project, the correlation coefficient is

0.86 for Uttlesford, 0.67 for Haringey, 0.89 for Milton Keynes, 0.78 for Wellingborough. However, for districts with dense population and diverse community in metropolitan area, the situation could be complicated by variation of household composition across space and over time. It might lead to weak correlation between delivery and population (Brimicombe et al., 2009). In such case, multiple regression models could be developed by domestic delivery along with other variables, such as household size, empty households and multiple occupied households.

3.2 Correlated distances

As mentioned early, this study proposes an approach to measure the relative inequalities in spatial accessibility based on distant. The distance is therefore calculated for comparing the ease of travel rather than the exact travel cost. In order to achieve general applicability and lighter computation, a straightforward distance measure is expected in the proposed approach. The correlation of different distance measures has then been explored in various UK districts. This study will prefer the distance measure with less computation load if it is well correlated with complex distance measures.

In geographical information systems (GIS) there are three measures of distance that are readily computable: Euclidean, Manhattan and network distance. The network distance can be taken as is (network geometry), or further refined to reflect impedances such as speed limit, congestion level, one-way systems and restricted access (attributed network). Euclidean distance is the simplest to calculate, attributed network the most complex.

The correlation between Euclidean and road network distance is initially investigated in the case study areas of London Borough Haringey (with 2500m buffer zone) and Uttlesford district (with 5000m buffer zone) as typical urban district and comparable rural district respectively. Road network data is extracted from ITN (Integrated Transport Network) layer of OS Master Map.

Distances are calculated from each CodePoint delivery centroid to the nearest Pharmacy and GP surgery. Results in Table 1 show very strong distance correlations at both districts. It is consistent with other research carried out before (Dusheiko et al., 2009). The correlations in rural area are even stronger than in urban area. It may be because distances to Pharmacies / GP surgeries in rural area are much longer than those in urban area. Moreover, routes in rural area are not constrained by building blocks. Euclidean distance is then chosen as the preferred distance measure in this study.

Table 1. Correlation between Euclidean distance and road network distance

Case Study Area	Correlation of distances to Pharmacies	Correlation of distances to GP surgeries
Haringey (Urban)	0.916	0.947
Uttlesford (Rural)	0.977	0.980

3.3 The average weighted distance

In order to overcome the methodological issues mentioned early in this paper, an innovative variable (i.e. Average Weighted Distance - AWD) is devised to calculate an overall accessibility for small area geography (OA or LSOA) based on the distance from each residential home to the nearest facility. The distance is calculated from each CodePoint delivery centroid to the nearest facility, weighted by the number of domestic deliveries and averaged for the OA or LSOA. This makes no assumption about details of travel cost. Such accessibility measurement is relative and therefore comparable across a study area. To avoid boundary problems, it is recommended that the study area could be buffered.

Euclidean distance is often the preferred distance measure in Average Weighted Distance while other distance measures are not excluded. As mentioned early, the principle is that the preferred distance measure will have less computation load and be well correlated with complex distance measures.

The general principle for AWD is expressed in equation (1). Figure 2 illustrates how AWD is derived within an OA.

$$OA_F = \frac{\sum \left(W_{ddp}^{P} \times D_F^{P} \right)}{N_{ddp}^{OA}} \tag{1}$$

where:

OA_F = OA average weighted distance to a facility

D_F^P = Euclidean distance from postcode centroid to nearest facility

W_{ddp}^{P} = weight equal to the number of domestic deliveries within each postcode unit

N_{ddp}^{OA} = total number of domestic delivery points for the OA

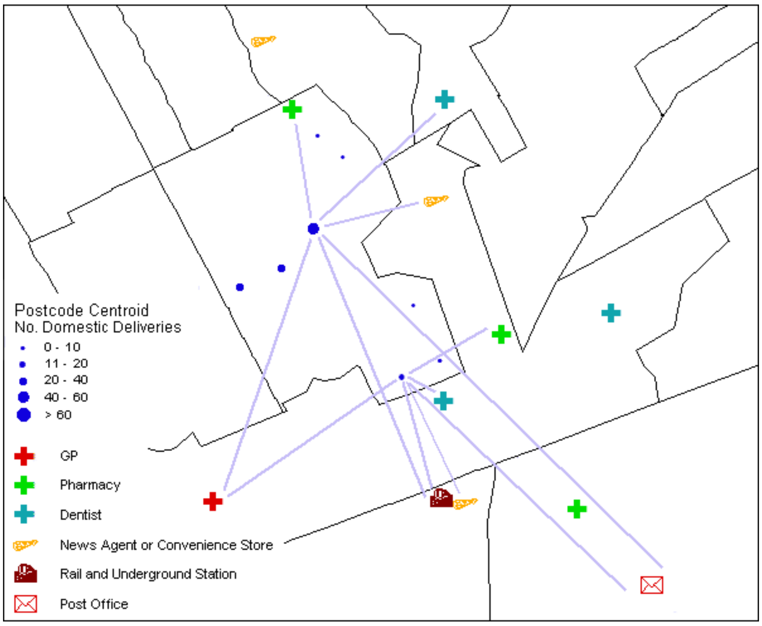

Figure 2. Deriving AWD for an OA
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4. Case Studies

A series of case studies have been excised to test the feasibility and pragmatics of the proposed approach. Average weighted Distances (AWD) are computed and mapped for various UK districts by OA. Investigation is particularly carried out for the correlations and patterns of spatial accessibilities based on different distance measures. Local inequality could then be assessed in term of the chosen spatial accessibility.

Distance measures examined in the following case studies include Euclidean distance, network distance and attributed network distance (or travel cost). Attributed network distance here is calculated as travel time which takes into account speed limit, congestion level and other impedances. The input data are mainly from NHS (i.e. GP data and pharmacy data), Ordnance Survey (i.e. CodePoint) and ONS (i.e. MYE population). Network geometry is available from OS ITN data and further attributes from NAVTEQ routing.

To reflect various spatial conditions, four UK districts are selected as case study areas. London Borough of Haringey is a typical urban district with high population density. Uttlesford is a comparable rural district with only small to medium sized towns. Milton Keynes is a district with nearly half rural area and half urban area. Wellingborough is a rural district with a large town. All case study areas will be buffered to overcome boundary effect. In the other word, residents could cross administrative boundary to reach nearer social services/facilities. A 2.5km buffer zone is created for Haringey and a 5km buffer zone is created for Uttlesford. A 10km buffer zone is created for both Milton Keynes and Wellingborough, as these two districts are adjacent to each other. The size of buffer zone is mainly based on the consideration of population density and geometric shape.

4.1 Case study for AWD to local pharmacies in Haringey and Uttlesford

Two case study areas are selected: London borough of Haringey and Uttlesford district. Pharmacy is selected as the social facility for modelling accessibility. There are 4738 postcode units in Haringey and 185 pharmacies within 2.5km buffered boundary while 2631 postcode units in Uttlesford and 26 pharmacies within 5km buffered boundary.

As illustrated in Figure 3, Euclidean distances can be rapidly calculated using GIS whilst network distances need more editing and higher computational loads. It takes approximate 8 hours for Haringey and 2 hours for Uttlesford to calculated network distance from each CodePoint delivery centroid to the nearest pharmacy. AWDs are then computed based on Euclidean and network distances by OA. The exact lengths are of course different for Euclidean-based AWD and network-based AWD. The median percentage difference is 28% (130m) for Haringey and 21% (670m) for Uttlesford. However, there are strong correlations between these two types of distance measures where coefficient is 0.936 for Haringey and 0.981 for Uttlesford (see Fig 4 for regression models). Such strong correlation supports the concept that AWD based on Euclidean distance can provide an acceptable relative measure, which aims to develop a straightforward approach for rapid assessments.

Although correlations and regressions are generally strong (consist with the earlier test). In the up-right part of Fig.4 (a), there are 4 dots noticeably beyond the 95% confident line. They correspond to 4 OAs in south-east of Haringey, which are marked by yellow colour in Fig.5 (a). The zoom-in map of Fig.5 (b) shows that these 4 OAs is a relatively isolated community with only one way-out road to the nearest pharmacy according to OS ITN data.

A visual comparison of the results is given in Fig 6. This shows the relative inequalities in accessibility to a pharmacy. It can be seen that

Euclidean-based AWD and network based-AWD result in very similar spatial patterns in both Haringey and Uttlesford. Such similar patterns will make no difference on decision-making in social infrastructure planning.

Thus if a local GP consortium wishes to evaluate filling the gaps in accessibility to commercial pharmacies, with Euclidean-based AWD, it can rapidly 'what-if' model additional pharmacies attached to existing surgeries.

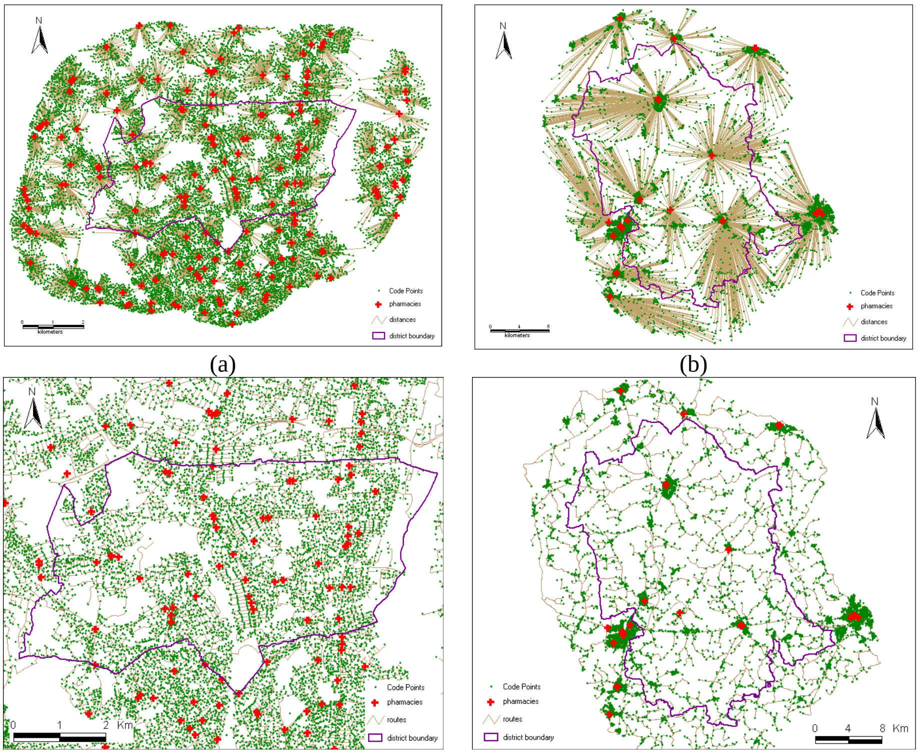
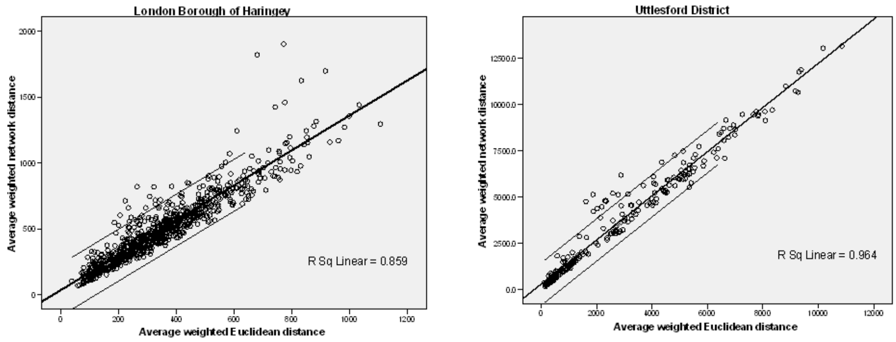
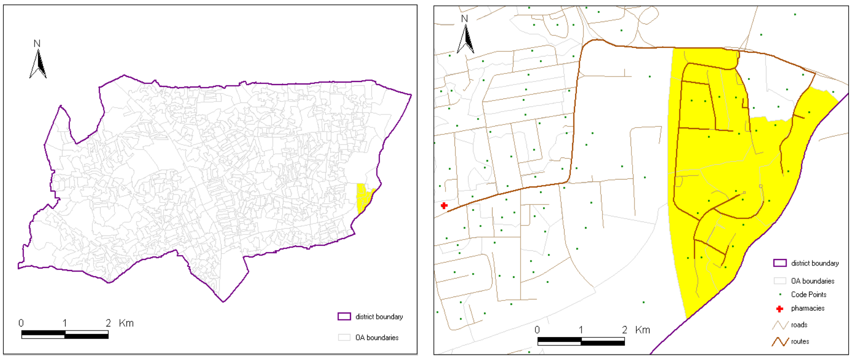


Figure 2. Distances from Code Points delivery centroids to nearest pharmacies
(a) Euclidean distances for Haringey, (b) Euclidean distances for Uttlesford,
(c) network distances for Haringey, (d) network distances for Uttlesford.
(data Crown Copyright)



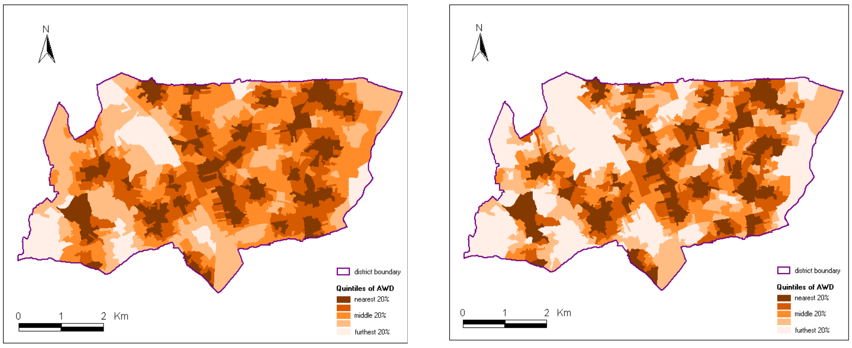
(a) (b)

Figure 3. Regression between Euclidean-based AWD and network-based AWD
(a) London Borough of Haringey, (b) Uttlesford District.

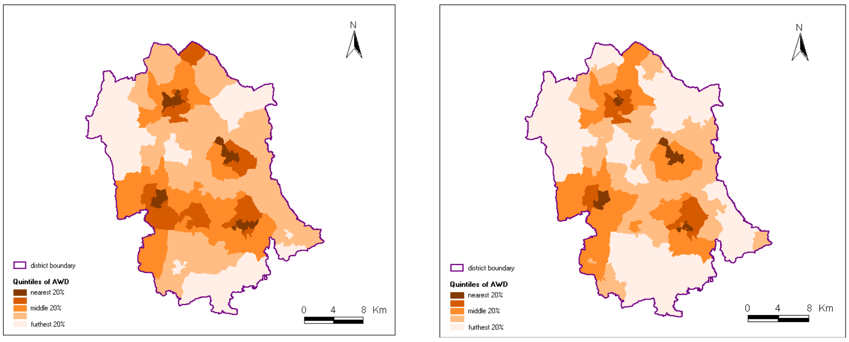


(a) (b)

Figure 4. (a) Haringey by OA, (b) the 4 OAs corresponding to 4 outliers in regression



(a) (b)



(c) (d)

Figure 5. Spatial accessibility to local pharmacies

(a) Euclidean-based AWD for Haringey, (b) network-based AWD for Haringey,

(c) Euclidean-based AWD for Uttlesford, (d) network-based AWD for Uttlesford.

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4.2 Case study for AWD to local GP surgeries in Haringey, Milton Keynes and Wellingborough

Here are three case study areas which are London borough of Haringey, Milton Keynes district and Wellingborough district. GP surgery represents the social facility in accessibility modelling. Haringey has 4738 postcode units with 92 GP surgeries within 2.5km buffered boundary, Milton Keynes and Wellingborough have 8893 postcode units with 130 GP surgeries within 10km buffered boundary.

For each OA, AWDs are computed by Euclidean distance, network distance, driving time by car and driving time by ambulance. All distances are calculated from each CodePoint delivery centroid to the nearest GP surgery in three case study areas. Correlation and spatial pattern are then studied between AWD based on Euclidean distance and AWDs based on other types of travel cost.

Table 2 shows very strong correlations between Euclidean and network distances, Euclidean distance and driving time by car, Euclidean distance and driving time by ambulance. Furthermore, Table 3 confirms very strong correlations between Euclidean-based and network-based AWDs, Euclidean-based and car-based AWDs, Euclidean-based and ambulance-basded AWDs. Again, slight stronger correlation can be seen in rural area. These results are consistent with the case study in 4.1.

Maps in Fig.6 and Fig.7 represent spatial accessibility to local GP surgeries for Haringey, Milton Keynes and Wellingborough respectively. In all 3 districts, similar spatial patterns can be found for Euclidean-based AWD, network-based AWD, car-based AWD and ambulance-based AWD. Having considered more complex travel cost (i.e. driving time by car and ambulance), Euclidean-based AWD is still the preferred spatial accessibility measure for this case study.

Table 2. Correlation between Euclidean distance and other distances

Study Area	Euclidean & network distances	Euclidean distance & driving time by car	Euclidean distance & driving time by ambulance
Haringey	0.905	0.870	0.875
Milton Keynes	0.943	0.921	0.919
Wellingborough	0.962	0.924	0.908

Table 3. Correlation between Euclidean-based AWD and other AWDs

Study Area	Euclidean & network based AWDs	Euclidean & car based AWDs	Euclidean & ambulance based AWDs
Haringey	0.924	0.902	0.903
Milton Keynes	0.951	0.945	0.935
Wellingborough	0.967	0.924	0.904

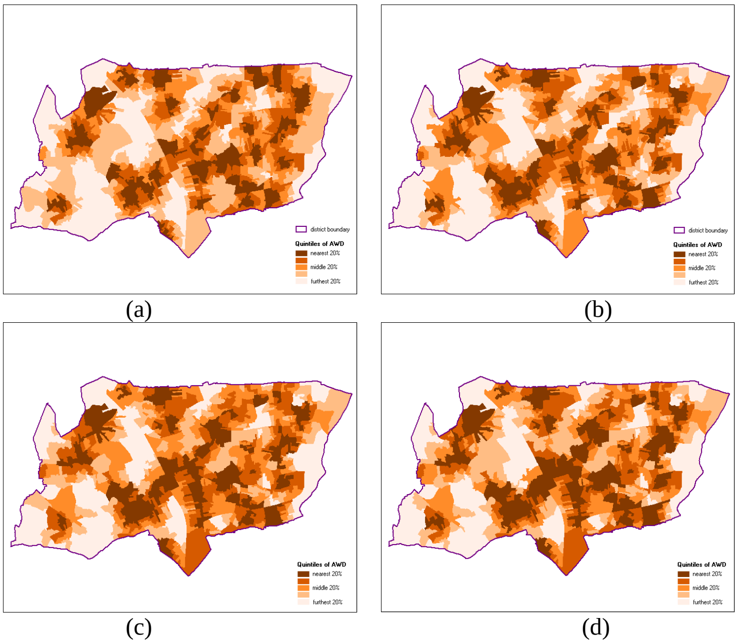

Figure 6. Spatial accessibility to local GP surgeries in Haringey
(a) Euclidean-based AWD, (b) network-based AWD,
(c) car-based driving AWD, (d) ambulance-based driving AWD.
(boundaries Crown Copyright)

(a) (b) (c) (d)

Figure 7. Spatial accessibility to local GP surgeries in Milton Keynes and Wellingborough
(a) Euclidean-based AWD, (b) network-based AWD,
(c) car-based driving AWD, (d) ambulance-based driving AWD.
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5. Conclusion

A novel approach based on AWD is developed to measure and analyse spatial accessibility by small area geography. Input data of this approach are available in public domain and can be easily accessed. It will support rapid assessments of inequalities and 'what-if' analyses in local social infrastructure planning. The approach can use Euclidean distance, network distance and other travel costs with postcode delivery centroids as the atomic spatial unit. However, it is found that AWDs based on different distances / travel costs have high correlations and therefore result in similar patterns of relative inequality. The Euclidean distance approach has less computational load and is generally applicable, particularly where rapid 'what-if' analyses are required for decision-making support in a planning context when various alternatives are considered at early stage. Local organisations are then able to interpret spatial accessibility measurement and further analyse inequality with a range of demographic and socio-economic variables as well as monitor changes in accessibility over time.

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Establish, Exchange and Engage:

A Support System for Multiple Decisions to Co-produce

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Key words: Participatory, Housing Design System, Computer-Aided, Bottom-up

Abstract: This paper explores the conference theme of design decision support system within the context of participatory housing in urban cities. An alternative to the standard one-fits-all formal housing typology is introduced. The authors believe that by utilizing a Computer Aided Participatory Housing Design System (CAPHDS) to incorporate the end-users (occupants), an informal and collective housing typology that best matches the end users desires can be achieved. The participation of end-users could help encourage informed inclusion in the design process. Ultimately, this would facilitate in achieving a closer match to the expectations and desires of the end user. In this constant changing environment, the collective data from a CAPHDS provides opportunities for innovation to inspire the architects in preparing the framework for the remaining parts of the design and building production.

1. INTRODUCTION

The increase of city dwellers has resulted in an increase of dwelling density and limitations to urban land availability. This led to a higher demand for high-rise residential buildings. Housing, thus becomes one of the major topics of discussion; from political point-of-view as a form of nation building (Wright, 1983), to economics in providing affordable houses to the mass (Grimes, 1976) and using housing as a form of investments (Case et al, 1990), and to social aspect of community planning (Bauer, 1951).

Along with the rise in housing demand, is the constant evolution of housing needs. This is usually due to factors such as changes in family sizes, development of technology, changes in the climate environment and moving simply to relocate. It is not surprising that there is numerous research with the keywords revolving evolutionary habitat: adaptable, expandable, a la carte, convertible, dynamic, elastic, scalable, extensible, flexible, mobile, modular, customizable, flexible, convertible, variable, etc. (Perianez, 2013).

Architects have historically aimed to design with a response to context and to reflect the needs of occupants (Rapoport, 2005). If given the choice, they would tailor every design to suit every user who could help move towards a sustainable future (Fuad-Luke, 2013). However, the current issue lies with property developers trying to meet the markets base level of desire and are largely not motivated or responsive to the sensibilities or skills of architects and architectural design. This is especially pronounced in the context of high-rise apartments, where the number of occupants further hinders the architects to achieve this ambition. This lead to the rise of research undertaken by John Habraken (1961) who created an architectural research foundation, SAR, to look at the open building. The seminal objectives of his research are to promote a flexible design that could collaborate all players in the design-build-promoting process which he puts them into two main problems.

"We had to solve two problems of methodology: The first was the coordination problem. First, make possible the development and construction of the systems "support" so that any detachable unit can adapt the other hand make possible the production of the detachable unit so that they adapt to any medium. It was then necessary to develop a modular system of coordination that allows such technical coordination, a modular system of coordination that is not used primarily for the standardization of compositional elements but for the coordination of decisions at the design plan. This coordination, standardization could follow. The second methodological problem was the assessment. The support project is to be judged by a set of possible solutions to current plans……" (Habraken, 1975)

This paper will focus on the first problem of Habraken's methodology by identifying the need for a digital platform to increase design participation in creating flexible yet cost effective mass housing. The research that has been undertaken (Lo et al., 2015) further indicates the possibilities and opportunities but are not sufficient to execute the process for high-rise high-density mass-housing context. Most of the research focuses on single houses as the complexity is minimum and the parameters can be controlled much more efficiently. Also, most of the systems still work in a top-down, single directional manner where the architects will design almost everything, provide very limited choices to the users. The users will also use the systems without any communication with the architects. This paper thus looks into the missing links in mass housing designs from the design stage to the construction stage.

2. CAPHDS FOR CO-PRODUCTION

Participation using digital tools is always presented with one challenge: how can we engage participants, or in our case end users? CAPHDS can be summarized to two main objectives: i) aiding end users to envision their housing needs and ii) provide a platform for sharing and communication between the architects and end users during the design process. This ontology would be used to ensure consistency in the evaluation of the design outcome. Since the system allows the end users to set their criteria and target values, it is possible that, although the targets are met, the end users may still not be satisfied when they compare their outcomes with those of others.

The definition of the practicability in computer aided design systems has however always been ambiguous. In a participatory context, the diverse and changing perceptions of the participants makes it increasingly difficult to determine if the outcome from the system is effective. In addition, there are many challenges faced in this system. Shuffling between simplification for the people and complexity for the architects demands a clear structure to ensure the possibility of this collaboration. The idea of an ideal living space can somewhat be easily achieved individually, but to fulfil the overall collective needs in the building design requires a great deal of complex design networks that this research might not be able to resolves. The design structure itself is only possible theoretically in an ideal situation, certain assumptions have to be made to complete the current level of demonstration. This paper sets out to establish a framework aiming to identify and discuss the assumptions behind the development of the CAPHDS framework for ‘ModRule.'

ModRule is a platform designed to facilitate collaboration between architects and future end users during the preliminary stage of mass housing design (Lo et al., 2015). Individuals set their desired parameters for the design by completing a built-in questionnaire, which elicits problems with their current living space and provides for the design of an improved version of their living space 'dream' that might not be achievable. It is possible for users to interact, viewing each other's profiles on the site, thus gaining insight into tolerances within the housing system.

Using ModRule as the CAPHDS structure of design participation, the architects set the range of system parameters, within which the end users set their space requirements, budget, orientation, daylight preference, etc., thus defining their desired way of living. By combining automatic and end user driven iterations, ModRule proposes a design solution that matches the intent of the end users.

Using ModRule, architects layout the building form accordingly with necessary elements such as building core, access, and utilities. The design layout will be grid accordingly so that every grid space can be input with parameters and variables. This information will be kept in the system's black box. A goal system will then be set based on their profile and end users will be engaged to design their desired living space. This goal system is like a checklist of targets that end users should follow. This is taken in reference to 'objectives' in games where players try to achieve while playing the game. A 'goal bar' is available in ModRule interface that is interacting with the parameters and variables input in each grid. The goal bars fill up accordingly while choices are being made by the end users, indicating whether they are achieving what they declared they wanted (Figure 1).

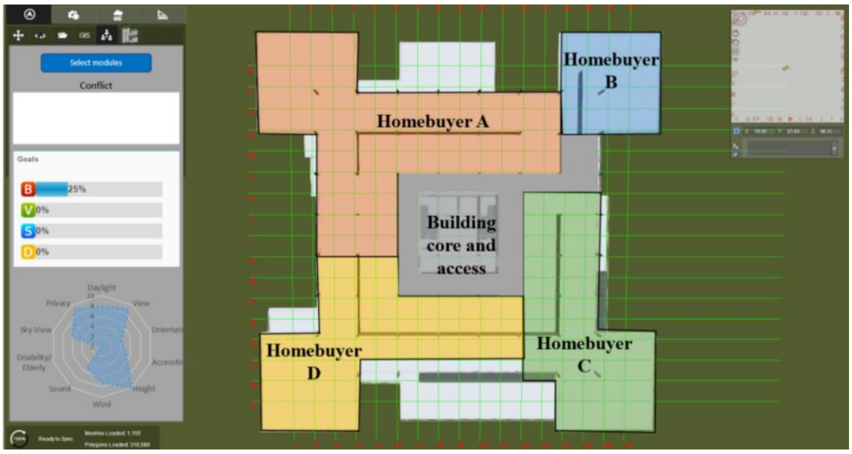

Figure 1. Interface of ModRule system showing the fixed building core set by the architects with the layout 'drawn' by four end users according to their goals and profiles

The role of the goal bar is for every individual to manage their desires. This is to ensure that users are not taking more than what they need. It is also be opened for every other participant to look at to encourage sharing and understanding as well as social interaction. Ideally, this transparency will encourage every participant to help others to achieve both, their personal and their common living spaces with neighbours since the participants will be living together in their future building.

As it is almost impossible to fulfil all goals, especially with the need to negotiate with the other end users, the aim is just to achieve as high as possible. There might even be possibilities where some goals will have to be compromised to achieve others, and these will all be decided by the end users themselves offering the participants a better understanding of the overall process and a possible higher acceptance of the outcome.

Once everyone’s goals are achieved to a certain extent, to the point everyone is satisfied with the outcome, this brings us to the final stage and the most important stage as this is where the individual ideal living spaces will be synthesised to form a common overall architectural design. At this stage, the architects take a leading role. Although the aim is to achieve an overall design through a bottom-up, ‘democratic’ process, the top-down is not negligible especially in this context of mass housing. There are too many building and architectural issues that need the knowledge of professionals to be practical.

3. PRINCIPLES OF DIGITAL PARTICIPATION

To have a better understanding and balance between the design control of architects and end users, some theoretical concepts have to be laid out. These concepts will then be applied to become the three main principles for the proposed digital participation process. The idea of open design will help with the *establishment* of the design system. The generation of the design collaboration making use of the virtual environment to enhance the information and data *exchange* between end users and architects. The formulation of the collaborative design workflow by adopting gamification as the development technique will attract more *engagement* with the end users.

3.1 Establish

How is ModRule established? Although it is now clear in terms of ModRule’s objectives and capabilities, there is still uncertainty with its foundation. In design participation, the key component is to be ‘open’. This is not simply about having people giving feedback to the designs. The idea here expands from the design process to the design components to the overall design outcome. Every detail plays a part towards establishing an accessible, efficient and flexible CAPHDS, which in this case is ModRule.

3.1.1 Open Source Architecture

Open Source Architectural (OSA) is an increasingly important field describing new procedures for the design, construction, and operation of buildings and infrastructure. Drawing from references as diverse as Open Source Culture, avant-garde architectural theory, science fiction, language theory, and others, it describes an inclusive approach to spatial design, a collaborative use of design software and the transparent operation throughout the course of a building and city's life cycle (Op-ed, 2011).

In architectural field, although the ideas and the approaches of Open Source Design have been borrowed for years, it could not yet breed a new practice of architecture due to the complexity of the architectural industry including but not limited to design, procurement, construction and many other intertwined issues. The recent Wiki-house could only deal with the simplest house solutions without really exploiting the power of collective design with the participation of the end users for collective housing, the type of architecture that need negotiation between multiple users, as well as the designer and the stakeholders.

3.1.2 Open Building

Open building is an approach to building design, and John Habraken (1961) was the first among many other incubators of open building around the world to promote it and was recognized internationally during the sixties to represent a new wave in the architectural field. The open building was not invented but developed over time in response to the ever-changing social, economic and political forces (Kendall, 2010). The idea of a bottom-up design approach is not new, and Habraken proposed two main domains of actions - the action of the community and that of the inhabitants. Without the individual inhabitant, the result is usually uniform and brutal, which can be seen in most mass housing projects nowadays. On the other hand, the community which in this case involve the designers is necessary as well. Without the design control, the spontaneous result will be chaotic and disturbing. The coherent balance between the individual participation and the top-down design manipulation is challenging as it involves all parties during the building process, which ideally led by the building masters - the architects.

The building design can be broken down into three levels of decision making; namely the Tissue, the Support and the Infill (Kendall, 2010). They are separated, yet dependent. The town fabric (tissue level) is at a higher level than the buildings, positioned within the town fabric. Buildings can be altered or replaced while the town fabric remains consistent. The buildings, in turn, can be divided into the base building (support level) and the fit-out (infill level). The higher level (support) accommodates and limits the lower level (infill), which in turn determines its requirements towards the higher (Cuperus, 2001). On every level, there is an 'ultimate customer': the consumer on the infill level, the housing corporation or developer on the support level, the municipality on the tissue level (Figure 2).

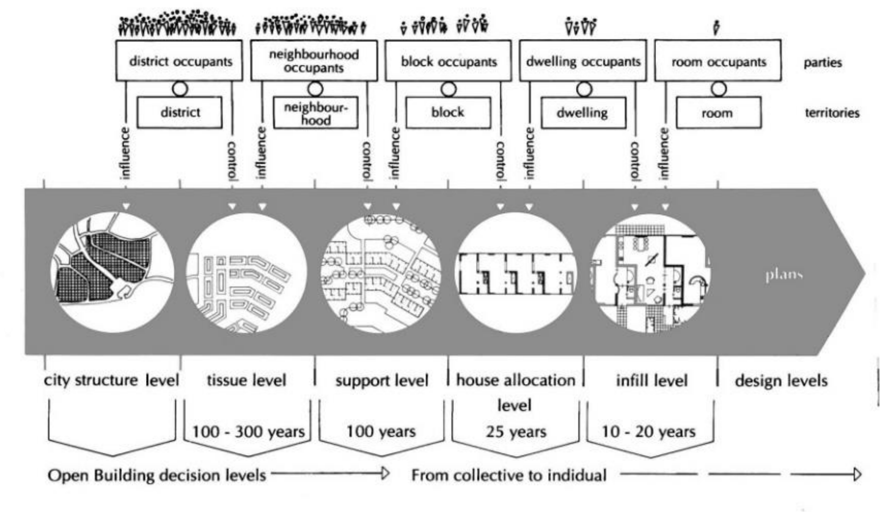

Figure 2. Open Building (Kendall, 2010)

3.1.3 Open Design

"Open Design" is made possible from the two previous definitions; Open Source provides information, and the open building provides the methodology. The main characteristics in open design are that professionals and layperson are on equal ground. Only then can communications and collaboration happens smoothly. Any stakeholders who share an interest in the design will be able to influence the design.

Open Design looks into two main aspects, social optimization and technical optimization, which cannot be separated. "A professional design also incorporates the social views of the professionals and therefore implicitly includes their social group optimum. And a social design incorporates the technical views of the non-professionals, thus implicitly including their technical group optimum." (Gunsteren, 2000).

Mass housing is one of the building typologies that requires and demands open design. The outcomes from the design process should not be dictated but communicated. Many housing that is built by the architects or governments are based on past experiences, proven concepts and methods. New urban areas in Amsterdam appears to come from the same drawing board due to the authorities following rules and proven design is creating dissatisfaction among the residence (Gunsteren, 2000). Although it is in an urban context, mass housing is the same. In fact, housing demands much more individuality as it aims to house a single family compares to urban areas which serve the general public.

3.2 Exchange

With the establishment of the design system, the next important procedure is communication and the exchange of information. In mass housing design, information ranged from individual profiles to community connection formation and to building spatial arrangement. The environment to contain all of these information has to be set up properly to enable smooth exchanges between architects and end users. Virtual environment has the capability to provide 4-dimensional information from numbers to drawings to volumetric models and even to stages of design construction. This enables the limitless exchange of data and information necessary for any form of communication during the participation process.

3.2.1 Virtual Environment

Computer Aided Design (CAD) has advanced to parameterizing of design and Building Information Modelling (BIM). Parameterizing design in line with BIM is being explored and experimented by many architects and students. Frank Gehry and Zaha Hadid, for example, are using parametric design instruments to generate specific design outcomes which were almost impossible to realize a few decades earlier. Digital tools such as *Grasshopper* with *Rhino3D*™ or *Bentley's Generative Components*™ have simplified the parameterizing of the model such that designers can now use a network of nodes to generate buildings.

Indeed, there is numerous CAD software which offers design freedom to architects. However, many are simply too sophisticated for non-professionals. Unless one has prior experience in the design field, it is likely that he will find it inconvenient to use.

To simplify the design process, open building techniques can be implemented by breaking down housing units into sophisticated parameters, to the extent that every wall, windows, furniture, equipment, and doors become digital components; it allows great flexibility in generating a different type of floor plans with the click of buttons. By employing specific algorithms or methodologies such as Shape Grammar or Space Syntax one can generate as many possibilities in terms of geometric forms and layout possibilities with the help of computers (Benros et al., 2007). At this moment, defined constraints are introduced in such a way that design solutions are diverging to one that suits the users and fits the overall context of the building.

Designs can then be customized in mass for the community using parametric design techniques. These complex visuals can be articulated when surfaces are defined digitally with algorithms. The easy manipulation of the virtual 3D-design can generate a wide variety of design options in the VE at a significantly low cost, which provides an incentive for more architects to adopt this system.

To advocates convenient collaboration that save time and cost for building construction, BIM was targeting the professional industry. However, coupled with its collaborative flexibility and easy information exchange among professions, more resources can, therefore, be spent in bringing more community involvement into the design process.

The community can participate in a Virtual Environment (VE) (Schnabel, 2001, 2003, 2005). The research by Schnabel has inspired and demonstrated the huge potential of using VE for communication not only between professionals but also with laypersons. VE is a useful platform for architects to communicate with the community. In accordance to the likes of social network systems, VE, with its added support in visualization and engagement, can be used by architects to generate and develop design while maintaining close communication with the community. Furthermore, VE provides simulation results that are more intuitive for interpretation, hence facilitating discussion among the various groups.

The involvement of the community in the design process could greatly change the position of the architects. Instead of taking full control of the design, they will manage the ideas generated to create a more community-based architecture – replacing rigid geometrical forms with dynamic and participatory processes, networks, and systems.

3.3 Engage

Establishing the design system within a virtual environment for information exchange existed in some software but catered mainly for the professionals. The communication with the end users are still in the form of questionnaires and surveys and sometimes interviewing directly. To enable collaboration with end users who are a layperson with minimal knowledge of design, a new form of engagement tool has to be developed or integrated into existing virtual environments.

3.3.1 Gamification

The mean for collaboration can be achieved through gamification. Comparing the concept of the mass housing to a game, one can observe some similarities. Without going further details about the game playing, the most important factor of gaming is that they provide the best methods for players to pick up the gameplay and enjoy the operation processes. Players do not need to have any specialised skills to start a game, but they can pick up the necessary skills easily to complete the game within the gameplay. The controls require little skills for the players to manoeuvre within the environment and get accustomed to the gameplay, though some time will be necessary to master the game.

The process demands variations for the participants to obtain a more individualized outcome. This could instil a sense of belonging towards the outcome. For participants to grasp the content easily, a clear visualisation system should also be integrated. The fact that the mass housing participation relates to games interaction to such a great extent (Figure 3) provides a great opportunity for gamification.

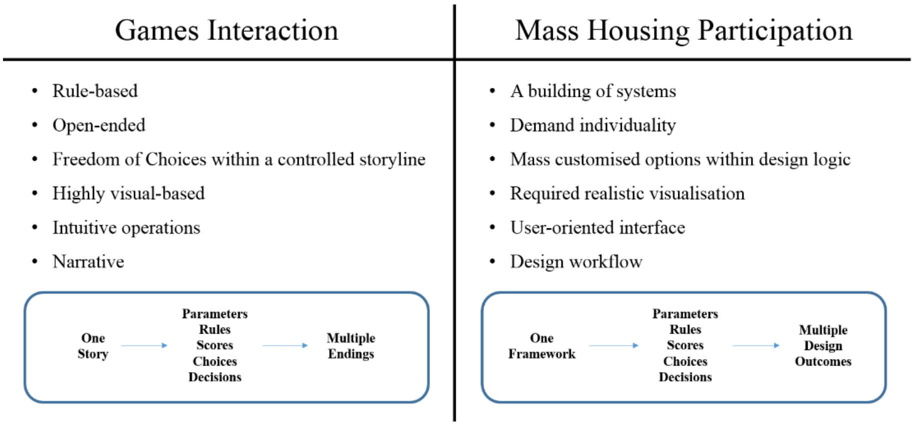

Figure 3. Characteristics comparison between games interaction and mass housing participation

As the main objective is to enable the public to engage the complex model to achieve a higher level of collaboration, simple control and graphics are necessary. Also, some games nowadays do not just allow the players to follow the story towards one ending but demands the players to engages with the stories and make a decision that would change the course of the multiple ending. Similarly, mass housing now demands the need for the public to engage with the design with the various parameters set by the architects to achieve the various possible design outcomes that could better fulfil their spatial needs. These methods would also help to engage with the public easier since this research is working with complex strategies.

First of all, gamification is not turning everything into a game. It is a process of enhancing operations which in this particular context, is design process, through motivational affordances to invoke game-like experiences (Huotari et al., 2012). It is used to invoke psychological experiences similar to games. Secondly, they are not ‘serious games’ which are used as a training and learning environments such as in military and education. The focus of serious games is improving their skill sets in a virtual environment similar to real conditions. Thirdly, the need for decision-making ‘strategies’ or individual ‘choices’ is different to the game theory used in mathematical analyse (Kelly 2003). In this case, gamification is used to help improve collaboration for 'a choice' and encourage involvement in 'a strategy' (Kapp 2012). Hence, gamification here relates to the implementation of motivational affordances using the game and through the modified design process proposed in this research, to engage users in design tasks and to improve the perceived ease of use of digital platform collaboratively.

Gamification functions both to promote participation and simplify the process of communication between various parties. Through the involvement of end users, the complexity of the design process is likely to increase especially in the context of mass housing. Recognition of a layperson’s interest in the conceptual design stage necessitates immediate communication with the architects and opens up the problem of dovetailing layperson demand, and maintenance of the professional architects’ quality control.

4. IMPACT

The significance of this research is that end users will be greatly involved in the design of their apartment, empowering them the opportunity to create a living space according to their preferences in the context of mass housing.

This challenges the role of the architects, but it is important to note that the role of the ‘architect’ has been changing with time. Initially, architects were in charge of the whole building. They are the masters of the building, from overall shape to technical details. However, building technologies have advanced to the level it is impossible to be dealt by a single individual. The complexities of buildings are redefining the architects’ role. The significance, in this case, is by attaching the same weight to all relevant aspects; the architects can play a more central role. He will be like the conductor of an orchestra, whose sole responsibility is to ensure all the musicians will collaborate well to produce a coherent masterpiece collectively. The musicians, in this case, does not only refers to the specialists but all stakeholders who have an interest in the design and can contribute to it. This research, therefore, creates and demonstrate the possibility of using a computational system to enhance this `ability'.

The current mass housing design methodology and process demands some changes and optimization not in the construction process but the collaboration process. By adopting the available technologies such as BIM and defining the suitable parameters, this research could encourage a great deal of participation and bring about a completely new typology of building types.

Creating communities and bonding people together in the neighbourhood has been one of the key intentions of building designs. In current practice, most of the solutions are to create public space for people to use and hope to achieve communication among people when using the space. However, the result was not always achieved. In fact, most of the time, space would be used for un-targeted activities that do not encourage any community building. This research, therefore, provides a great opportunity to bring people together to design their living space yet at the same time, communicate with their neighbours and get to know all the people around the neighbourhood before moving into the building.

This bottom-up and participatory approach that response to the need for both designers and users can be proven possible and effective with the help of computational tools which is not yet available today.

5. CONCLUSION

This paper has presented three key principles that are necessary for a digital participation system for architects and end users to co-produce collaboratively. These principles provide great opportunities to develop a design participation process that generates an outcome through the flexibility set up by the architects coupling with the decisions made by the end users.

ModRule, which is used to demonstrate the process is designed and developed to promote and facilitate collaboration between architects and future occupants during the design stage of mass housing buildings. It is much more than just an architectural design instrument; it is also social, political, and economic. Its aim is to bifurcate the decision-making process toward the end-user. The system utilizes gamification methodologies as a reference to promoting incentives and user-friendliness for the layperson who has little or no architectural background. Therefore, ModRule focuses on different aspects to translate a design environment into a digital platform and to improve on remote control discussions, visualizations, and profound parametric design techniques.

The collaboration tool instils a greater sense of belonging to the people, as well as giving the providing architects with a better understanding and control of how to give people more control over their living spaces. The adopted open-source strategy and open-collaborative design approach of this research developed a platform for a bottom-up design methodology that allows for mass-customization and maintains efficiency and cost-effectiveness in the housing industry. Future developments of ModRule will allow a better connection to BIM software and a refinement of the algorithm allowing more parameters to be set. The here presented principles have shown that a digital support system not only enables stakeholders to engage seamless in a collaborative process but also that the resulting design can successfully express the design desires of users and architects leading to a novel architecture.

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Empathic Lighting

Fast responding personal Lighting based on Sensors and LEDs

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Key words: Lighting, Smart Building, Micro-Controller, Responsive Architecture

Abstract: Empathic lighting as project explores the usage of computers, sensors and actors to illuminate a scene. Starting from a modern colorful LED mounted on a tilt-swift bracket, which is controlled by a single micro-computer, a fast responding lighting system is developed to not only defy the impact of changing daylight conditions but to answer the environmental light intake on the fly and even anticipate a viewer's acting. Still at model scale the working system comprises two lighting units and a smart phone as both as camera input and user interface.

1. INTRODUCTION

The concept of flexible and dynamic lighting is not new at all. Personal lighting on demand has always been flexible and dynamic. Illuminating a place while carrying a torch is in fact one of the oldest use cases of lighting a scene at all.

Starting with electric lighting remote and unattended illuminations now have taken over. A scene, in architecture it is usually a room, is illuminated independent from its viewers, bystanders or, as room, occupants.

With computers and digital cameras at hand and the new possibilities of small sized micro-computers the old concept of personal lighting can be revived without the hassle of carrying personal items. This is what empathic lighting will stand for.

2. DIFFERENT CONCEPTS OF LIGHTING

In general there are three concepts of lighting, personal, scenic and ambient lighting. All of them are artificial, although ambient lighting as daylight can be natural. The knowledge of all three types are taken are taken from principles of the lighting of virtual models with CAD visualizing software.

2.1 Personal lighting

The concept of personal lighting is simply best described by the devices in use. These are headlights, flashlights or even torches, but also lights attached to vehicles and vessels. They are commonly not stationary and usually pointing into the same direction as their associated viewers.

2.2 Scenic lighting

Scenic lighting relates only to a scene, regardless whether or not observers are present. Several light sources are arranged in order to illuminate a designated space as scene.

These light sources are always point lights. Their light beams are radiating from a single point into all directions, even though they can be manipulated through reflection and refraction.

2.3 Ambient lighting

Ambient lighting does not always use dedicated light sources. Indirect lighting like soffit or close to wall lighting are intentionally hiding the light sources, while direct ambient lighting with bright illuminating surfaces like panels is an still evolving technology.

A special case of ambient lighting is simple daylight. Then there is no device at all.

3. DEVELOPING THE CONCEPT

The overall idea of arranging various light sources and to anticipate a desired illumniation is a known concept in lighting. Especially stage lighting with dozens or hundreds of orchestrated luminaries controlled manually or by automated applications reveals a wide range of possible use cases.

What is new is however the direct use of sensed and computed informations in an easy to reproduce lighting application.

3.1 General Idea

The main concepts evolved around the idea of implementing the effects of headlights without the headlights itself, meaning lights should be used similar to an illuminated stage and without carrying personal lightd.

In addition personal, scenic and ambient lighting should be integrated into one system.

3.2 Idea of the Prototype

The idea of the prototype integrates all three different concepts into one model of a user controlled illumination.

The system is based on the assumption that there would be an optimal state of lighting a designated scene for any user observing it. This illumination can be defined in relation to the user. By evaluating a current visual impression of the scene with the ideal state additional controllable light sources can be adjusted to match it.

This concept is introduced as empathic lighting: A user is observed and the surrounding scene is illuminated once the user enters the scene. The overall ambient light and, based on face detection, the viewing direction of the user is determined and the scene is illuminated according to the desired illumination and the detected values.

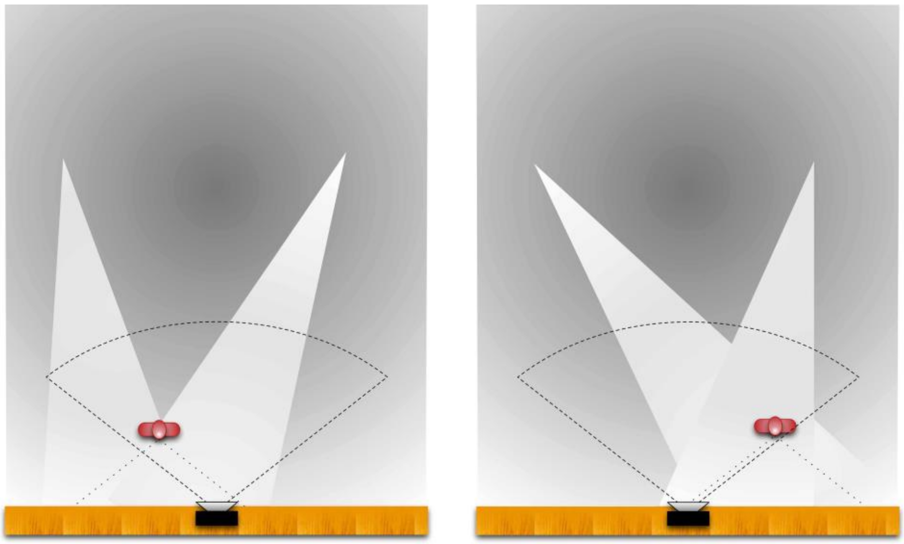

Figure 1. Concept: Two lights follow a user while moving.

3.3 Prototype

The prototype system itself is comprised of two specially designed lighting units. These are spot-lights with RGB-LEDs mounted on pan-tilt brackets. They are individually assessable: color, brightness and the direction can be changed on demand.

Each lighting unit deploys its own computational control component, an micro-controller on a board. The limiting factor here is the wiring, or better the number of pins that can be used. They have to not only provide digital values, like on and off, but analog values. Otherwise dimming the lights and controlling a motor would be unachievable.

The common technique is pulse-width modulation. The software of the micro-controller encapsulate this function. It can be simply controlled with one line of code.

To determine the present illumination a camera is used, which is for simplicity part of a mobile device. By means of image processing the immediate visual appearance is analyzed.

The first evaluation is the presence of observers at all. Otherwise all lamps are off and the system remains idle.

If a person is noticed, then the eye's position is determined to detect the viewing direction. Finally the lamps are directed accordingly.

Responding to the ever changing conditions introduced by an the observer and possible environmental effects the lighting color is corrected.

Any person in a scene provides both shading and color modifications even in an otherwise complete artificial illuminated setting.

With methods of image processing an overall color value is generated by summarizing all pixels and calculate a mean value thereof. This value is for correction, either as weighted value according to a designated field of interest inside the camera's view, or in relation to an overall referenced value taken before under controlled environmental conditions, or both. Then in an opponent color space the opposite color components of the lamps are raised. If, as example, a viewer in front of a painting is wearing green clothes and the detected overall value is more green than it should be then the emitted light of the luminary would be kind of reddish.

3.4 Maker culture

Making is yet another form of developing. Derived from the DIY (Do-it-yourself) culture it combines physical objects with the beneficial effects of programmable computers.

The makers' movement, like similar movements, is prudent when it comes to finalized definitions or even worse, the culture is subject to academic disputes. It has two consequences. By nature a theoretical discussion is almost impossible, and secondly, because of the avoidance of established rules some of their labels like 'experimental play' or 'basic democracy' compromise the movement and cast an unprofessional light on the results.

This is mentioned beforehand, because the project presented here is created with tools and techniques from the makers' scene. Otherwise it would not have been developed at all and the accompanying concepts could not have been established without them.

4. MAKING A LIGHTING UNIT

To give an insight, how to build such a project from scratch a more detailed than usual description of the process of making is given. Although working with electrical parts is not one of the main activities of architects, this project demonstrates that making an electronical design can be accomplished.

4.1 In the Making

The two lighting units deploy each a light source mounted on a servo operated position control and a controller. The light source itself is a colored LED with three color channels. It can deliver almost any color to the scene.

The pan-tilt mechanism is controlled by two servo-motors. Each can cover almost a complete semi-sphere.

4.2 Building the Lamp

Three essential elements are comprising the lamp, an RGB-LED as lighting source, a reflector, a diffusor and a small dowel pin made from plastic as enclosure.

Figure 2. RGB-LED, reflector and diffusor.

The LED is fixed onto the reflector and covered with the diffusor. The four pins on the backside are routed through the plastic pipe, which is fixed with some glue on the rear side of the reflector. Finally the wires are connected.

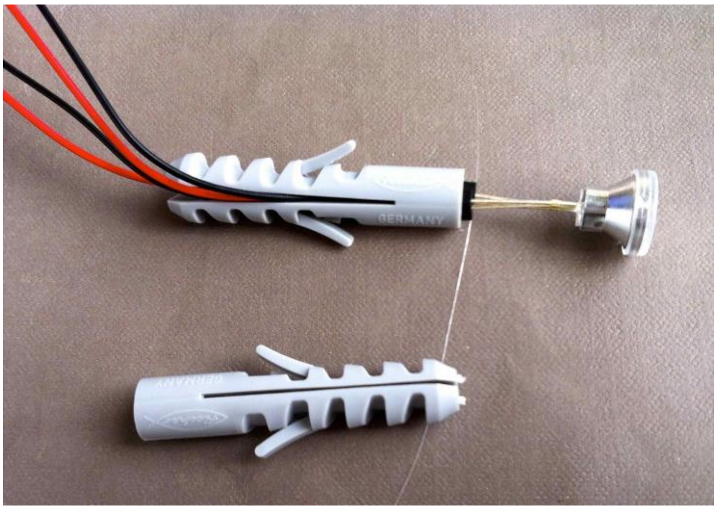

Figure 3. Assembled lamp with a second dowel pin

4.3 Making the Mount

To get a motorized pan-tilt bracket as mount several pieces of hardware needed to be assembled. Brackets and motors had to be assembled according to their accompanying instructions.

Figure 4. Two brackets and two servo motors, wheels, nuts and bolts

By putting the brackets together and installing the servos special care had been taken of controlling the brackets orientation. Not only had they point towards the right direction, they also have to be perfectly in synchronization for best results.

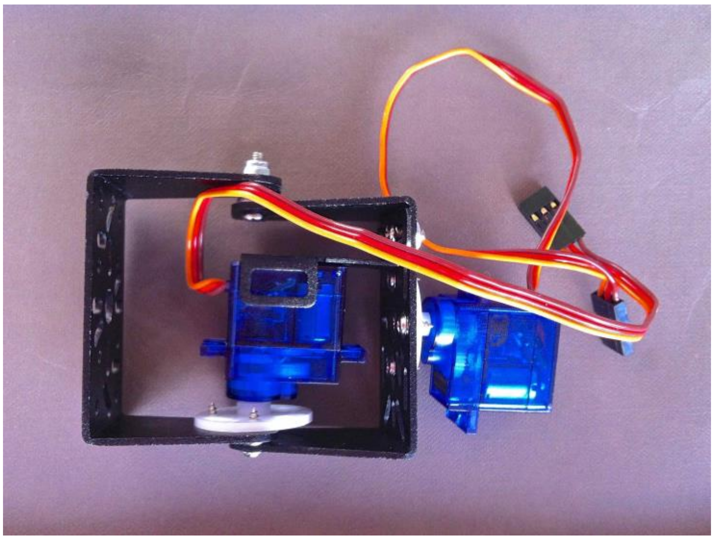

Figure 5. Motorized pan-tilt bracket.

4.4 Completion

Once the pan-tilt bracket and the lamp have been assembled a fixation was needed to mount the lamp onto the bracket. Luckily a simple cable tie could fulfill the task.

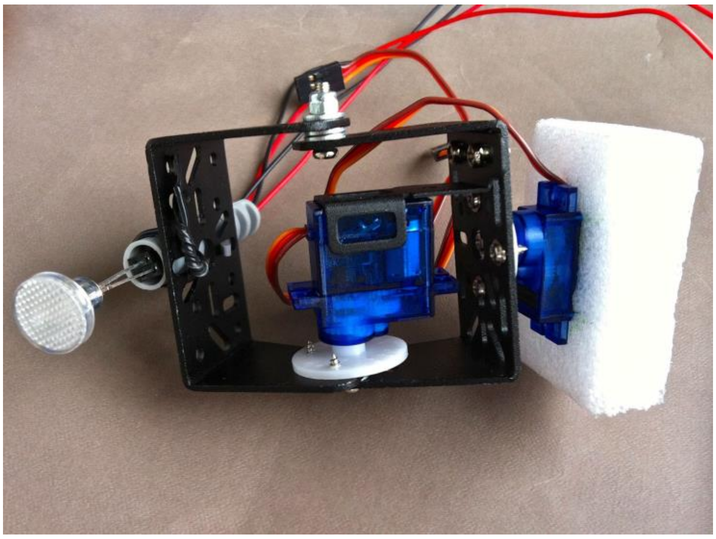

Figure 6. Completed lighting unit

Finally all wires, four from the lamp and 6, 3 for each servo, had to be routed to the breadboard.

4.5 Micro-Controller

The last component be assembled is the micro-controller. It is placed on a board which has only the bare functions as the pins to be connected and a programming interface implemented. During development the interface as USB-connector also did provide the power.

Enhancing the board is simple, other boards with dedicated functions for all purposes are available. They match the form factor and hence usually are pin-comaptible and can be stacked.

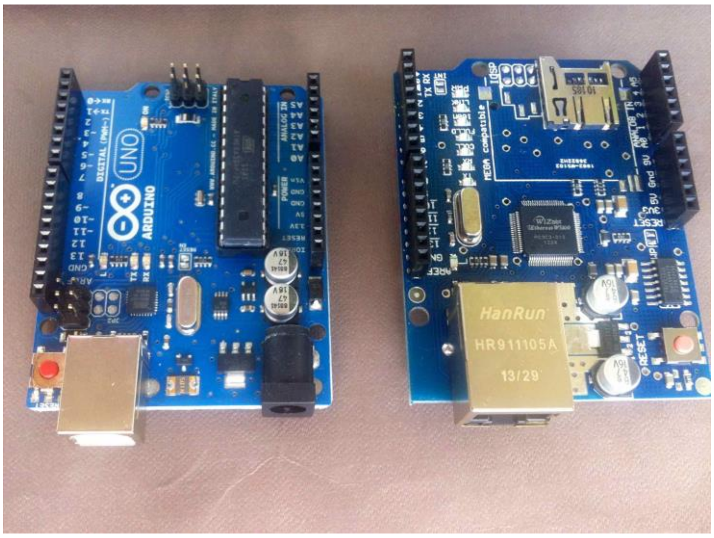

Figure 7. Micro-controller board and Ethernet shield

The prototype presented here got an Ethernet shield to the board of all lighting units attached to gain access to some network.

The outlets on both shields, power and USB on the micro-controller's board and above it the Ethernet connection provide the interfaces for a complete single luminary.

4.6 Connection

While all devices have contact to a network the last remaining task was to ensure that all units are connected to the same network established. Especially the wireless connection on the mobile device employing the camera need some extra care. Addressing itself is then simply managed by routing the IP-address of each unit.

4.7 Wiring

Finally all bits and pieces need some electrical connections. To avoid soldering and to enable reusability and refactoring, as it is a prototype, a common small breadboard is used to connect all wires.

In addition the resistors, one for each color channel of the LED, are placed on it. They are, as only elemental electrical parts in this project, necessary to protect the LED by limiting the current.

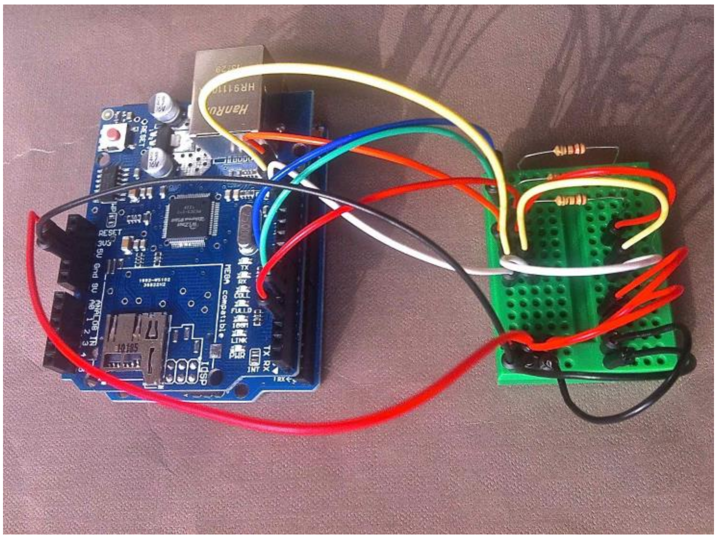

Figure 8. Stacked shields, small breadboard and wires

As the board itself provides enough power on all used outlets fortunately an external power supply for either the lamp or the motors is not necessary.

Other pins or outlets are not used. While it is contemplated, that locally attached sensors could render some useful results, like a photodiode to detach the overall intake of light, their usage was avoided.

The lighting unit is strictly regarded as an acting device following instructions without being influenced from other source. The restriction enables encapsulation, a technique known from object oriented programming. In other words, it will not talk back, which makes the progamming of the system much easier.

The key result of the assembling all parts is a functional lighting unit. It can cover the complete circle of colors in the color-hue model and it covers a semi-shere in space by rotating two brackets at 180 degrees with two servo-motors.

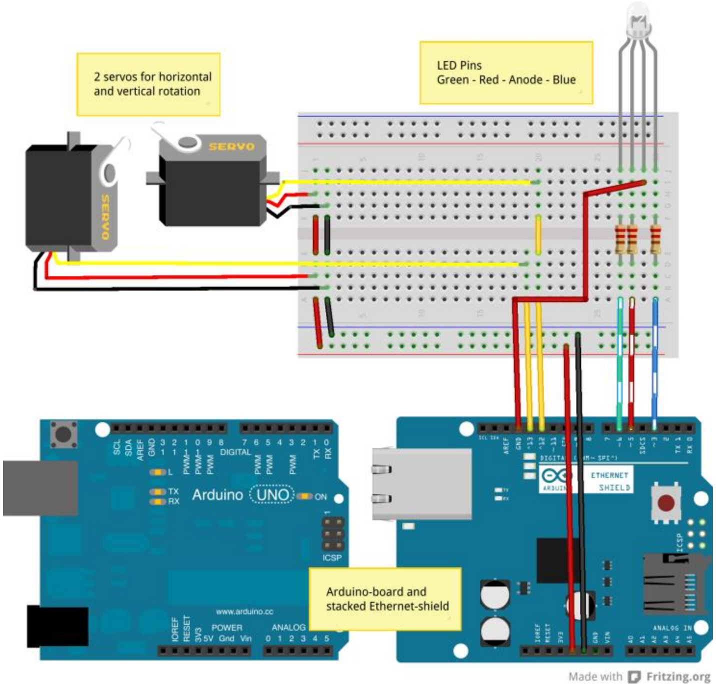

Figure 10. Schematic view of a single lighting unit.

Besides power, every unit needs instructions provided by an external source. A single unit is independent from other units, hence by design they can be arranged at any order and any count.

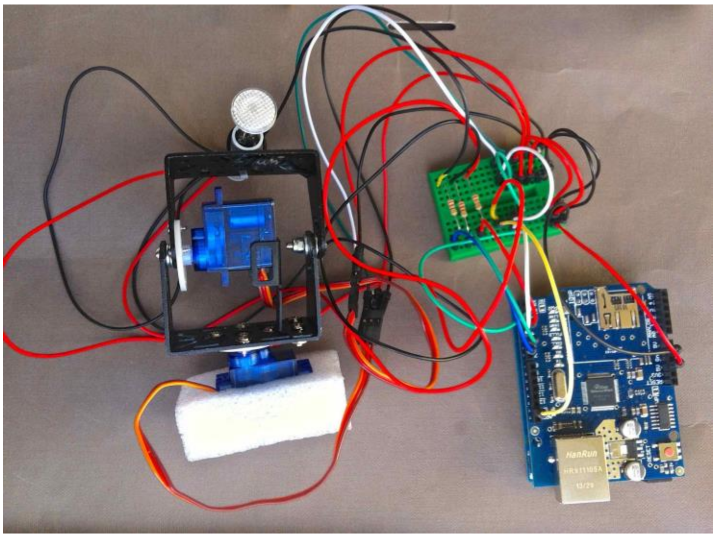

Figure 11. Finished lighting unit

5. SENSING UNIT

The sensing unit, as the name implies, provide the sensors in use like a camera or microphones. For simplicity this is a smart phone or similar with a camera and microphone attached.

5.1 Camera Input and Image Processing

The main camera is the main source of input. The incoming video stream is analyzed frame by frame in order to calculate both the color and the positional values for the lighting units.

Modern mobile devices are very capable of face detection and other personalized image processing tools. Hence they can perform a significant amount of computational workload, especially the sophisticated perception of users and their eyes' direction.

5.2 User Interface

While a mobile device was already in place for practical reasons it could also provide some user interface. Without the interference of sensed or perceived interactions it is a convenient tool for testing the lighting units and also for demonstrations.

It consists of two views. The camera shows the camera's view overlaid with some rectangles to indicate what values are about to be send. It is the view to watch while the system is under automatic controll.

The tool menu comprises two circular touch areas and some buttons.

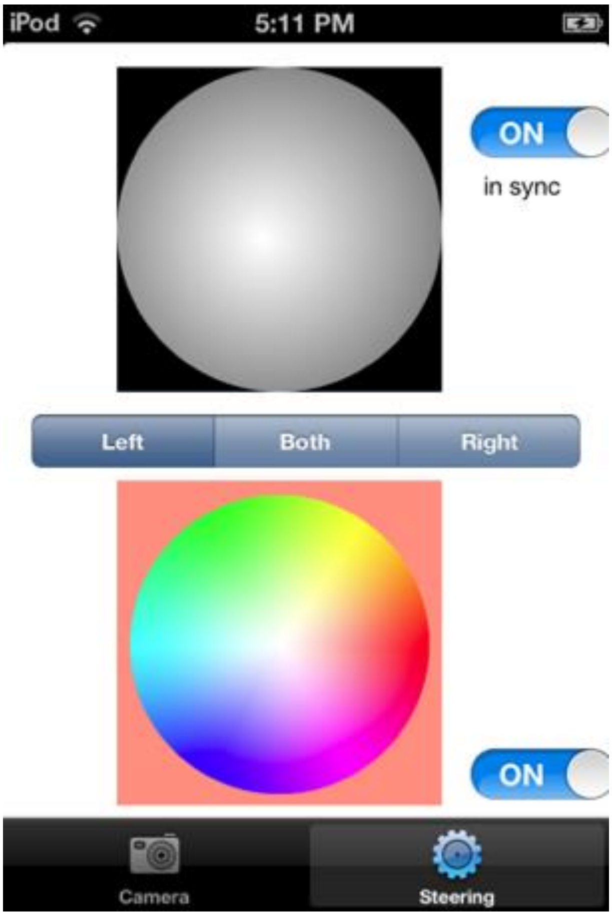

Figure 11. User-interface on a mobile device.

The upper circle controls the direction of the lumiary, the lower its respective color. These values are send as simple strings with numerical values, separated by commata. This little higher level of complication, the string needs to be parsed, allows for manual input through other interfaces.

6. RESULTS

As first prototype, while the working model is under continuous development, some options to enhance the system have become apparent, besides its overall outcome of two different kind of achievements.

6.1 Enhancements

The sensing part of the system, the camera with subsequent image processing, is aso under investigation because the embodying mobile device is already bloated with unused functionalities and more specialized cameras and optical sensors are entering the market.

The number of light sources can be increased, and the pattern of the light emitters, right now a single spot light, can be more flexible. Additionally ambient light source like an OLED panel can be added.

Most importantly the project could grow from its actual model scale to a real life scale.

6.2 Synchronization

One problem not anticipated is the synchronization of both the pure electrical and the motorized adjustments. While an LED itself can be controlled with the speed of light, changing their position with servo-motors take time and the delays have to be considered during calculations.

It is contemplated, that in a system on a larger scale the detected physical objects would move relatively slower than now on the model scale, while there are other options remaining, e.g. mirrors to direct the light.

6.3 Empathy

At first the direct goal of the project is fulfilled: A scene can be automatically illuminated. The system reacts to visual stimuli as if the lights are in a user's hand, at least a bit. This is an achievement.

6.4 Making

More important is the outcome, that the idea of Empathic Lighting has come into being with the tools and techniques of makers. In combination, but affordable controllers and other devices

In architecture, where there is still a focus on virtual models and how to bring them to reality, working with other than simple building materials is not yet regarded as an option. Electricity belongs to home automation, which then is better appliances and, as the name implies, not part of a building but applicated to it.

In this sense the creation of the system has proven that more than isolated applications can and should be mastered by architects. Buildings will no longer be static envelopes, they will become adaptive and responsive, to avoid the term ‘smart’.

The approach of architects to buildings has been always holistic. If they like to maintain it, they have to step in. Creating an empathic building will be as important as defining and creating the building’s shape.

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Towards a simulation of mixed land use impacts on transport

A procedural urban modelling of urban layout

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Key words: Urban simulation, Procedural modelling, Land use, Road network

Abstract: This paper introduces an urban simulation system generating urban layouts with population, road network and land use layers. The desired urban spatial structure is obtained by generating a population map based on population density models. The road network is generated at two spatial levels corresponding to the road hierarchy. The land use allocation is based on the *What If?* allocation model. The expected results are urban layouts suitable for academic scenario analysis.

1. INTRODUCTION

The impact of land use mix on travel behaviour is a traditional research topic, which has recently raised more concern for its influence on energy consumption and exhaust gas emission. Over many years, however, whether land use has a marked impact on travel behaviour is still under debate. For example, in empirical studies on land use mix, an elasticity of vehicle miles travelled (VMT) differs greatly (Spears et al., 2014). An important reason is that most studies focused on neighbourhood level land use patterns, but travel behaviour is more influenced by larger spatial level land use patterns (Nasri and Zhang, 2015). Another reason is that the empirical study is always restricted by data collection. Therefore, a simulation study is designed, aiming to investigate the city & district level land use mix impact on travel behaviour.

The whole simulation process consists of two parts: one is simulating an urban layout, another is simulating the corresponding traffic. The traffic simulation model must be able to simulate the length, time and mode of trips of a given urban layout. There are many existing travel demand models that can meet this requirement.

The urban layout simulation model must meet two basic requirements. First, it is able to generate desired urban layout. The urban layout includes three aspects: population, road network, and land use. In the aspect of population, some existing urban simulation models don't take population into account (Aliaga et al., 2008; Beneš et al., 2014; Weber et al., 2009), and others use real data as input. So the existing models cannot generate desired population distribution maps. As for the road network, it can be generated by a variety of methods which can be basically classified into static and dynamic methods. The dynamic methods generate road networks from several growing points and during some growing periods (Beneš et al., 2014; Lechner et al., 2003; Weber et al., 2009), so it is hard to precisely generate a desired result. The static methods generate road networks at one go, which is relatively easily to control, but the existed algorithms still do not meet the requirement. For example, in the L-system, highways connect population centres (Parish and Müller, 2001), then the road network is mainly determined by the population density map. In the example-based algorithm, the streets and blocks are mainly influenced by the input urban images (Aliaga et al., 2008). And in the tensor fields, before generating road network, a tensor field should be drawn and modified (Chen et al., 2008), which is an abstract process and is not easy to precisely control. Land use allocation algorithms, however, can produce realistic results (Lechner et al., 2006, 2004; Weber et al., 2009).

Another requirement is flexibility, which means the simulation results should be easily modified, in order to generate a series of scenarios from one basic urban layout. This requirement is not met by existing urban simulation models especially in land use modification: users must change the land use of lots and parcels one by one.

Therefore, an urban layout model for academic simulation research is needed. In this paper, we introduce such a system. The system will generate a population layer, a road network layer, and a land use layer. In section 2 we introduce the basic concepts and the pipeline of our system, and then the generation of population, road network and land use are described in section 3, 4 and 5 separately. Finally the results are shown and discussed in section 6.

2. OVERVIEW

The urban simulation model consists of three basic layers: population, road network, and land use. The road network in our system, in accordance with the widely used road hierarchy (Lay, 2009; Marshall, 2005), consists of three levels: highway, arterial and distributor. Accordingly, in our definition, a city is divided into districts which are surrounded by highways and arterials, and a district is divided into neighbourhoods surrounded by distributors. Finally, we consider a set of five land use types: residence, industry, office, commerce, and open & green.

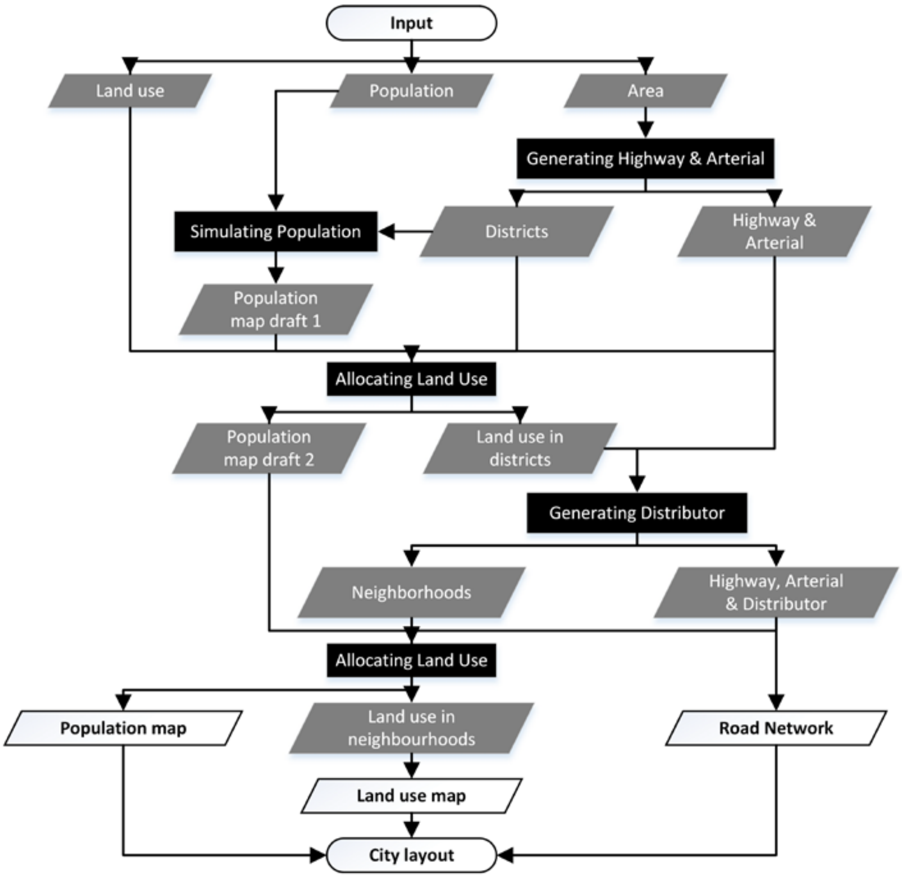

Figure 1. The framework of the city simulation model

Figure 1 shows the framework of the system. The input to our model includes: the population, the area of the city, and the desired land use percentages. First, the highway and arterial of road network is generated at city level to form a spatial framework of urban layout, and the city is divided into districts at the same time. Next, a draft population density map is created based on population density models. This draft map, which is an input to the land use allocation process, is then adjusted to a final population density map. The land uses are allocated to the districts, in the form of a set of percentages of land uses. After that, the distributor network is generated, which is influenced by the land use condition at district level, and districts are divided into neighbourhoods simultaneously. Similar with the district level, the land use is then allocated at neighbourhood level.

3. GENERATING POPULATION

The generation algorithm is based on academic urban population distribution models. A model library is set for users to choose to create most typical spatial distributions of population. At this stage, the model library includes: the negative exponential function (Clark, 1951) and the normal distribution function (Newling, 1969). More models such as the cubic spline function (Suits et al., 1978) will be implemented in the future.

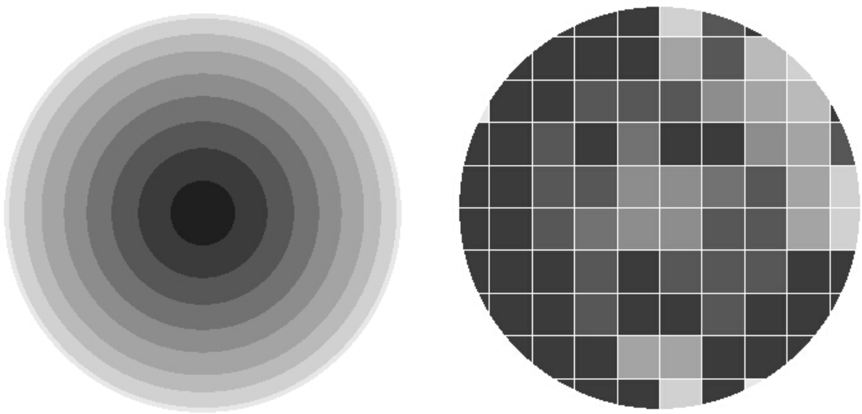

Figure 2. Population density map generated by negative exponential function. The left is an originally generated map, the right is an adjusted map.

With a population density function, a population density map can be easily drawn, but the draft map is a hypothetical structure with a population that is evenly distributed at all directions, see Figure 2 (left). Thereafter an adjustment process combined with the land use allocation process is followed to make it more realistic. This part will be introduced in section 5.

The result is that the population is finally adjusted in accordance with distribution of residence land use, see Figure 2 (right).

In the proposed urban simulation system, the users are also allowed to use their own population data of a real city as an alternative input to further generation steps.

4. GENERATING ROAD NETWORK

4.1 Basic procedure

The algorithm of generating road network could be described as pattern-based. A road network pattern library is built, and users just need to pick a desired road pattern form the library. The library currently have two pattern types: radial and checker.

The basic elements for creating a road are start point, segment length, direction, and end point. In our system, the start point can be the city centre, or more generally an intersection on an existed road of the same or higher level. Users can control the distance between two intersections (as well as two parallel roads), which is also the segment length of a road. Land use will also influence the distance. For example, the road distance tends to be smaller in residence areas but larger in industry areas. The direction of a road is determined by the picked pattern.

A road grows with a segment length every time, generating a new node (the end of the segment), till the node is judged as an end point: (1) the node is outside the urban area (where population density is zero); (2) the node is near an upper level road which should not be crossed, for example, a distributor should not go across an highway.

4.2 Generating the highway

As shown in Figure 3, users should decide whether to build the highways at first, because a highway network is usually presented in big cities, but it is not compulsory. If users do not want to build it, the model will jump to the arterial part.

We currently collect two typical patterns of highway network in the pattern library - the ring & radial and the checker & radial. The two patterns have in common is that they have at least one ring road and have 4 to 8 intersections (also the start points of radial highways) on the ring road.

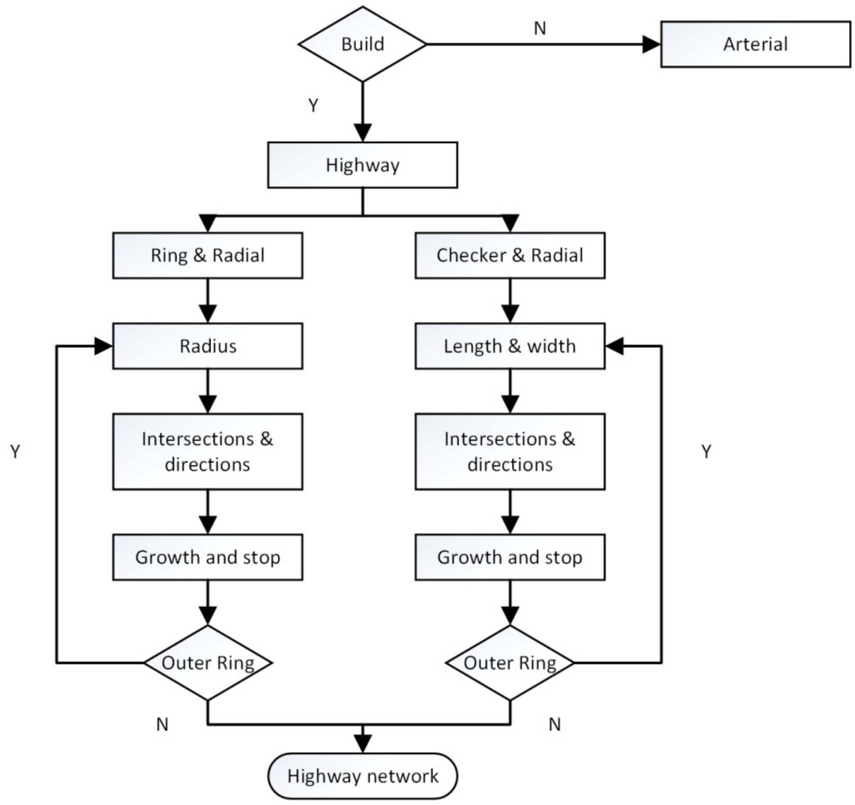

Figure 3. Highway generation

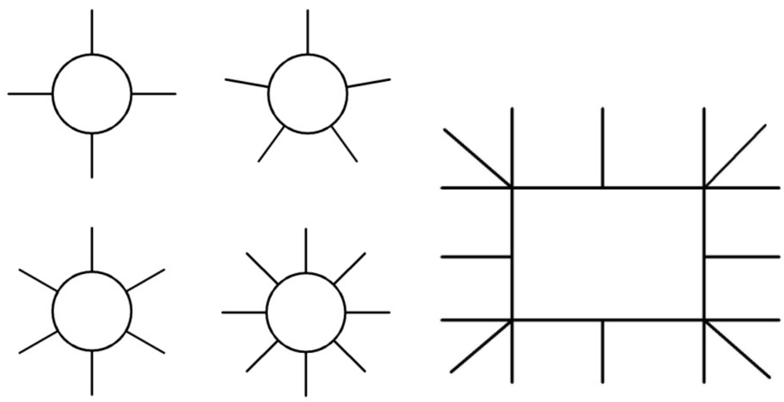

Figure 4. Highway patterns of ring & radial (left) and checker & radial (right)

The start points and directions of radial highways are easy to set in the ring & radial pattern, and Figure 4 (left) shows the basic networks. As for the checker & radial pattern, the start points could be on lines or corners of the rectangular ring, see *Figure 4* (right).

An outer ring could be built if the inner ring has a large distance to the urban edge, and the distance between the two rings is equal to the segment length of highways. Also, new start points of radial highways could be added on the outer ring.

If the distance between the outermost ring and the urban edge is less than the segment length, no other outer rings will be built. As for the radial highways, they should grow to regional or national highways, but in our system they stop just outside the urban area because we focus on the road network in a city.

4.3 Generating the arterial

Similar to the highway network, the arterial network has basic patterns collected in the library. In this paper we introduce two patterns, the radial and the checker, see Figure 5 and 6.

The generation of the checker network begins at the city centre. A horizontal and a vertical arterial grow from the point. Then, along the two roads, with a segment length controlled by users, four new start points are set, and then four new roads are generated. Consequently the arterial network expands continuously.

The radial arterials begin to grow from the city centre, with 4 or 8 radial directions chosen by the users. Then ring arterials grow with the segment length. On the outer ring arterials new radial arterials can grow between two existing roads, if the distance in between is too large.

An arterial will stop growing if it reaches the urban edge.

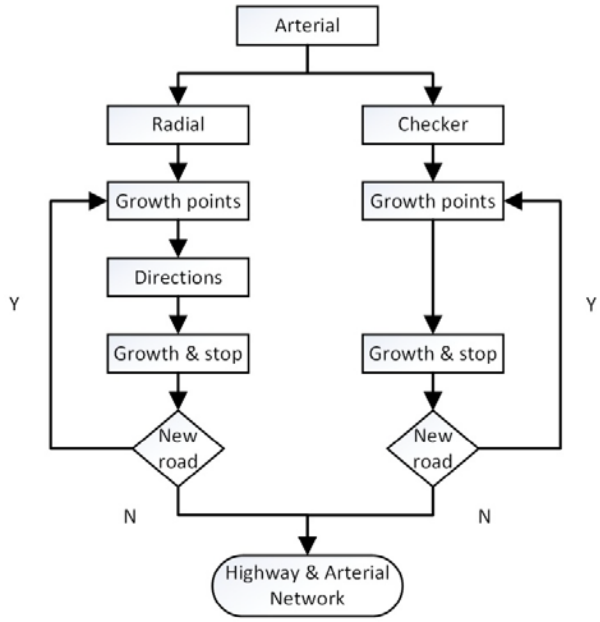

Figure 5. Arterial generation

4.4 Generating the distributor

After the generation of highway and arterial network, a city is divided into districts surrounded by existing roads and urban edge. The generation of the distributor network starts at the central district, then moving on to the outer districts. The segment length of distributors in a district is influenced by the dominant land use. The districts dominated by industry use prefer a large segment length, while the ones dominated by commerce prefer a short length. According to the size of the district and the segment length of the distributor, the start points are distributed on the adjacent two edges of the district. The distributors follow the direction of the arterials or highways nearby, or follow a direction in between the two directions of neighbouring two roads.

5. GENERATING LAND USE

5.1 Overview

The whole land use generation process consists of three sub-processes: land use allocation in districts, and then in neighbourhoods, and at last in lots. At district level, the input includes the series of land use percentages input by users, as well as the area of the city. The allocation sub-process generates a series of land percentages for each district, for instance, residence: 60%, industry: 10%, office: 10%, commerce: 15%, the open & green: 5%. At neighbourhood level, this series of percentages and the area of a district are the input of the allocation of neighbourhoods within this district, and the output is similar with the district level. At lot level, with similar input, the land use is ultimately allocated to each lot with a specific use.

We design such an allocation process for three reasons. First, it can balance land use and population at district and neighbourhood level, which can provide a more reasonable allocation result. Second, the land use conditions at district and neighbourhood level influence the generation of lower road network – it is obvious that a residence district has a different local road network from an industry district. Last, in the simulation analysis case mentioned in section 1, the users need systematically change the land use conditions of districts and neighbourhoods. In our model the user can easily change the total land use percentages of a district instead of the specific land use of many small lots.

The algorithm of land use allocation is based on *What If?* planning support system (Klosterman, 2001; Pettit, 2005). The *What If?* model consists of three sub-models: a land-suitability analysis model, a growth-analysis model, and a land-allocation model. In our system the growth-analysis model, which predicts the future demand for land uses, is not needed because the users will input clear land use percentages. Within every land use allocation sub-process there are two steps: suitability analysis and allocation.

5.2 Land-suitability analysis

The suitability of each land unit is calculated using the following equation:

$$S_{ik} = \sum_j w_{kj} r_{ij} \tag{1}$$

where S_{ik} is the suitability of land unit i for land use k, w_{kj} is the weight of factor j for land use k, and r_{ij} is the rating of land unit i on factor j.

Table 1. Suitability factors and ratings of districts

Factor	Factor Type	Industry	Residence	Commerce	Office	Open & Green
Highway	Entrance	1	-2	0	-1	0
	Line	0	-2	0	-1	0
	No	0	0	0	0	0
Land value	High	-1	0	2	2	-1
	Medium	0	1	1	1	0
	Low	1	1	0	0	1
Population	High	-2	2	2	2	0
	Medium	0	1	1	1	0
	Low	1	0	0	0	0
Industry	Local	--	-2	0	-1	1
	Nearby	1	-1	0	0	0
	No	0	0	0	0	0
Residence	Local	0	--	2	0	1
	Nearby	0	1	1	0	0
	No	0	0	0	0	0
Commerce	Local	0	1	--	0	0
	Nearby	0	0	0	0	0
	No	0	0	0	0	0
Office	Local	0	1	1	--	0
	Nearby	0	0	0	1	0
	No	0	0	0	0	0
Green & Open	Local	0	2	1	1	--
	Nearby	0	1	0	0	0
	No	0	0	0	0	1

Table 1 provides an example of the factors of suitability at district level, and their ratings. The rating ranges from -2 to 2 which implicates from most unsuitable to most suitable. At this stage only most important factors are considered, and other factors will be added to make the result more realistic. Because all the districts are surrounded by arterials and highways, we only use factor highway to implicate traffic convenience and noise to a district. The factor land value of a district is determined by its location – central districts get the factor type high, fringe districts get the factor type low, and districts in between get the medium. The population is also an important factor. At last, the interactions between land uses must be considered. The factor type local (see Table 1) of a land use means the allocating district has such land use, and the factor type nearby means the district doesn’t have but its adjoined ones have such land use, and the factor type no means no such land use in or around the district. In this paper the value of weight is set as 1, but the value can be adjusted by users in different cases.

Basically, what is expressed through the suitability factors is that residence land use prefers to be away from highways, industry and high land price, but near parks and open space. Commerce land use tends to get close to market (population) and high land value, while office land use has similar preference but contradict busy roads and industry. Industry land use tends to be clustered, and likes land units with low price and population but convenient transportation. Green & open land use tends to get a balanced distribution and prefers low price land units.

5.3 Land use allocation

With the input, the series of land use percentages and the area of upper level land unit, the amount of each use to be allocated can be easily calculated. Other parameters include: land use allocation order, minimum and maximum land unit sizes, and land use controls. Table 2 shows an example of values of these parameters in the districts allocation sub-process.

Before allocating the uses in the allocation order, the least amount of land use, such as the commerce and open & green according to the land use controls in Table 2, should be allocated firstly. At district level, the industry, the commerce, the office, and the open & green uses follow a similar standard allocation algorithm. A land use, according to its result of the suitability analysis, is allocated to any one of the districts with highest suitability (there may be several districts with a same highest suitability). After that, the suitability of the neighbouring districts will be re-evaluated, for the cluster effect of land uses. Next the land use is allocated to any one of the left districts with highest suitability. The last two steps are repeated until all of this land use is allocated. Following the next land use type in the allocation order is to be allocated.

Table 2. Default allocation parameters at district level

Land use	Allocation order	Land use controls	Min size (%)	Max size (%)
Industry	1		5	90
Residence	2		1	90
Commerce	3	At least 5%	5	95
Office	4		1	90
Open & Green	5	At least 5%	5	95

The residence allocation algorithm at district level is a bit different, because it interacts with the population map. After the residence suitability analysis, the draft population map generated directly by population density model is adjusted – people move from districts with lower suitability to districts with higher suitability. According to the updated population map, the residence land is firstly allocated to any one of the districts with highest population density. The allocating principle is to provide just sufficient dwellings for inhabitants in the district. In case the available land for residence in the district is not enough, the exceeded people then move evenly to the surrounding districts which have not yet been allocated, and of course the population map is adjusted as well. Next the residence is allocated to the other districts with highest population density in the remaining districts, until all the residence land is allocated.

The land use allocation at the neighbourhood level follows the standard allocation algorithm mentioned at district level, with according values.

6. RESULTS AND DISCUSSION

The output of this system is a city layout with population, road network and land use. Figure 6 shows two results of road network. The left one is the radial pattern, and the right one is the checker pattern. Figure 7 shows a result of land use.

At this stage of our work, the system is designed to produce general urban layouts. So compared to other work, the results at this stage are more hypothetical rather than plausible. But our proposed model needs less input, fully controls the output, and provides a good flexibility. Also, the results could become much more realistic if other aspects are advanced in the future.

The road pattern, which is simple at this stage, can be enriched with more patterns such as the star, organic and mixed patterns. In addition, the road network itself is insufficient for traffic analysis, therefore important transport infrastructure, such as bus stations, subway lines, railways and the airport will be considered. Besides the traffic layer, the land use layer will be improved, for example, taking old town areas or historic districts into account. The natural environment or terrain, which we do not consider at this stage for simulating general urban layouts, will be added to our system to provide a more realistic result.

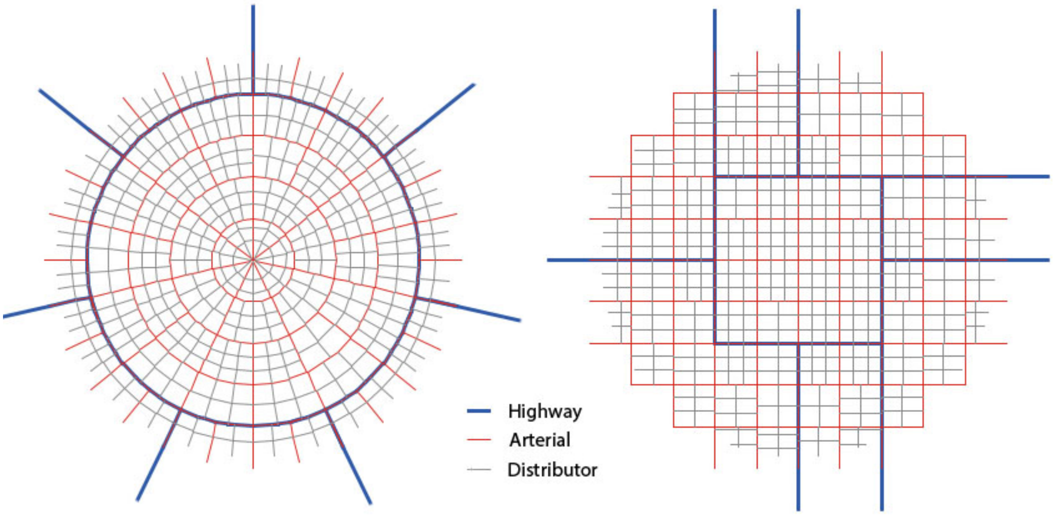

Figure 6. Examples of road network. Left: radial. Right: checker.

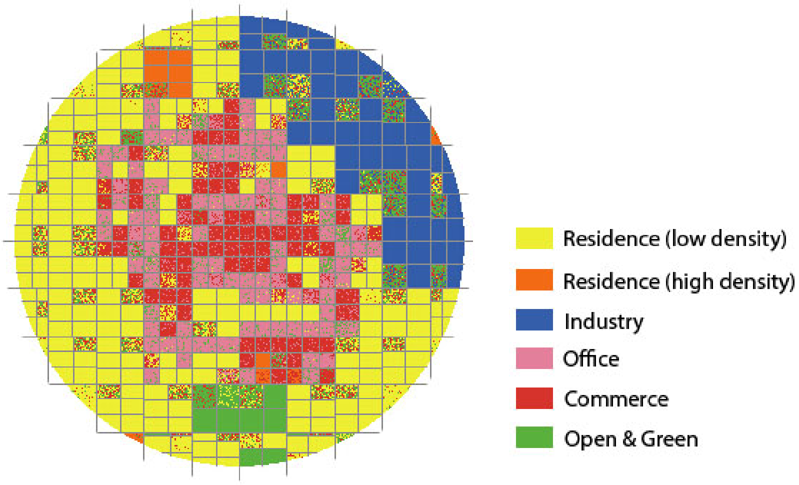

Figure 7. An example of land use

The procedural urban model is a platform for complex urban study. In next stage, the model will be combined with a traffic simulation model. The ultimate combined system, which can generate desired urban layouts and their corresponding traffic data, will be used to systematically analyse the influence of urban land use on traffic.

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A study on the city street survey questionnaire for wheelchair users' optimal routes

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Key words: Decision support tools, Consensus building, Urban redevelopment projects

Abstract: We have conducted a simple road survey for wheelchair users with a questionnaire for both wheelchair users and able-bodied persons. We used statistical analysis to determine the correlation between their answers. It revealed some interesting facts, such as wheelchair users care about getting rained on but able-bodied people do not consider it as a problem.

1. INTRODUCTION

In 2006 the "Act on Promotion of Smooth Transportation, etc. of Elderly Persons, Disabled Persons, etc." (Aka: new barrier-free law) was enacted. There has been a significant improvement in the legal system concerning universal design of the surrounding living environment. Compared to newly built malls in suburban areas, there is a mix of new and old buildings/shops in the city center, so renovation of those areas to incorporate universal design is limited. Therefore, mobility-impaired people are still restricted in their area of daily activities.

We have conducted interview surveys as well as a local area investigation to collect the data on each road in a target area (M. Koga, S. I, et al., 2014, Y. Inada, S. I., et al., 2014, D. Yoshioka, M. K., et al., 2015) to provide an optimal route navigation for self-driving wheelchair users (hereafter, wheelchair means self-driven wheelchair if it is not noted otherwise). However, a detailed investigation by people with knowledge specific to the problem is difficult to apply in a wider area due to the lack of human resources and the cost (time and money). To efficiently investigate a wider area, we need a method to replace the detailed investigation so that it can be operated by able-bodied persons who are not specialists in this field. For this, we propose the use of simple questionnaires as an approach to investigate the road condition for optimal route navigation. We have assumed that the wheelchair users and the able-bodied individuals might evaluate the same route differently.

We have conducted the same survey on both wheelchair users and able-bodied individuals. This paper describes the questionnaire, methods of analyzing the questionnaire answers, and the acquired knowledge from the analysis. Firstly, we have analyzed the questionnaire survey results of wheelchair users to obtain factors that influence the route selection. Then, we have compared the survey results of wheelchair users and able-bodied persons to analyze the differences between them.

This paper is organized as follows: Section 2 introduces the related research about optimal route finding for the mobility impaired and describes the need for a simple road survey method. Section 3 proposes the simple survey method which uses questionnaires. Section 4 describes the questionnaire evaluation experiment. Section 5 explains the result of the analysis. Section 6 discusses the analysis and Section 7 is the conclusion.

2. BACKGROUND

Here, we introduce related research about optimal route finding for the mobility impaired and explain the need for a simple survey method.

Yairi et al. built a pedestrian support GIS (Geographic Information System) prototype for 2 areas (I. Eguchi-Yairi, S. I., 2005). One contains Koganei (12 km^2) and a part of Kokubunji cities (2 km^2). The other contains Higashiyama area in Kyoto. This system aims to provide the optimal route navigation for all kinds of pedestrians, for example able-bodied, elderly or mobility impaired people. This study conducted an interview for the disabled and able-bodied people. Then created a network structure for the pedestrian paths and surveyed them to collect data. Yairi et al. used survey sheets to collect data on each road. This survey took 80 man-days for the 12 ㎢ of Koganei city area. And it took 40 man-days for a part of Kokubunji city area after modifying the data structure.

Thorsten at al. proposed the navigation optimization method by using the information posted by users (T. Völkl, R. K., et al., 2008a, 2008b). This method works like crowdsourcing and will help to survey wider areas more cost-efficiently. However, they have only tested this method on the university campus. The crowdsourcing has to have a lot of users for the system to succeed. Thus, in order to apply it to the real world, it will require a strategy to gain a lot of attention.

The information acquisition for providing optimal route for the mobility impaired is still limited due to the human-time-money cost problems. Therefore, these proposed systems are covering few areas. We need a simpler survey method to collect data to provide route navigation in a wider area. It is important to reduce collected information when conducting the survey. We need to determine the sufficient and necessary information to provide the optimal route for the mobility impaired. This way, the survey could be performed even by people who are not familiar with mobility impairment (e.g. able-bodied).

3. PROPOSAL OF THE SIMPLE SURVEY METHOD

We propose a simple survey method that uses questionnaires to solve the cost problem, which we described in the previous section, and provide the optimal route navigation in a wider area.

This questionnaire is to be answered while observing or navigating the route. It aims to collect road information for optimal route navigation for the mobility impaired by anyone who is not knowledgeable about disabilities. We are currently targeting self-driving wheelchair users as the mobility impaired. Questions in the questionnaire are based on the previously conducted interview survey, discussions in workshops and other related reports about optimal route finding for wheelchair users.

We ask able-bodied and wheelchair users to take the same questionnaires in the targeted area. In the questionnaire we include a question “Do you want to use the street?”. Then we compare the answer for the question with other questions such as “Is the street wide enough?” to analyze the answering trend. This comparison is to understand how wheelchair users or able-bodied people select roads to travel.

Then we compare answers between these 2 groups to understand the relationship between their selections. We use the statistical method for the evaluation and the comparison for the questionnaire answers. For the qualitative evaluation, we compute the optimal route based on the questionnaire answers and conduct workshops to discuss how wheelchair users feel about the computed optimal route. Here we compare the computed optimal route with the “user route”. “User route” means a route that is preferred by wheelchair users who know the target area well.

From the evaluation result, we find out which questions are important for wheelchair users, which questions have similar answers between able-bodied people and wheelchair users and which questions help to compute the optimal route for wheelchair users.

4. PROPOSAL OF THE SIMPLE SURVEY METHOD

Here, we explain about questionnaire contents, target area and the on site experiment.

4.1 Questionnaire contents

We chose 11 questions for the questionnaire (Table 1). These Questions were chosen based on the previously conducted interview survey, discussions in workshops and other related reports.

Table 1. Questions

Question
1. Do you use the street often?
2. Is there any cover from rain?
3. Do you want to use the street?
4. Is the street wide enough?
5. Does the unevenness of the road bother you?
6. Is the street angled horizontally (perpendicular to the heading direction)?

Question	
7.	Is there a pedestrian road good enough to pass?
8.	Is there a step between the car road and the pedestrian road?
9.	Is it difficult to pass by pedestrians?
10.	Are unmovable obstacles (e.g. trees or lights) a hindrance?

We asked wheelchair users to answer questions 1 to 10. We asked able-bodied persons to answer questions 1 to 3 normally and questions 4 to 11 as if they were using a wheelchair. We used Likert scale (Vagias, W. M., 2006). The scale has 5 steps: 1- Strongly disagree, 2-Disagree, 3-Neither agree nor disagree, 4-Agree, 5-Strongly agree.

4.2 Target area

As a target survey area, we chose a part of central urban area in Kumamoto city, consisting of the Citizens office, Major shopping department T and P, central arcade streets S and G (approximately 16.07ha). We also defined 93 roads to survey (Fig. 1). We chose these 93 roads as roads that are possible to navigate with a wheelchair on the advice of a doctor helping disabled people who himself uses a wheelchair for daily activities.

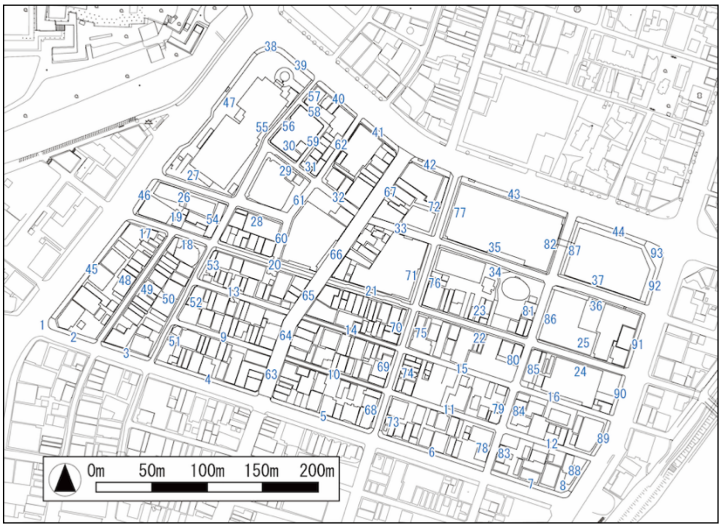

Figure 1. The target area and 93 roads

4.3 Questionnaire Experiment

We conducted the questionnaire survey with 8 able-bodied participants (Table 2) on the 1st of November, 2015. They were 18-20 year-old university students who were not familiar with wheelchair use. We used paper for the questionnaire form. They walked through each road and answered questions by observing its condition. The survey started at 10 am and finished at 2:30 pm including a 1-hour lunch break.

Then we conducted the questionnaire survey with 5 wheelchair users (Table 3) on the 3rd of November, 2015. We used an application on a smart tablet as the questionnaire form. The application showed a simple map and the 93 roads with sequential numbers in the target area. The user could choose the number of the road to assess it. Then the questions were shown and users could answer by tapping. Answers were immediately sent and stored on the server databases. Also, users could review their answers on the tablet. The survey started at 10 am and finished at 6:15 pm including several breaks. They drove through each road and answered questions. When it was hard for them to input answers on the tablet, accompanying students (who also participated on this research) listened to the answer and did it for them.

Table 2. Questionnaire Experiment Participants (Able-bodied persons)

Participant	A	B	C	D	E	F	G	H
Age	20	20	18	19	19	20	18	19
Gender (F-Female, M-Male)	F	F	M	F	F	F	M	M

Table 3. Questionnaire Experiment Participants (Wheelchair users)

Participant	I	J	K	L	M
Age	24	28	39	42	45
Gender (F-Female, M-Male)	F	M	M	M	M

4.4 The Workshop

We held a workshop to discuss the survey on the 17th of January, 2016. We provided an optimal route that is computed based on the average of values given in the answers to the question “Do you want to use the street?” by 5 wheelchair users, and we asked their opinion. 6 wheelchair users, 2 support persons for wheelchair users, 4 university students, 3 faculty members - a total 15 people participated in the workshop. The computed optimal route showed a similar route to the "user route", which wheelchair users declared to frequently take, in several origin/destination points.

5. RESULTS AND THE EVALUATION

Here, we used a statistical method to evaluate the questionnaire experiment results which we previously talked about in the section 4. First, we used T-test to evaluate the correlation between answers by able-bodied persons and wheelchair users to determine if the answers by able-bodied persons are sufficient to substitute answers by wheelchair users. Secondly, we evaluated correlations between questions in each group. We used scatter plot on Excel to see the correlation, and used "R" for principal component analysis. "R" is a free software environment for statistical computing and graphics (R project).

T-test

T-test indicates statistical significance as to whether or not the difference between two groups' averages most likely reflects a "real" difference in the population from which the groups were sampled. We used the TTEST function in Microsoft Excel. Here, we set 2 (using both side distribution) for 3rd argument and 3 (targeting a two-sample of unequal variance) for 4th argument.

Principal component analysis

Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. This reduces the dimension of multidimensional data so that it is possible to visualize the entire data atmosphere.

5.1 Evaluation of answer trends for wheelchair users and the able bodied persons

We used T test to evaluate trend differences between wheelchair users and the able bodied persons for each question. Here, we defined null hypothesis as "Answer trend for both groups are similar" and alternative hypothesis as "Answer trend for both groups are not similar". We defined the significant level as 5%. Alternative hypothesis is a hypothesis to be proven when null hypothesis is declined. Thus, if the tested value is nearing 1 then answering trends of both groups are similar and might have a correlation. We used average value of 5 wheelchair users and 8 able bodied persons for each question on each road for T-test input. Table 4 is showing the T-test results.

Table 4. Questionnaire Experiment Participants (Wheelchair users)

Question	Q1	Q2	Q3	Q4	Q5	Q6
Value	0.171793	0.974401	0.362191	0.035477	0.000006	0.000525
	Q7	Q8	Q9	Q10	Q11	
	0.060069	0.000001	0.000004	0.024622	0.109380	

We also ran T-test on every combination of 2 members in each group. Figure 2 is showing the rejection rate of the test. The rejection rate is a value of the rejected number divided by the total number of combinations.

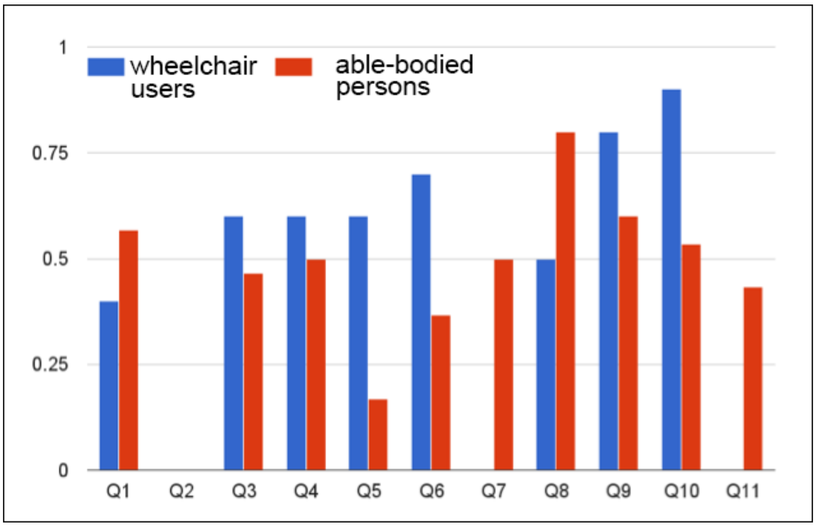

Figure 2. Rejection rates

5.2 Evaluation using a scatter plot

In the workshop we proposed an optimal route computed based on the answers to the question "Do you want to use the road?" by wheelchair users. This route was accepted positively by wheelchair users. However, this question is hard to answer by those that do not use wheelchairs.

We needed simple questions, that anyone could answer similarly, such as “Are there eaves?”, to make it possible to collect feasible data from the questionnaires answered not only by wheelchair users but also by able-bodied persons. So, we analyzed which question shows correlation with “Do you want to use the street?”
First, we plotted the question “Do you want to use the street?” and the others on scatter plot then compared the contribution ratio. Table 5 is showing the strength of correlation with contribution rate.

Table 5. Contribution rate and strength of correlation

Contribution Rate (r)	Strength of Correlation
r = 0	No correlation
$0 < r^2 \leqq 0.2$	Almost no correlation
$0.2 < r^2 \leqq 0.4$	Weakly correlated
$0.4 < r^2 \leqq 0.7$	Correlated
$0.7 < r^2 < 1.0$	Strongly correlated
r = 1.0	Perfectly correlated

Table 6 shows the result of contribution ratio on scatter plot (Linearly approximated) from each group. Q1 shows strong correlation for both groups. For group A, Q2 shows a strong correlation. Group B shows strong correlation on Q4, Q7 and especially Q11.

Table 6. Contribution ration

Question	Q1	Q2	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
Wheelchair Users	0.776	0.691	0.488	0.393	0.180	0.409	0.262	0.028	0.001	-------
Able-bodied persons	0.623	0.463	0.587	0.243	0.021	0.556	0.015	0.341	0.143	0.642

5.3 Principal component analysis (PCA)

PCA helps to show the atmosphere of the data visually. We applied PCA to the results of each person as well as to the average of each group. Figure 3 shows PCA on each average value of each group. Here, the axis scale of two figures in the plot can be ignored. The important part is the difference in orientation/length of the arrow lines that represent the principal component loadings between variables and the state of each subject, being its auxiliary in that direction. Evaluation scale 5 “Strongly agreed” for Q2 “Is there any cover from rain?” means the best (easy to use the road), however, evaluation scale 5 for Q5 “Does the unevenness of the road bother you?” means worst (difficult to use the road). Therefore, we flipped the values of questions Q5, Q6, Q8, Q9 and Q10 so that it means best when it gets higher value. For flipping the value, we subtracted the original value from 6.

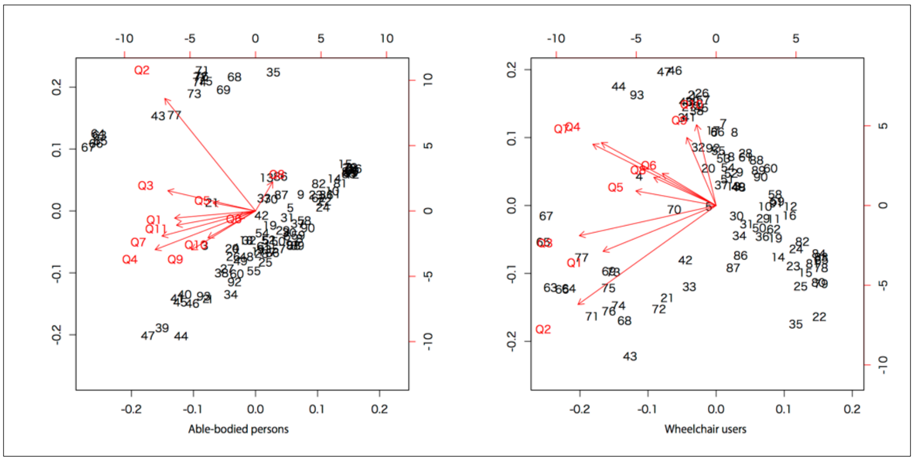

Figure 3. PCA Result

6. DISCUSSION

We discuss the evaluation results we described in section 5.

Contribution ratio from the scatter plot shows that able-bodied persons think that wheelchair users consider the existence of pedestrian roads and if those roads have sufficient width. It seems there are no distinguishable roads to realize the differences between walking and wheelchair use as indicated by Q11, which showed a strong correlation between the 2 groups. For example, it may show a different result if there is a road with coarse stone pavement that has a pretty view but is difficult to travel by wheelchair.

Group A had a strong correlation to Q2. It means wheelchair users consider not getting wet as an important factor in choosing a road. In the workshop after the questionnaire survey experiment, they said that if the wheelchair gets wet then it feels uncomfortable even the next day. On the other hand, this problem was not apparent to the able-bodied persons, since it did not show a correlation in the results.

From the PCA results for wheelchair users, questions Q4, Q6, Q7 and Q8 are showing the same trend, as well as Q9 and Q10. Q4, Q6, Q7 and Q8 are questions about the road condition and can be replaced by a question asking if the road condition conforms to universal design. Q9 is asking about the ease of passing by pedestrians, and Q10 is asking about unmovable obstacles on the road. Both are questions about hindrances to the wheelchair movement. From the result of able-bodied persons, Q11 and Q8 are almost opposite. Q11 is asking whether they want to use the road when they are using wheelchair, and Q8 is asking about the step between car and pedestrian roads. It suggests able-bodied persons do not consider the step or that it is hard to determine by just observing it.

We are able to see the differences in the consideration between wheelchair users and able-bodied persons from PCA plot. Q2 and Q5 are similar to Q3, where wheelchair users prefer the route that does not get wet when it rains. Able-bodied persons consider bumpiness when they think about wheelchair use, however not getting wet is not considered much. This result matches with the result form the contribution ratio on scatter plot.

In T-test results, Q2 showed a significant level of 0.97. It means both groups answered similarly. Q2 is asking “Is there any cover from rain?” This question is easy to answer by observing if there are eaves or roofs. Thus both groups answered almost the same. Q5 is asking “Does the unevenness of the road bother you?” The significant level is almost 0. When you are driving a wheelchair, you feel a lot of vibration caused by the road bumpiness, however, it is difficult to know the extent just by observing or walking through the road. That is why there was no correlation in the answers between the 2 groups.

Q2, Q3 shows a strong correlation between both groups. It suggests the possibility of performing the questionnaire survey by able-bodied persons, if you choose the questions carefully. However, Q5, Q6, Q8 and Q9 does not show enough correlation.

Figure 2 is showing the distribution of answers in each group. Q2 has a small rejection rate. It means it does not depend on a person’s opinion so the question matches easily as seen in the 2 group comparison. Q7 shows a small rejection rate in the group A. It suggests that wheelchair users have similar opinions about the pedestrian roads that they can use.

7. CONCLUSION

In this paper, we proposed a road survey method that uses questionnaires for optimal route navigation for wheelchair users in the shape of a simple survey.

For the evaluation, we conducted an experiment where wheelchair users and able-bodied persons answered the same questionnaire in the target area. We analyzed the results using T-test to check whether evaluation by wheelchair users could be substituted by able-bodied persons. Also, we used scatter plot and PCA to analyze each question. It revealed which questions show distributed answers and unified answers. Also it suggested an answer trend and the differences in consideration between wheelchair users and able-bodied persons.

We have conducted a research about road survey methods, while existing researches are mainly targeted on providing the optimal route. From the result, we found out that getting wet in the rain is very uncomfortable for wheelchair users, and able-bodied persons do not know this fact. The analysis method we applied revealed some questions that could be answered by able-bodied persons as a feasible survey result. With this, we will be able to collect road evaluation data more easily.

In the future we will conduct the evaluation to select more questions that give unique answers. Also, briefing able-bodied persons before the questionnaire as to what they should consider and evaluate if the result changes.

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ACKNOWLEDGE

This work was supported by the Japan Society for the Promotion of Science KAKENHI Grant Number 26350031 and the Mitsubishi Foundation. A special thanks to Ms. Maria Izumi for the help in translating the paper.

Smart Data Infrastructure for Smart and Sustainable Cities

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Key words: Smart cities, Information architecture, Virtual 3D city model, Spatial data infrastructure, Smart city data infrastructure, CityGML, OGC web services, Decision support system

Abstract: To make the cities smart and sustainable, there is an urgent need for developing a stable information architecture which is interoperable, functional, extensible, palpable and transferable. Data infrastructure as part of this architecture covers the services for supporting dynamic data collected by various sensors in addition to a virtual district model, which models the physical district's objects and can be enriched with semantic information. Open Geospatial Consortium (OGC) standards such as CityGML and Sensor Web Enablement (SWE) play an important role in the establishment of this model. In this paper a detailed description of this information architecture is given from the information viewpoint according to the standard ISO 10746 "Information technology – Open Distributed Processing- Reference model".

1. INTRODUCTION

An efficient and sustainable system, attractive living areas, citizens' satisfaction, economical improvement and stable businesses are the concerns of cities all over the world. The term "Smart Cities" is an ever more popular topic for cities that aim at improving their services and their citizens' quality of life by considering sustainability concepts such as applying factor four (Weizsäcker, Lovins, et al., 1997) or even factor ten concepts. However, sustainability cannot be achieved by individual strategies alone but is dependent on an infrastructure designed specifically with the goal of sustainability in mind. Clearly, there are many obstacles for successful implementation of sustainable smart cities plans. The smart city is a complex system i.e. a system of systems (ISO/IEC JTC 1 Information technology, 2014). It needs collaboration between various parties in the cities which is inherently a difficult task in terms of implementation of solutions. Besides, the unique characteristics of each city make the translation of the solutions from one place to another very difficult. These difficulties encourage different societies, from academia to standardization bodies, to start thinking about a solution which can be replicable as well as reliable and stable.

Offered solutions in the framework of Smart City projects are mainly focused on new technologies such as “Humble lamppost”, “parking sensors”, etc. for various domains such as energy, mobility, crowd management, etc. Although each of these technologies works efficiently and is well-adapted to the present needs of the cities, a lack of well-designed data infrastructure has resulted in incompatibility of services. This lack results in ineffective integration of tasks and solutions (Sánchez, Elicegui, et al., 2013). The given definition by Yin et al (Yin, Xiong, et al., 2015) stresses the role of smart data infrastructure in approaching toward sustainability: “a smart city is a system integration of technological infrastructure that relies on advanced data processing with the goals of making city governance more efficient, citizens happier, businesses more prosperous and the environment more sustainable”.

Nowadays, there are many districts in European cities that have individual preferences for reaching factor four standard. To do so, districts should know what they need to acquire and which measures and solutions can be applied to achieve factor four. Throughout a European project funded by EIT Climate-KIC, called “Smart Sustainable District (SSD)” a general concept has been developed which addresses the current issues of districts. This project work which is still under progress, has brought together different districts with real challenges. This opportunity helps both stakeholders and local partners as well as European experts from private companies and universities to gather together and exchange their knowledge in order to improve the situation of districts in terms of behaving in a smart and sustainable manner.

Notably, amongst different challenges and opportunities, data management is one of the biggest challenges for the districts to cope with. We, at the chair of Geoinformatics from the Technical University of Munich, as one of the partners in the SSD project, have been responsible for developing a concept to cover and address the data issues. In this project, by working with different districts and communicating with different stakeholders, we have learned about the existing challenges and requirements of districts in relation to the data management field. This helps us to drive a solution which can cover these issues and can provide a way to move towards sustainability and smartness. The proposed solution is indeed a data infrastructure smartly designed for the districts. This solution is currently being tested in different districts in European cities such as London, Paris and Berlin. However, it can be applied also in other districts and on different cases. In fact, the main purpose of SSD is to offer a concept/tool/solution which is suitable for different districts with different cases and situations.

In this paper, we first explained the SSD project and then in the next section we discuss the essence of the information architecture for the cities. Moving towards smart cities requires the perception of the current situation and future needs. A process is recommended and explained in this section, which can achieve this. It is a mechanism for management of complex distributed systems which defines the necessary steps to achieve the smart city criteria, following ISO 10746 standard. Section 3 concisely summarizes the proposed solution by introducing SDDI as the backbone of the whole process. This includes a short explanation of the data entities designed for SDDI. In the last section, a conclusion is given with an outlook to the future work in order to improve this solution.

2. SMART SUSTAINABLE DISTRICT (SSD)

Climate-KIC Launched in 2010, is one of the three original Knowledge and Innovation Communities set up by the EIT. Their mission is to deliver innovative solutions to climate change via a dynamic alliance of European partners drawn from academia, industry and the public sector. In Climate-KIC there are three types of project in which “Flagship Project” has the highest importance in terms of scale and scope. “Smart Sustainable District (SSD)” is a Climate-KIC flagship project that aims at partnering with the most ambitious district level developments in the cities and regions represented in the Climate-KIC. It will demonstrate how new thinking, coupled with effective tools, technologies and policies, can lead to factor-4 improvement in city district performance across a range of sustainability measures.

Seven work packages are introduced in this project, one of which concerns data and digit. We as the leader of this group have been working on developing an approach that takes into account all the requirements of the existing and possible future challenges of the districts.

The work in this group was started with several surveys distributed to the district networks in order to have a better understanding of the present situation. Parallel to this activity, several engineering reports and Best Practice reports were studied in order to examine the existing solutions, to find out the gaps which need to be worked and to identify the available solutions that can be used. Later a workshop was designed based on the results of the previous work, focusing on the districts data issues and current solutions especially from international standards and by standardization bodies. In this workshop, the discussion concerning data was guided toward a focus on different domains such as energy, water and mobility each with different use cases such as the local use of locally produced PV energy, greening roof surfaces, matching energy demands and consumption, intelligent parking, re-use of waste water, etc. In this way, for each use case the required and available data were examined. During this discussion, different data providers, stakeholders and related parties were mentioned. In addition, the difficulties around collecting data and having access to the data were discussed. As a conclusion, the required data were grouped into a number of categories. For example sensor data regardless of its type (e.g. collecting from mobile, weather sensors, etc.) were grouped into one category. This was done in order to show which elements are necessary for being considered as data entities. Amongst them are topographic data, sensors (different types) and utility networks.

One of the difficulties mentioned was that it is not only one group which facilitates the use of data but there are different stakeholders and groups providing data in different formats and with different accessibility rights. On the other hand, there are more than one group who are interested in using the data which again makes it is necessary to consider interoperability. Therefore, there is a huge need to set up a service oriented architecture which can address the issues such as data communication and transformation among different functional units, ensure data security and extensibility of data structure and be independent of changes in data providers and technologies. Accordingly, regarding the data semantics, data format and IT infrastructure, it is vital to build this infrastructure based on sophisticated international standards. For this aim, OGC and ISO standards are the most suitable.

The outcome of the workshop has inspired us to think about a smart data infrastructure which can be used by every district or city for managing their data in a standard manner. In the following chapter this infrastructure is presented in detail.

3. INFORMATION ARCHITECTURE

Existing challenges of the cities have proved that in order to smartly manage the physical infrastructure, a well-designed communication system between different actors, parties and organizations as well as services to the citizens are required (Degbelo, Granell, et al., 2015). Information infrastructure as the backbone of this communication system can help promote the prosperity and security of citizens.

To architect such an information infrastructure, it is necessary to first understand the whole process. This starts from the investigation of existing challenges and the roles of different parts and their relations and continues with the understanding of the expectations of all involved groups and their roles. The derivation of existing resources and required data and tools for meeting the needs of cities is also essential at this step. A smart city with sustainable outlook needs a sustainable information infrastructure that is interoperable, functional, extensible and transferable.

Observing cities that are passing through the smart transition of their services and structures highlights the complexity of these systems. In fact, a city is not only one system but rather a system of systems which are deeply interconnected with each other. In most cases, changes in one system or service will affect the others. Therefore, it is essential to break down the complexity of cities which are indeed an open complex distributed system. On the one hand, the system is open in that it should be extensible. This means that different partners can be part of the system in different ways. On the other hand, the system is called distributed because a number of different stakeholders (e.g. owners, operators, solution providers, citizens, and visitors), agents, communities and various data layers including sensors, analysis tools, etc. are present in it. This stresses the debate around centralized and monologue approach and its disadvantages. Although the centralized approach allows pumping all the various information from different sources into a single repository, the limitations with this approach such as the unwillingness of different source providers for releasing their data in a central repository, difficulty in management of semantics of various data, etc. makes the centralized approach impractical and will put it out of the discussion.

Thus, to manage such a complex distributed system, following the standard ISO 10746 “Information technology — Open Distributed Processing – Reference model (ODP-RM)” is recommended (ISO/IEC JTC 1/SC 7, 2009). It is necessary to look at the entire task from different views. The standard provides a coordinating framework for the standardization of open distributed processing.

Based on this standard, a management process is developed and suggested which will be helpful in defining the challenges of a Smart City project and distinguishing the responsibilities and tasks on different levels. The overall view of this process is depicted in Figure 1.

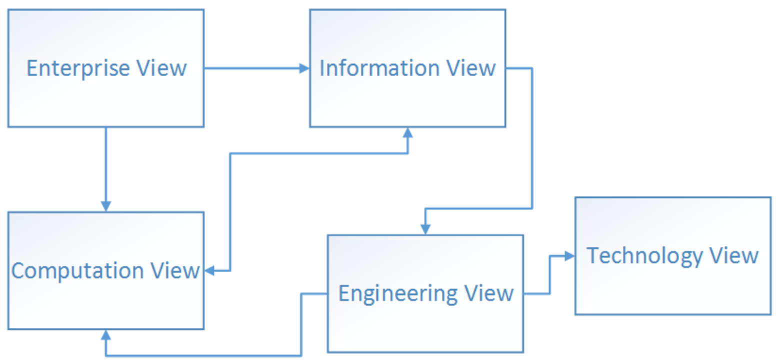

Figure 1. Management process for complex distributed system in the context of Smart Cities.

The process starts with the “Enterprise View”. This view focuses on the purpose, scope and policies for the system. It describes the business requirements and ways to meet them. This crucial step is the basis for other steps as it describes their direction and relevant tasks.

Using the information taken from the Enterprise view, the next step can be focused on the Information and Computational view. In “Information View” focus is on the semantics of the information and the information processing performed. It defines information models/ ontologies specified by data models and their semantic definitions, whereas “Computational View” enables distribution through functional decomposition of the system into objects, which interact at interfaces. As can be seen in Figure 1, these two views also affect each other in that the Computation view defines the priorities in terms of data for the analysis on one hand, while on the other hand the Information view can help the development of the computational view.

“Engineering View” focuses on the mechanisms and functions required to support distributed interactions between objects in the system that can be called, systematic interoperability. It describes the distribution of processing performed by the system to manage the information and provide functionality. This view affects the design of the computational view and will be influence by the Information view.

Technical View can be introduced as the last step. This view focuses on the choice of technology of the system. It describes the technologies chosen to provide the processing, functionality and presentation of information. This step is indeed independent from the order of the other steps and can be defined in parallel with them. Nevertheless, a mutual decision about proper software and hardware can be taken after the other views are settled. Generally, each of these views can be examined independent from each other. However, considering the outcome of each of these views and its effect on the others will help the efficient progress of the process.

The aforementioned steps show how important the process in structuring a well-designed infrastructure can be. Through the declaration of “Enterprise view” for designing the information architecture, it is confirmed that every stakeholder has different interests, goals and tasks, and different roles and rights. This immense diversity of the interests brings up a set of challenges and questions. Some questions that must be addressed are for example: What are the use cases? Which data should be used? Which data are required? How many of them are available? How the data should be collected? What are the data access issues such as data privacy and security? How should the data be stored and managed?

The proposed solution is indeed a data infrastructure smartly designed to answer these questions for the districts. Therefore, it is named “Smart District Data Infrastructure (SDDI)”.

4. SDDI STRUCTURE

Enterprise view depicts interests, conflicts of interests, requirements and the most important use cases and their clients. By holding discussions in the different districts with different stakeholders, local partners and citizens, common challenges were examined. Through the study of these challenges, it was discovered that in most of the current cities that have planned to move smartly towards sustainability, there exist many similar barriers. Although, these barriers are very specific and different from one place to another in terms of national regulations, they are in general very similar especially with respect to the technical point of view.

When it comes to the data, there are many similar questions and issues, which proves that there is a huge need for a standard solution that can address the existing issues and be capable of covering future requirements. Obviously, there are many domains the cities are interested in working on such as energy, mobility, water, etc. Each of these domains has various applications. Despite the differences in these use cases and the necessary techniques for carrying out the computation and analysis, more than half of the data required for the calculations are common amongst use cases. This is not only true between the use cases in one domain but also between different use cases of different domains. Unfortunately, in many situations, these use cases are examined independently from each other. Due to a lack of a comprehensive data infrastructure, this causes misunderstandings and incorrect estimations of the influence of taken decisions and applied measures on each other. Treating the use cases individually and neglecting their similarities will eventually result in incompatibility of services. Hence, "smart cities require a framework of trusted/authoritative data; for example, core reference data in 2D and 3D (i.e. topography), identifiers and addressing, smart infrastructure (BIM, smart grid), sensor feeds", etc. to build the backbone of the Smart City framework (Percivall, Rönsdorf, et al., 2015). A Smart city also needs to be open to different "data types, such as volunteered, unstructured and linked data. Such a framework needs a robust data integration platform" (Percivall, Rönsdorf, et al., 2015).

In this work, a framework has been created which was initially designed considering the priorities and needs of the examined districts and was then tested with more examples and use cases in order to be improved. The key characteristics of the model called "SDDI" are as follows:

- Redundancy avoidance: In many cases there are many data describing or related to a specific object. Nevertheless, this object is defined differently in different sources or by various providers. This leads to ambiguity and redundancy of the data which need to be interpreted later. In order to avoid data redundancy, standards play a crucial role. Even undefined elements can somehow be linked to a predefined element or object which has already been determined in the standards. A good example for this, is the CityGML building object to which different sensors can be linked without any redundancy in terms of the reference object (in this case a building).
- Well-specified Data Semantics: Data are often interpreted with a bias. This leads to the misuse of the data over time and by different users. This is the case especially when there is not enough documentation for the interpreted data and data models. Thus, it is important that a data model presents the information in a way that is understandable by and meaningful for everyone. Sufficient documentation for the data model is of course essential. Standards from ISO or OGC are good examples for this characteristic which are considered in this model.
- Interoperability: According to ISO 2382-1 (ISO/IEC JTC 1/SC 7, 2009), the term interoperability is defined as "the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units". Interoperability is one of the most important characteristics of this model. It is challenging for the application and simulation tool developers to get the data they need in a way that they can simply work with, as in many cases data are provided by different providers and in different structures. Interoperable systems can

overcome obstacles such as institutional barriers and avoid vendor lock-in, thus provide openness for extension, and lead to the sharing of information.

- Unified handling and integrating of sensors: The diversity of sensor devices and dynamic data that are being used and produced, is an aspect that needs to be considered. This heterogeneity of device classes and technologies as well as heterogeneity in data produced by various devices from different manufactures, for example smart meters, weather sensors, surveillance and monitoring cameras, mobiles, moving people, etc. should be homogenized and unified. OGC SWE standards used in this model, provide unified representations of sensors and observations
- Extensibility: The model has to be extensible in order to meet the future needs and cases.
- Functionality: A standard solution ensures the functionality of the approach and model apart from the use cases. This means that the model is designed such that it can be used for different use cases.
- Transferability: Notably, the proposed model should not work only for one example or in one specific place, but needs to be transferable so that other districts or cities can benefit from it. This includes both the use of related standards and also the existing datasets. For example, there are many cities in the world, which have already developed the 3D model of their cities following the OGC CityGML standard.

5. SDDI TIERS

The proposed “SDDI” has four tiers, data entities, simulation and modelling tools, applications, and users. The “users” module includes all end users such as stakeholders, different companies, citizens, etc. The interface between the users and simulators and data is through applications that can be specified for one specific case or a dashboard that merges a set of different applications in one. The input of these applications comes either directly from pure data or through modelling tools, all categorised as “Urban Analytical Toolkits”. Considering the other three tiers of this infrastructure, it becomes clear how important it is to design the data entities in an interoperable and well-understood way so that both application developers and the experts who need data for their simulations can use it. Through the examination of the requirements of the existing challenges in the cities, the data entities is divided into two main categories, “Virtual District Model – (VDM)” including 3D city information model “CityGML” and networks, and “Sensors”. OGC and ISO have mature and well-supported standards, which are directly compatible with the designed data infrastructure. In addition to that a place has been reserved for those data which are not part of these two categories but can be represented by linking them to the virtual district model. The model is illustrated in Figure 2.

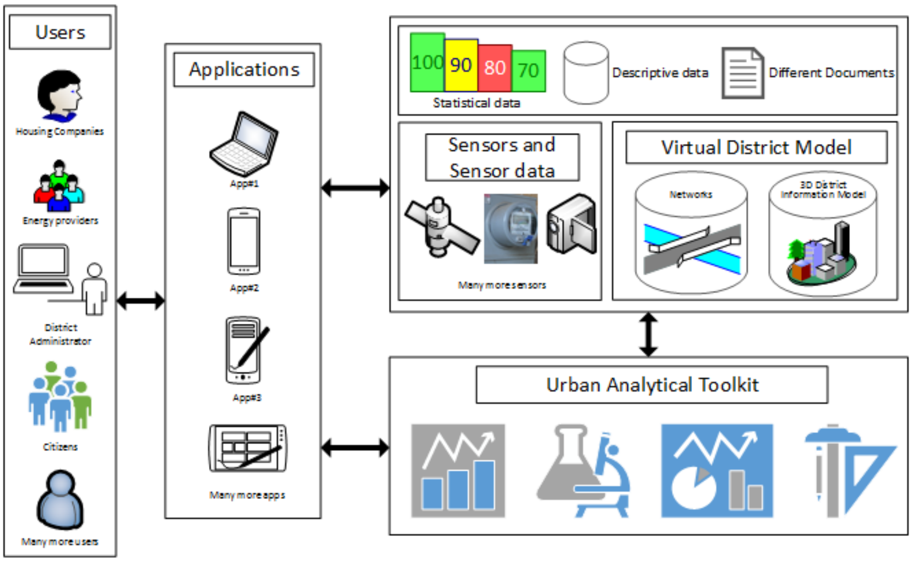

Figure 2. SDDI consists of 4 main parts including data entities, urban analytical toolkit, applications and users.

In this paper the main focus is on data entities. The aim is to provide the required information for both the analytical toolkit and applications. The results of analytical tools and produced data from applications can be both fed back to the data entities which results in a bi-directional flow of the information. The structure and elements of the data entities, VDM and Sensors, are explained in the next two subsections. The last subsection is dedicated to an example of the proposed data entities which have been tested in the Queen Elizabeth Olympic Park (QEOP) district in London.

5.1 Virtual District Model

When it comes to discussions concerning Smart Cities, the physical objects of the cities are always the points of interest in some way or another. These object are defined regarding their locations and their physical characteristics in the real world. Many other examples, which are not directly related to the physical objects, can be linked to the objects. This highlights the role of geospatial data and model in the context of Smart Cities projects.

Location-based service as the principle method for organizing the Smart City has the capability of communication between different systems (Percivall, Rönsdorf, et al., 2015). To be established, these types of systematic communications require standards. There have been several standards developed by OGC and ISO, which can be used extensively in an interoperable data infrastructure. "Spatial Data Infrastructures (SDI)" play a critical role by including location information which are undoubtedly an important factor in managing all that governments deal with, from roads and sewage systems to education and public health. OGC standards and complementary standards from ISO are essential elements, which are being used in SDIs (Open Geospatial Consortium).

The idea behind development of VDM as a basic element of data entities comes from the fact that in order to cope with the challenges in the districts, we need to have a virtual model of real objects in the districts. This includes objects such as buildings, city furniture, water bodies, etc. in addition to networks such as water utility networks, smart grid or transportation networks.

The VDM itself consists of three parts:

i. A 3D spatio-semantic model, which represents the district's physical objects/entities in reality. It represents not only the spatial characteristics of the district's objects, but also semantic information defining functions, thematic properties and characteristics of those entities and the interrelationship between them. The advantage of having such a model is that it would allow each real world identity to be represented by a unique object within the district model. Unique and stable identifiers will be used to unambiguously refer to such virtual objects. Each object can serve as a reference object to which sensors and datasets can be associated; this 3D model may include buildings, streets, vegetation, utilities and terrains. It is proposed to base this spatio-semantic model on the Open Geospatial Consortium (OGC) CityGML standard (Gröger, Kolbe, et al., 2012);

ii. The network model, which defines functional behaviours, and resources and their flows, e.g., transportation, energy, water, or communication networks. Such network elements correspond to the 3D spatio-semantic model; unfortunately, at the moment there exists no OGC standard regarding the network modelling. Moreover, it is currently not possible to define network models according to the CityGML standard. However, the development of an Application Domain Extension (ADE) has already been started for utility network and currently there is a research project working on developing and complementing this ADE (Kutzner and Kolbe, 2016).

iii. The visualisation models, which are 3D computer graphic models (offline or browser based) for rendering the district objects or 2D maps (paper maps or web maps). They are typically derived/generated from the 3D spatio-semantic model. The visualisation model is useful for many purposes such as presentation, communication, interaction, etc.

5.2 Sensor and sensor data

To offer better services, smart districts should be able to continuously monitor their environment and the activities of the citizens. To do so the existence of sensor webs is essential. Large scale sensing requires the deliberate deployment of various sensors accessible by their owners or/and the use of sensors in mobile devices carried by people or vehicles (Percivall, 2013). The way in which different sensors produce information and store the data varies widely from type to type. Therefore, there is a need to provide a solution, which can deal with different data types and datasets on one hand and on the other hand provide valid data for the applications that are understandable by any tool developer/data user. Open standards for sensor webs are needed to achieve flexibility and loose coupling (ad hoc interaction) of diverse systems.

SDDI also provides the possibility to work with diverse sensor data by utilizing the OGC based initiative Sensor Web Enablement (SWE). This set of international standards includes:

i. An information schema to define a wide variety of sensors and their metadata.
ii. Sensor services allowing discovery, tasking, and accessing/planning of sensor information in an interoperable way. Amongst the different services, the Sensor Observation Service (SOS) is initially recommended and tested in this project. However, according to the requirements of the cases, other services can be applied too.

Sensors themselves can also be linked to VDM elements. In addition to the SWE, another option to include the dynamic data from sensors is the newly developed dynamizer for CityGML. This will shift the static model of CityGML to dynamic according to Chaturvedi et al. (Chaturvedi and Kolbe, 2015).

The “CityGML Dynamizer” enables the feature representations of city models to support variations of individual feature properties and associations over time. This may involve variations of not only spatial properties but also thematic attributes. The dynamizers reference a specific attribute of a specific object within a 3D city model providing time-dependent values to override the static value of the referenced object attribute. The dynamic data may be given by tabulation of time/value pairs, patterns of time/value pairs or by referencing a Sensor Observation Service (SOS). The dynamizer can thus be used to inject dynamic variations of city object properties into an otherwise static representation (Chaturvedi and Kolbe, 2015).

The advantage in using such an approach is that if an application does not support dynamic data, it simply does not allow/include these special types of features. However, if an application does support dynamic data, it can be fully exploited for different querying capabilities (Chaturvedi and Kolbe, 2015).

5.3 Case study

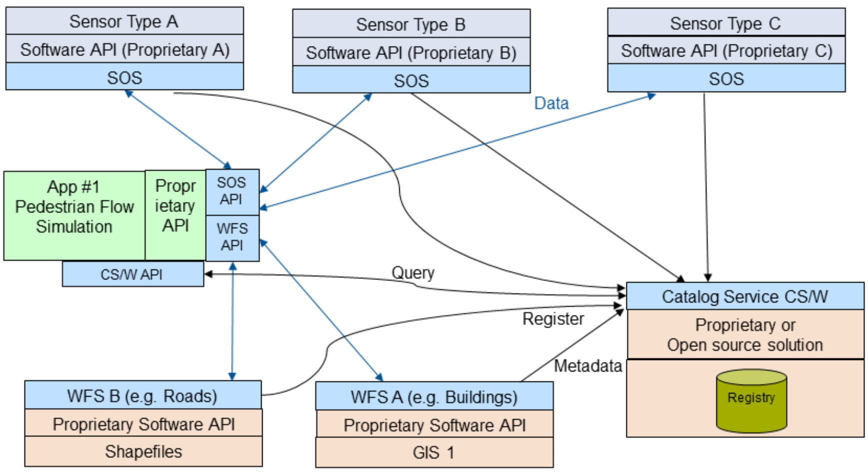

Figure 3. SDDI distributed architecture based on OGC services (Source: Kanishk Chaturvedi – Technical University of Munich)

An example of the proposed SDDI architecture, which enables a standardized integration of distributed data items is shown in Figure 3. Here the setting up of service interfaces on top of distributed data repositories is displayed. SOS services or SOS facades for example, are setup for the proprietary sensor devices. SOS services or facades allow the export of sensor data in the OGC Observation and Measurements (O&M) standard. This standard defines the semantics as well as the exchange format of the data. Web Feature services (WFS) facades on the other hand, can be set up to provide standardized access to any third party proprietary data. The city objects such as roads, buildings or weather data can be accessed by utilizing WFS or Web Coverage Service (WCS). The catalogue service interface (CS/W) facilitates the querying of all the data items and the registering of new data items. This interface may also accommodate the retrieving of metadata concerning the data items. The user application includes service interfaces, which give access to data from different sources in a standardized manner. The user application may also include a catalogue service (CS/W) interface, allowing search/query of the data items.

6. CONCLUSION AND OUTLOOK

The proposed SDDI and specifically its data entities have been implemented in QEOP in London and the whole concept is currently applied in Docks de Saint Ouen in Paris. It is going to be tested in more districts such as Moabit-west in Berlin and other European cities. The purpose is to test the designed infrastructure in more districts and cities with different use cases to improve the functionality of SDDI and extend it in order to cover as many data types and formats as possible. It should be noted that although the use cases are specifically tested in the SSD scale, the model has the capability of being applicable for large-scale cases.

According to "TC 1/SG 1 Smart Cities Report 2015" the current challenges of Smart cities are mainly focused on domains such as "Energy efficiency", "Renewable energy", "Mobility", "Water", "Citizens engagement", etc. These domains have various use cases many of which are related to the physical environment. To deal with this challenge we need to work with the wide variety of physical objects provided by CityGML, which are easy to create. For example in London a CityGML model was constructed for the QEOP district and different sensors were linked based on the designed infrastructure. These data are being used for different simulations such as crowd management, event management, building energy efficiency and smart park navigation and are the basis of a 3D visualisation tool offered through an interactive dashboard developed by a local academic partner.

It should be noted that not all existing objects are included in CityGML. Luckily, the CityGML has a mechanism to extend its functionality for those modules that are not inherently included. One of the future works for this model is to develop a stable CityGML ADE for utility network.

Another aspect of an information infrastructure, known as one of the most challenging problems, is information security and data privacy. Of course not all of the data providers would like to share their data openly nor is it legally allowed in many countries. So, it is a vital feature for an information infrastructure to ensure the security of the data for both data providers/owners and users. The future work that should be carried out for the proposed solution, is to include protection measures focusing on three aspects; authentication, authorization and encryption.

Last but not least, our solution includes some OGC and ISO standards. However, there are still some areas that are not adequately covered by these standards. Especially, in the area of citizen engagement there is a big gap that needs to be considered in the work of standard organizations.

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Correlation between GA-based optimization of green spaces and air pollution reduction:

A Case Study on Dhaka City

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Key words: Urbanization, Air-pollution, Greeneries, Genetic Algorithm (GA), Optimal-distribution, GIS

Abstract: In this study, we establish a correlation between GA-based optimization of green spaces and air pollution reduction thereby presenting the contribution of greeneries in lessening air pollution. In this context, we first used the grid-wise spatial distribution of CO_2 in Dhaka city using geographic information systems (GIS). Then, assess how many different sizes of trees are required to plant optimally in multi-variant green space locations obtained from genetic algorithms (GA)-based heuristic optimization. Next, we quantify carbon reduction capacity of different sizes of trees considering basal area of trees and standing woody biomass. Carbon sequestration has shown to vary significantly with the types of green spaces. More predominant effect was found with local parks. We found that different sizes of trees in optimal multi-variant green spaces could sequestrate up to 1,745,848 ton of carbon per year. In addition, we emphasized from GA-based sitting of green spaces that indeed *adequate and optimal* locations of green spaces in an urban setting can effectively reduce air pollution.

1. INTRODUCTION

Due to urbanization and industrialization, many developing countries all over the world are confronted with environmental problems. Air pollution is one of the major such environmental problems. Greeneries have substantial impact on air quality of a city. However, the processes of unexpected green area transformation leads to the physical and environmental instability of the city. Specifically, the reduction of green areas has significant deleterious effects by diminishing the pollution absorption capacity of the city. Optimal planting of multi-variant green spaces is thus important to consider during both new development and redevelopment of a city.

Dhaka with its overwhelming growth rate of population of 4.24% each year is predicted to be the third largest megacity in the world by year 2020. Evidently the most of areas of Dhaka is highly air polluted with pollutants comprised mainly of SOx, NOx and CO. In addition, there is CO_2 emissions resulting from natural and human sources. Among these deforestation (human source) is predominant resulting extensive rise (dangerous level) in the atmospheric concentration of CO_2.

Polluted air exacerbates increased cardiopulmonary mortality, hospitalization for respiratory diseases, exacerbation of asthma, decline in lung function and restricted life activity. Reportedly, Bangladesh is the fourth position among the ranking of 91 countries with the worst urban air quality. In such a scenario, about seven million people suffer from asthma and alarmingly more than half of them are children. Air pollution kills 15,000 people each year (Mahmood, 2011).

Evidently, air pollution is worsening day by day particularly in mega-city Dhaka. It is utmost important to put great attention now how to establish a healthy life by reducing air pollution. Many past literatures indicate that urban greeneries play many important functions such as air purification, air pollution mitigation, air temperature control, enhance beautification, etc. to promote a sustainable livable environment (Neema, Maniruzzaman, et al., 2013). In previous study, using GA-based multi-objective heuristic modeling for continuous optimization we have shown optimum locations and the number of multi-variant green spaces (Neema and Ohgai, 2013). Aspect of carbon storage by urban trees has qualitatively been assessed by some researchers (Zhao, Kong, et al., 2010; Strohbacha and Haaseb, 2012; Escobedo, Kroeger, et al., 2011; Setälä, Viippola, et al., 2013). However, none yet has considered the required number of different sizes of trees in multi-variant green spaces and quantify its carbon sequestration capacity in optimal way.

In this study, we thus correlate between GA-based optimization of green spaces and air pollution reduction. In this context, we first used grid-wise spatial distribution of CO_2 in Dhaka city using geographic information systems (GIS). Then, assess how many different sizes of trees are required to optimally plant in multi-variant green space sites obtained from genetic algorithms (GA)-based heuristic optimization. Next, we quantify carbon reduction capacity of different sizes of trees considering basal area of trees and standing woody biomass. Finally, we perform correlation between multi-type green spaces and their capacity of reducing air pollution in Dhaka city.

2. STUDY AREA AND ITS GREEN SPACE CONTEXT

We considered 90 zones (wards) of mega-city Dhaka as a case study. In our previous study, land use change and its impact on surface temperature of Dhaka city during 1988-2014 were investigated (Rafsan, et al., 2015). *Figure 1* shows the chronological change of green spaces in Dhaka from the year 1988 to 2014.

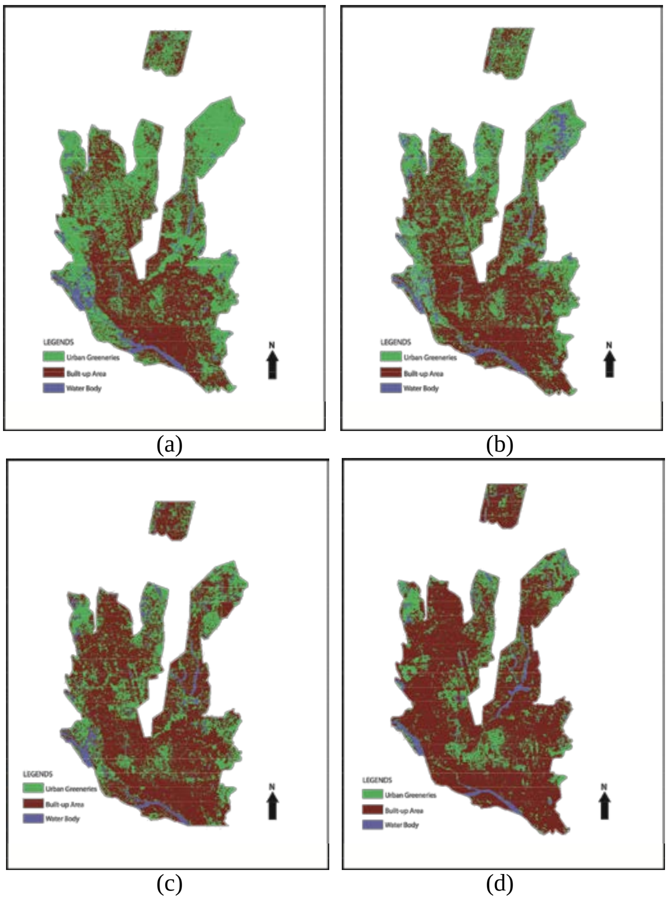


Figure 1. Map of chronological change of green areas of Dhaka city in year: (a) 1988, (b) 1995, (c) 2003, and (d) 2014.

The bar-chart representation of the change of land use pattern (green space, water-body and built-up areas) is depicted in *Figure 2*. The total green space in Dhaka was found to be 7887 ha in year 1988. It was reduced to 6382 ha (19 % diminished) within 7 years till year 1995. The remaining green space was badly reduced to 4749 ha (25 % diminished) within the next 8 years till year 2003. The green space was further reduced to 3283 ha (30 % diminished) within the next 11 years by the year 2014. It was observed that within the duration of only 25 years (from the year 1988 to 2014), the green space was substantially lessened which is about 58 %.

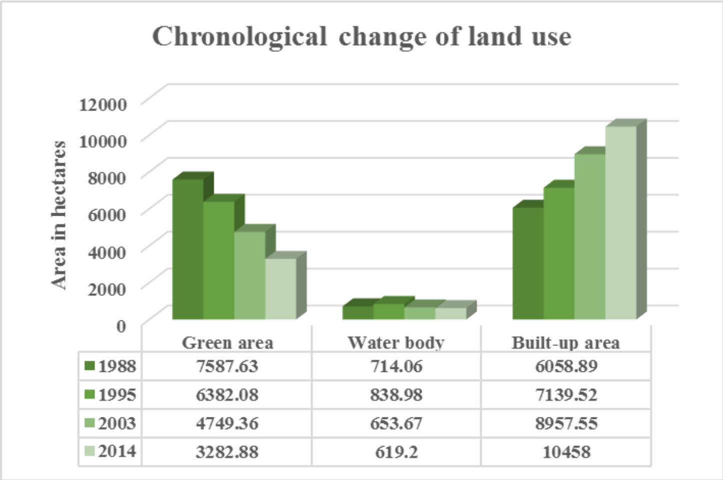


Figure 2. Bar-chart representation of change of land use pattern (green space, water body, and built-up area) from the year 1988 to 2014.

3. GA-BASED OPTIMAL GREEN SPACES

The genetic algorithm (GA) is a search heuristic that can be used to find optimal solutions to a real world problem. Genetic algorithm works on a population of solutions. Each solution is evaluated using evaluation/fitness function of GA. After evaluation, better solutions are selected to perform next iteration using two operations viz. crossover and mutation. There is a predetermined number of generations set prior to starting GA process. The GA process stops when the predetermined number of generations is completed. The details about GA and optimum locations of proposed multi-type green space can be found elsewhere (Neema and Ohgai, 2013).

However, there are multi-variant and multi-functional green spaces having different capacity of absorbing air pollutants such as city parks, local parks, play grounds, neighbourhood open spaces and other green spaces including road side green spaces and green areas inside shopping area or educational area. They usually differ in size, purpose, location and character and therefore are amenable to a variety of classifications. Green spaces may be small or large, near or far away and provide services to a neighbourhood or entire city. In our previous research (Neema et.al. 2008), we conducted a study on existing condition and location of multi-variant green spaces in Dhaka city. We classified multi-variant green spaces according to their space requirement, size and distribution. We found that there was only 0.22 acres of open space available per 1,000 population that is far below the recommended standards followed in different countries in the world. Therefore, the existing green spaces are inadequate to serve growing population of the city.

We found that there is a need of around 1500 acres of additional green spaces in Dhaka to improve its environment and to meet the recreational need of growing people. We also determined the number and area of different category of proposed multi-type green spaces as shown in *Table 1* (Neema and Ohgai, 2013). In this research, based on the optimally sited multi-type green spaces we have estimated the required different types of trees which is presented in the next section and establish quantitative correlation between optimal green space sites and air pollution reduction.

Table 1. Area and number for each category of proposed green space

Category	Proposed area (acres)	Area for each green space (acres)	Number of proposed green space
CP	300	100	3
LP	500	50	10
PG	300	15	20
NOS	400	8	50
Total	1500		83

CP: City parks, LP: Local parks, PG: Playgrounds, NGS: Neighborhood open spaces

4. RESULTS AND DISCUSSION

4.1 Estimation of types of trees in optimized multi-variant green spaces

In this section, we estimate the number of trees to be planted in the optimized multi-type green spaces. First, we studied different sizes of trees to be planted. We use diameter at breast height (DBH) as metric to determine different sizes of trees (Nahian, 2012). *Figure 3* shows the sizes of different trees. For our estimation, we considered the measurement of different sizes of trees as proposed (see in *Table 2)*.

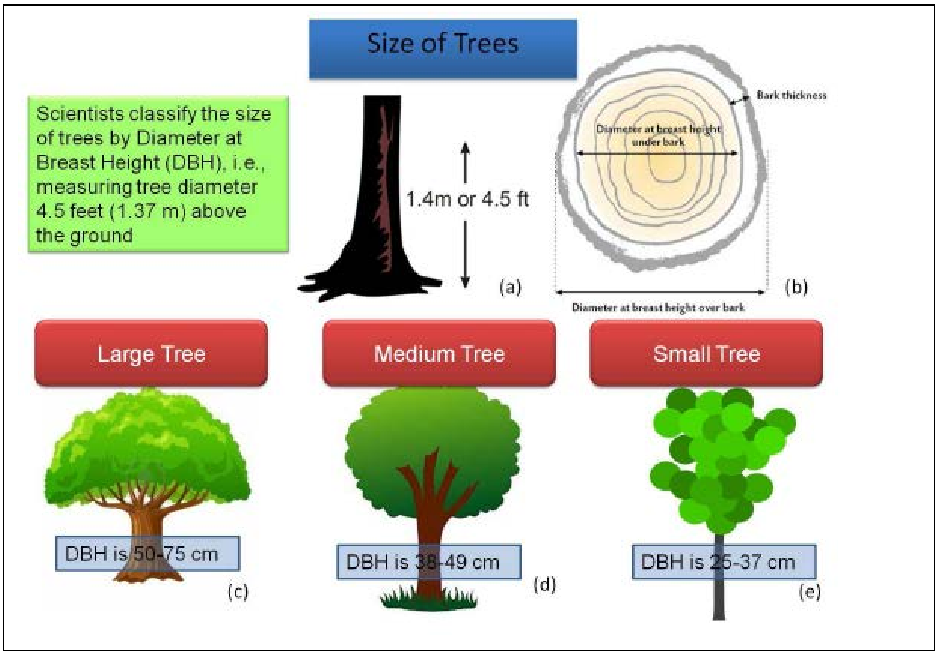


Figure 3. Different sizes of trees

Table 2. Sizes of trees based on diameter at breast height (DBH)

Categories	DBH (inch)	Average dia (inch)	Average dia (m)
Small Tree	10-14	12.0	3.0
Medium Tree	15-19	17.0	4.3
Large Tree	20-29	24.5	6.2

In this study, we first calculate the number of different types of trees to be planted in our proposed multi-type green spaces (see *Table 3*). We assumed the minimum distance (*D*) between different sizes of trees to be 15 ft., 10 ft and 7 ft. for large, medium and small sizes of trees respectively. Using the minimum distance, in a $D \times D$ sq. ft. area, number of each type of tree would be 4. Next, we calculated the number of trees to be planted in each type of green spaces. For example, in a city park of 4356000 sq. ft. area, the number of large trees to be planted would be = (4 × 4356000)/ (15 × 15) = 77440. Thus, the total number of large trees to be planted in 3 city parks would be = 77440 × 3 = 232320 (refer to *Table 3*).

Table 3. Number of various types of trees in multi-type green spaces

CP (100 acre)					
Tree category	[a]Assuming Min [m] distance maintained *D* (ft.)	[b]Trees in (*D*×*D*) sq. ft.	[c]CP area (sq. ft.)	[d]Trees in a CP	[e]Trees in 3 CP
Large Tree	15	4	4356000	77440	232320
Medium Tree	10	4	4356000	174240	522720
Small Tree	7	4	4356000	355592	1066776
LP (50 acre)					
Tree category	[a]Assuming Min [m] distance maintained *D* (ft.)	[b]Trees in (*D*×*D*) sq. ft.	[c]LP area (sq. ft.)	[d]Trees in a LP	[e]Trees in 10 LP
Large Tree	15	4	2178000	38720	387200
Medium Tree	10	4	2178000	87120	871200
Small Tree	7	4	2178000	177796	1777959
PG (15 acre)					
Tree category	[a]Assuming Min [m] distance maintained *D* (ft.)	[b]Trees in (*D*×*D*) sq. ft.	[c]PG area (sq. ft.)	[d]Trees in a PG	[e]Trees in 20 PG
Large Tree	15	4	653400	11616	232320
Medium Tree	10	4	653400	26136	522720
Small Tree	7	4	653400	53339	1066776
NOS (8 acre)					
Tree category	[a]Assuming Min [m] distance maintained *D* (ft.)	[b]Trees in (*D*×*D*) sq. ft.	[c]NOS area (sq. ft.)	[d]Trees in a NOS	[e]Trees in 50 NOS
Large Tree	15	4	348480	6195	309760
Medium Tree	10	4	348480	13939	696960
Small Tree	7	4	348480	28447	1422367

CP: City parks, LP: Local parks, PG: Playgrounds, NGS: Neighborhood open spaces
a: Minimum distance maintained between trees *D* (ft.); b: Number of trees in (*D* × *D*) sq. ft. area; c: Each type of green space area in sq. ft. as per *Table 1;* d: Number of trees in each type of green space area, d = (b × c)/ (a × a); e: Total number of trees in the predetermined number of each type of green space area as per *Table 1*.

4.2 Atmospheric CO_2 reduction by different types of trees

In this section, we will analyse and present the contribution of green spaces in reducing atmospheric carbon dioxide (CO_2). To assess CO_2 reduction, we performed detail calculation for different types of trees (large, medium and small) as discussed earlier for multi-type green spaces. We also computed the capacity of grass, shrubs and herbs in multi-type green spaces to reduce atmospheric CO_2 by using their covered area. The quantification was made employing the following steps:

Step 1: Calculation of average diameter or girth at breast height (DBH/GBH) of different types of trees

We first calculated average GBH of different types of trees following DBH metric mentioned in *Table 2*. For instance, the range of DBH of large tree is 20 to 29 inch. The average DBH of large tree would thus be 24.5 inch. Similarly, we calculated the average DBH of small and medium trees.

Step 2: Calculation of basal area (BA) of different types of trees

Basal Area (BA) of a tree represents the cross-sectional area at its breast height i.e. 1.3 meter (4.5 feet) above the ground [31]. BA of different types of trees were calculated using the following equation [13]:

$$BA = \left(\frac{GBH}{2\pi}\right)^2 \times \pi \qquad (1)$$

Basal areas of trees are measured in square meter (m^2) shown in column IV in *Table 4*.

Step 3: Calculation of standing woody biomass (SWB) of different types of trees

Biomass is the total mass of living plant organic material, and it is proportional to volume and basal area at the stand level, and diameter and height at the individual plant level [32]. The standing woody biomass (SWB) of different types of trees were calculated using the following equation [13] and shown in column *V* in *Table 4*:

$$SWB\ \left(\frac{ton}{ha}\right) = -1.69 + 8.32 \times BA \qquad (2)$$

Step 4: Calculation of carbon sequestration (CS) by different types of trees

Carbon sequestration (CS) by different types of trees was calculated using the following equation [13] and shown in column *VI* in *Table 4*:

$$CS\ (Carbon\ sequestration) = 0.46 \times SWB \qquad (3)$$

Step 5: Calculation of carbon sequestration (CS) by grass, shrubs and herbs (GSH)

Carbon sequestration by grass, shrubs and herbs (GSH) in multi-type green spaces was calculated taking their covered areas into consideration. To quantify, it is anticipated from literature that 1 ha area of grass, shrubs, herbs can sequestrate 1 ton of CO_2.

Table 4. Calculation of CO_2 reduction by different types of trees and grass, shrubs and herbs in proposed multi-type green spaces

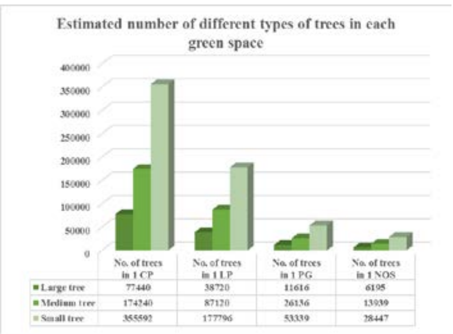
CP (100 acre)					
Tree Category	Number of trees	GBH (m)	BA (m^2)	SWB (ton/ha)	CS (ton)
Large	232320	0.62	692249.5	576.0	265.0
Medium	522720	0.43	749201.6	623.3	286.7
Small	1066775.5	0.30	744231.8	619.2	284.8
Grass-Shrubs-Herb	Area (hectares)		CS by leaves (ton/ha)		
	121.406		121.406		121.406
LP (50 acre)					
Tree Category	Number of trees	GBH (m)	BA (m^2)	SWB (ton/ha)	CS (ton)
Large	387200	0.62	1153749.2	960.0	441.6
Medium	871200	0.43	1248669.3	1038.9	8906557
Small	1777959.2	0.30	120386.3	1032.0	474.7
Grass-Shrubs-Herb	Area (hectares)		CS by leaves (ton/ha)		
	202.343		202.3		202.3
PG (15 acre)					
Tree Category	Number of trees	GBH (m)	BA (m^2)	SWB (ton/ha)	CS (ton)
Large Tree	232320	0.62	692249.5	576.0	265.0
Medium Tree	522720	0.43	749201.6	623.3	286.7
Small Tree	1066776	0.30	744231.8	619.2	284.8
Grass-Shrubs-Herb	Area (hectares)		CS by leaves (ton/ha)		
	121.406		121.4		121.4
NOS (8 acre)					
Tree Category	Number of trees	GBH (m)	BA (m^2)	SWB (ton/ha)	CS (ton)
Large Tree	309760	0.62	922999.3	767.9	353.2
Medium Tree	696960	0.43	998935.5	831.1	382.3
Small Tree	1422367	0.30	992309.0	825.6	379.8
Grass-Shrubs-Herb	Area (hectares)		CS by leaves (ton/ha)		
	161.9		161.9		161.9

GBH: Average dia or Girth at Breast Height, BA (Basal Area of All Trees): $(GBH/2\pi)^2\pi$, SWB (Standing Woody Biomass): – 1.689 + 8.32 × BA, CS (Carbon Sequestration): 0.46 × SWB

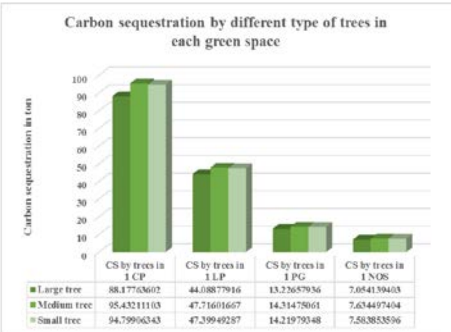
4.3 Correlation between optimized green space and air CO_2 reduction

In this section, we perform the correlation between optimized green space and their capacity to reduce CO_2. The correlation study is performed in two parts: 1) correlation between number of different types of trees i.e. large, medium and small in multi-type green spaces and their capacity in CO_2 reduction and 2) correlation between amount of grass, shrubs and herbs in multi-type green spaces and their capacity in CO_2 reduction.

First, we analyse the correlation between number of different types of trees i.e. large, medium and small in multi-type green spaces and their capacity in CO_2 reduction. *Figure 4(a)* shows the estimated number of different types of trees in each type of green spaces.



(a)



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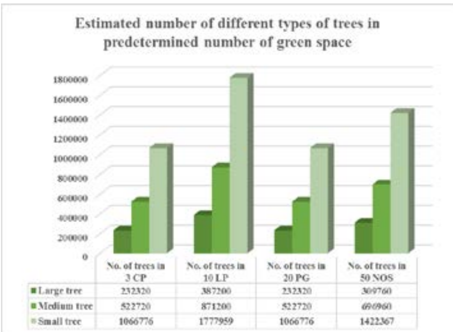

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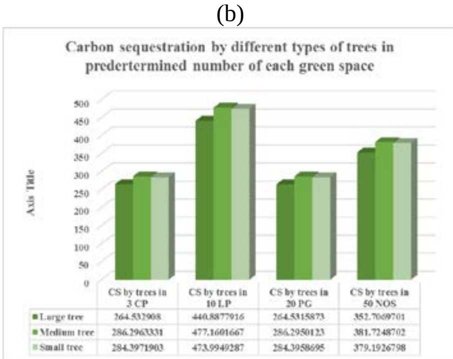


(d)

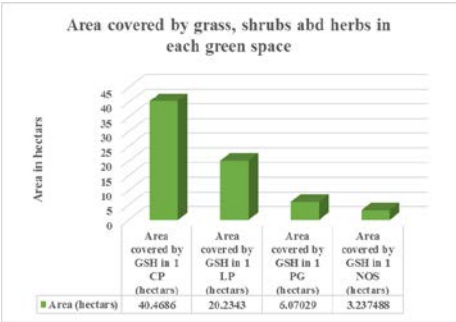
Figure 4. Correlation between different types of trees in multi-type of green spaces and CO_2 reduction: (a) estimated number of trees in each green space, (b) carbon sequestration by in each type of green space, (c) estimated number of trees in predetermined green spaces, and (d) carbon sequestration by predetermined green spaces.

It is observed that in a city park (CP), there is a higher number of large, medium and small trees than local park (LP), playground (PG) and neighbourhood open space (NOS). *Figure 4(b)* shows carbon sequestration of different types of trees in each type of green spaces. As a CP contains higher number of trees, its carbon sequestration capacity is much higher than a LP, a PG and a NOS.

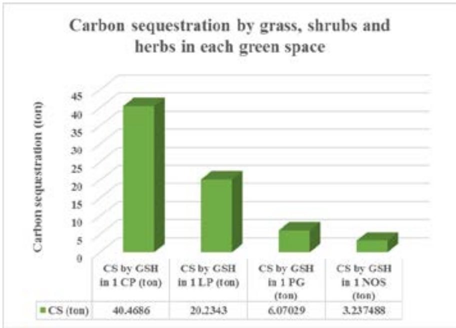
Figure 4(c) and *4(d)* respectively show the estimated number and carbon sequestration of different types of trees in predetermined number of multi-type green spaces (see in *Table 1*). It is observed from *Figure 4(c)* that there is higher number of large, medium and small trees in local parks than other types of open spaces. Evidently, carbon sequestration capacity of local parks is much higher than the capacity of trees in other types of open spaces (*Figure 4(d)*). Thus, planting higher number of trees in optimal green space sites is for CO_2 reduction is quantitatively established.

Now, we correlate between area covered by grass, shrubs and herbs in multi-type green spaces and their capacity in CO_2 reduction. *Figure 5(a)* and *5(b)* respectively show the area covered by grass, shrubs and herbs (GSH) and their carbon sequestration capacity in each type of green space. As area of a city park (CP) is higher than the other types of green spaces i.e. a local park (LP), a playground (PG) and a neighbourhood open space (NOS), the area covered by GSH in City Park outperforms the GSH covered area in other types of green spaces.

It is well-established that 1 hectare of GSH can sequestrate 1 ton of CO_2. Therefore, the area covered by GSH in a city park can sequestrate greater amount of CO_2 (*Figure 5(b)*). *Figure 5(c)* and *5(d)* respectively show the area covered by grass, shrubs and herbs (GSH) and their carbon sequestration capacity in predetermined number of multi-type green spaces (3 city parks, 10 local parks, 20 playgrounds and 50 neighborhood open spaces). It is observed from *Figure 5(c)* that there is a greater amount of GSH in local parks than in city parks, playgrounds and neighborhood open spaces. As there is a greater amount of GSH in local parks than other types in predetermined number of green spaces, its carbon sequestration capacity is much higher than the capacity of GSH in 3 city parks, 20 playgrounds and 50 neighborhood open spaces (*Figure 5(d)*). Thus, the higher amount of GSH can reduce CO_2 significantly.



(a)



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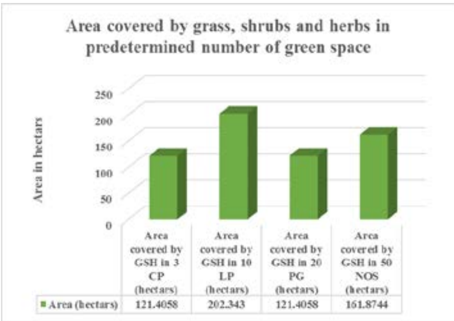

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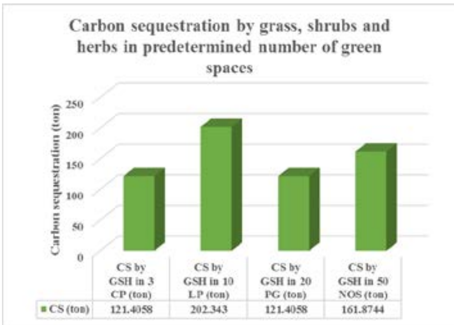

(d)

Figure 5. Correlation between grass, shrubs and herbs in multi-type of green spaces and CO_2 reduction: (a) estimated number of trees in each green space, (b) carbon sequestration by in each type of green space, (c) estimated number of trees in predetermined green spaces, and (d) carbon sequestration by predetermined green spaces.

Table 5 shows the calculated the total amount of CO_2 reduction by different types of trees in predetermined number of multi-type green spaces. The analysis and obtained results show that indeed areas with more green spaces can reduce more CO_2. Optimal plantation is thus an effective measure to reduce CO_2 towards mitigating air pollution and consequently helps to turn a city healthier and more suitable for living.

Table 5. CO_2 reduction by multi-type green spaces

Multi-type green space	Carbon sequestration (ton/day)	Carbon sequestration (ton/year)
City parks	956.63	349,170.76
local parks	1,594.39	581,950.85
Playgrounds	956.63	349,169.32
Neighborhood open spaces	1,275.50	465,557.11
Total	4,783.15	1,745,848.04

Figure 6 shows graphical representation of total carbon sequestration by all types of trees and grass, shrubs and herbs in proposed multi-type green spaces. It was found that local parks can reduce the highest amount of CO_2 i.e. 581,950 t C/year, neighbourhood open space can reduce the second highest amount of CO_2 i.e. 465,557 t C/year, city parks and playgrounds can reduce almost equal amount of CO_2 i.e. 349,169 t C/year.

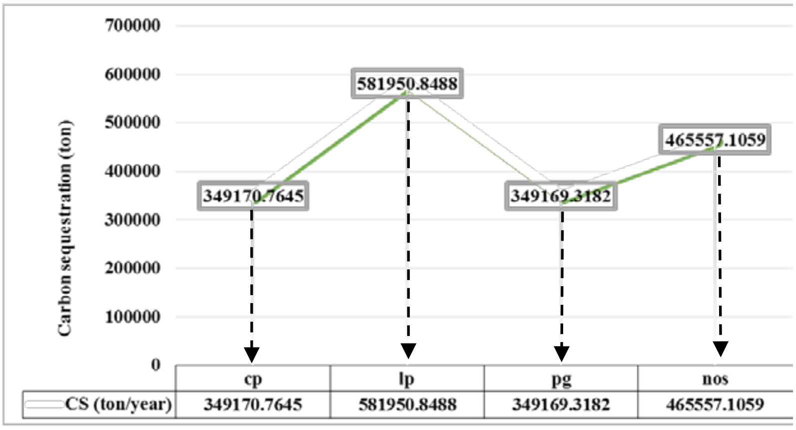

Figure 6. Total carbon sequestration by all types of trees and grass, shrubs and herbs in multi-type green spaces. CS: Carbon sequestration, CP: City parks, LP: local parks, PG: Playgrounds, NOS: Neighborhood open spaces.

5. CONCLUSIONS

We have quantitatively shown that indeed more green spaces in an urban setting can significantly reduce carbon dioxide towards mitigation of air pollution. We demonstrated that different sizes of trees in optimal multi-variant green spaces could sequestrate up to 1,745,848 ton of carbon per year. CO_2 reduction capacity of local parks is found to be more predominant followed by neighbourhood open space and city parks and playgrounds in succession.

As spatial distribution of CO_2 varies, the optimal placing of green spaces is shown to be an important pre-requisite for the reduction of CO_2. In this context, application of Genetic Algorithm (GA) and Geographical Information System (GIS) in green space optimization towards air pollution minimization has shown to be a unique approach. The results thus obtained would help both academia and city planners to apply greenery-based concepts in city planning for cleansing air pollution. In this study, we considered carbon dioxide reduction as the most important component of air pollution. We will consider other components of air pollution namely SO_x and NO_x in our future research.

6. ACKNOWLEDEMENTS

This research was supported by Japanese Society for the Promotion of Science (JSPS), the Ministry of Education, Culture, Sports, Science and Technology, Japan. The first author also acknowledges undergraduate students under her supervision for contribution in data settings.

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Using the Expert System Theory in the Development of Support Methods for a Compact City Plan

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Key words: Expert system, Compact city, Concentration Urban Structure Model

Abstract: In this study, we aim to gather suggestions about the designation technique of "Residence Instruction Area" in developing plans that for compact city creation in local governments. Therefore, we first developed guidelines based on administrative plans needed to build a Concentration Urban Structure Model. We then evaluated the model from various perspectives. Finally, we extracted the candidate area that reflected the "Residence Instruction Area" from the emerging study results.

1. INTRODUCTION

1.1 Background and purpose of the study

In recent years, the problems of population decline, low birthrate and an aging population have contributed to issues of uninhabited city centers and suburban sprawl in. The Japanese national government has developed measures that aim to realize the compact city in order to address these problems. In 2014, an Act on Special Measures concerning Urban Reconstruction was revised, and local governments pushed forward the development of a "Location Adequacy Plan" toward achieving a compact city. The law promotes the design of a "City Function Instruction Area" which encourages effective provision of various service by planning the concentration of a city functions, while a “Residence Instruction Area”*[1] keeps population density stable by managing the accumulation of residents. At December 31, 2015, 220 local governments were developing the plan.

*1 Resident population numbers are managed to ensure that community services are sustainably provided by keeping population density stable in an area.

1.2 Review of related studies

There are many studies that investigate the concept of a compact city. For example, there are studies that have examined compact cities in terms of public transport (Bouquet, 2014), and have proposed strategies for urban regeneration (Jung Geun, Hyum-Chang et al., 2014), as well as the support mechanisms needed to develop a compact city (Tsuboi, Ikaruga et al., 2015). However, there is a dearth of studies that examine Location Adequacy Plans.

1.3 Research methods

The target area for this study is Ube City in the Yamaguchi Prefecture. We first estimate figures of the future population by using a primary factors cohort. Then, we built a Concentration Urban Structure Model for 2035 from Knowledge Base, using administrative plans. Population concentration rules for the study were made using Knowledge Base. Once the model had been evaluated, we considered the techniques required for designating a “Residential Instruction Area.” This study additionally used 100 meters of mesh data for analysis.

2. OVERVIEW OF CASE STUDY

2.1 Location of Ube City

Ube City has been selected as the study site and is located in the southwestern part of the Yamaguchi Prefecture. Yamaguchi at the western-most tip of Honshu in Japan. Ube is adjacent to Yamaguchi City, which is the prefectural capital. Ube City has an area of 28,665 ha, and the Area Division System*[2] is not applied.

*2 The Area Division System divides city planning areas into urbanization promotion areas that promote development, and urbanization control areas that restrict development in order to preserve the natural and agricultural environment.

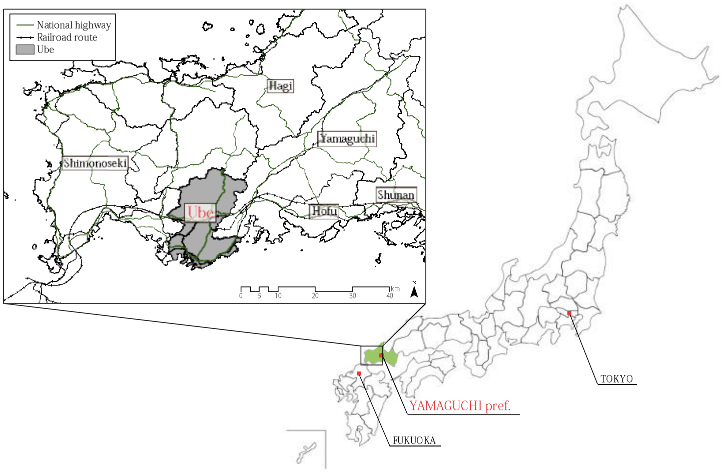

Figure 1. Location of target city of this study

2.2 Land use in Ube City

Around 25% of the land in Ube City has been designated for Use Districts, and around 60% of the administrative division has been allocated to forests. Of the total population, 12% live in forests, rice fields and on farmlands.

2.3 Population transition in Ube City

2.3.1 Future population projections

In Ube City, the population continued to grow from 1970 until 1995, then the population subsequently decreased. Presently, the population of Ube City sits at around 170, 000 people. By using the primary factor cohort analysis, it is shown that the estimated future population will be less than 140, 000 by 2035. Using mesh data, it is shown that low population density increases in the city center.

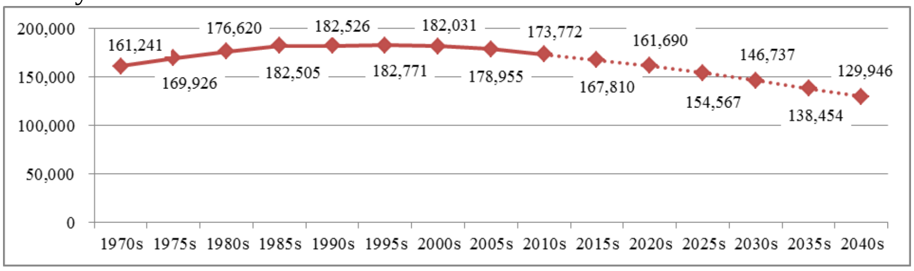

Figure 2. Population growth transition of Ube City

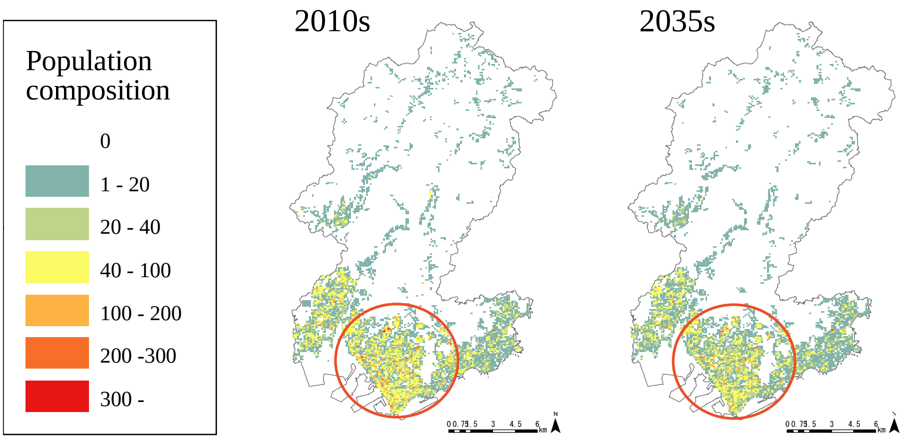

Figure 3. Population distribution (2010s, 2035s)

2.3.2 Changes in densely-inhabited districts (DIDs)

After 1960, the overall area of the DIDs spread. The population rate in the DIDs continued to increase until 1990, and a decrease was seen in subsequent years. Population density for the DID kept decreasing in line with the expansion of the residential areas to the external land use districts.

Table 1. Transition of the DID

	Area of the DID (ha)	Population of the DID	Population density of the DID (people per ha)
1960s	960	86,556	90.2
1965s	1,110	79,873	72.0
1970s	1,960	87,310	44.5
1975s	2,250	93,230	41.4
1980s	2,640	99,471	37.7
1985s	2,720	102,285	37.6
1990s	2,930	106,322	36.3
1995s	2,870	101,116	35.2
2000s	2,843	93,439	32.9
2005s	2,867	91,699	32.0
2010s	2,926	90,799	31.0

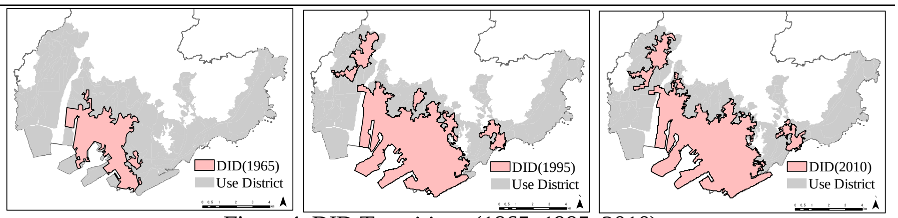

Figure4. DID Transitions (1965, 1995, 2010)

3. BUILDING A CONCENTRATION URBAN STRUCTURE MODEL

We built a Concentration Urban Structure Model using an Expert System, which draws on an inference algorithm that is based on organized expert knowledge and data.

3.1 Summary of collected administrative plans

We extracted descriptions from administrative plans in order to build a Concentration Urban Structure Model and create a Knowledge Base (Yamaguchi Prefecture, 2011, 2008, 2013, Ube City, 2016, and 2015). These plans included the “Basic Plan of Land Use in Yamaguchi Prefecture” regarding land use in the Yamaguchi Prefecture, the “Ube City Planning Master Plan” that describes the urban design of Ube City, the “Ube Eco City Plan” that aims to reduce environmental load and encourage the realization of a compact city, as well as the “Location Adequacy Plan” from the Ministry of Land, Infrastructure, Transport and Tourism.

3.2 Developing population concentration guidelines

Based on an administrative plan, we made population concentration rules to build Concentration Urban Structure Model. Radius of base areas is shown in table 2. Target population density of each base is shown in table 3. Figure 5-8 shown the designation area for urbanization, agricultural, forest and calamity danger by administrative plans. Figure 9 shows flow chart of rules for population concentration. Figure 10 shows user interface to simulate for building Concentration Urban Structure Model.

(1) Rule of the setting of the non-inhabitable area.

By four following rules, the non-inhabitable area is set.

Rule1(Setting the non-inhabitable area using land use): The area that is farmland, the forest, barren land, the surface of the water, a golf course is designated non-inhabitable area.

Rule2(Setting the non-inhabitable area using 5 Area Divisions[*3]): Forest Area is designated non-inhabitable area.

Rule3(Setting the non-inhabitable area using calamity danger districts): The area that is the site subject to sediment disaster and flood-assumed area is designated non-inhabitable area.

Rule4(Setting the non-inhabitable area using Use Districts[*4]): Exclusive industrial district is designated non-inhabitable area.

(2) Rule of population concentration in Urban Area and Agricultural Area.

By two following rules, population is concentrated around concentration bases (urban base, regional bases, local community bases) and public transportation axes that were set after having obtained civic agreement in "Ube Eco City Plan".

Rule5(The population concentration in Urban Area): In the area that it is Urban Area of 5 Area division and belongs around concentration base areas or a concentration axes, it is concentrated population by each after aim population density was designated.

Rule6(The population concentration in Agricultural Area): In the area that it is Agricultural Area of 5 Area Division and belongs around concentration base areas or a concentration axes, it is concentrated population by each after aim population density was designated.

Concentration bases are as follows.

Urban base: base that plays a central role in the city. Functions of the highly advanced city accumulate variously there. It creates a high lifestyle of the convenience of the Ube City version by utilizing accessibility with the lifestyle support function and the job function, and instruction of the residence function is promoted in the range and the outskirts that can enjoy it.

Regional bases: base that complements urban base. Functions of the city that play a central role of local accumulate there. The instruction of the residence function of medium and low storied buildings are promoted in the range and the outskirts that can move on foot from commercial facilities, railroad stations and bus stops which are provided of high convenience.

Local community bases: base that life service functions to support life-based daily life activity are accumulated. The area that basic services (government, medical, welfare) to be required in everyday life are provided. And it becomes focal point of community activity. The area is based on the school zone of the elementary school.

Concentration axes (public transportation axes) as follows.

Main highway axes: East-West axes that buses are operated relatively frequently.

Regional arterial highway axes: the axes connect local community bases and main highways.

JR axes: axes used for the transfer beyond the city limits and for the transfer of the comparatively wide area between a city base and local bases.

Concentration Urban Structure Model is shown in figure11.

*3 It plans the general and premeditated land use by dividing the area of prefectures into Urban Area, Agricultural Area, Forest Area, Natural Park Area, Natural Conservation Area.

*4 It prevents the mixture of the use by designating a local use about residence, commerce, industry in a city area.

Table 2. Radius of concentration base areas

Concentration base areas	Radius
Urban Base	800 m
Regional Bases	500 m
Local Community Bases	300 m

Table 3. Desired population density

	Names of bases and axes	Urban Area	Agricultural Area
Concentration bases	Urban base	100 population/ ha	×
	Regional bases	60 population/ha	×
	Local community bases	Keep population of 2010s	Keep population of 2010s
Concentration axes (public transportation axes)	Main highway axes	30 population/ha	30 population/ha
	Regional arterial highway axes	16 population/ha	16 population/ha
	JR (Japan Railways) axes	16 population/ha	16 population/ha

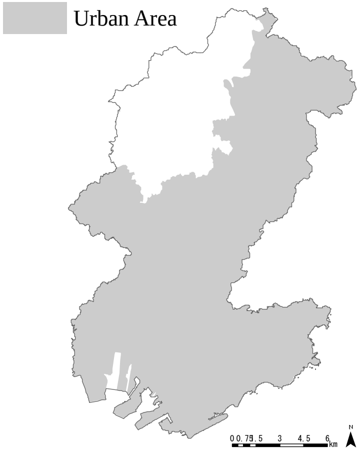

Figure 5. Urban Area

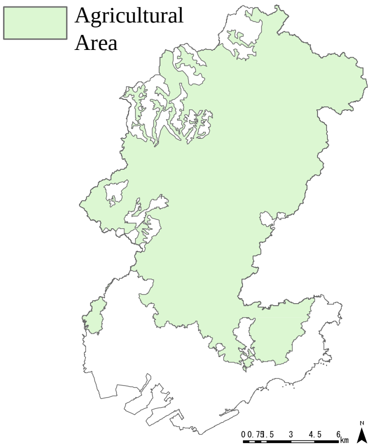

Figure 6. Agricultural Area

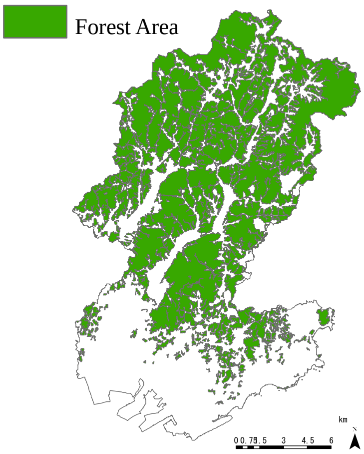

Figure 7. Forest Area

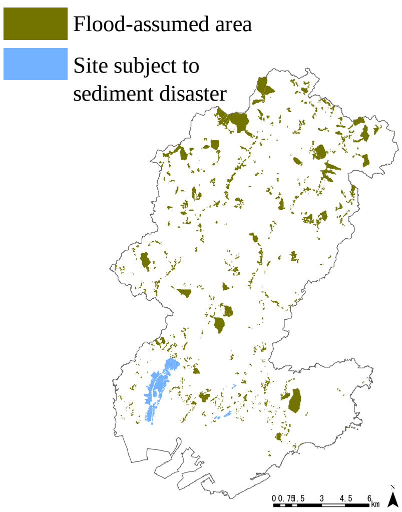

Figure 8. Disaster risk districts

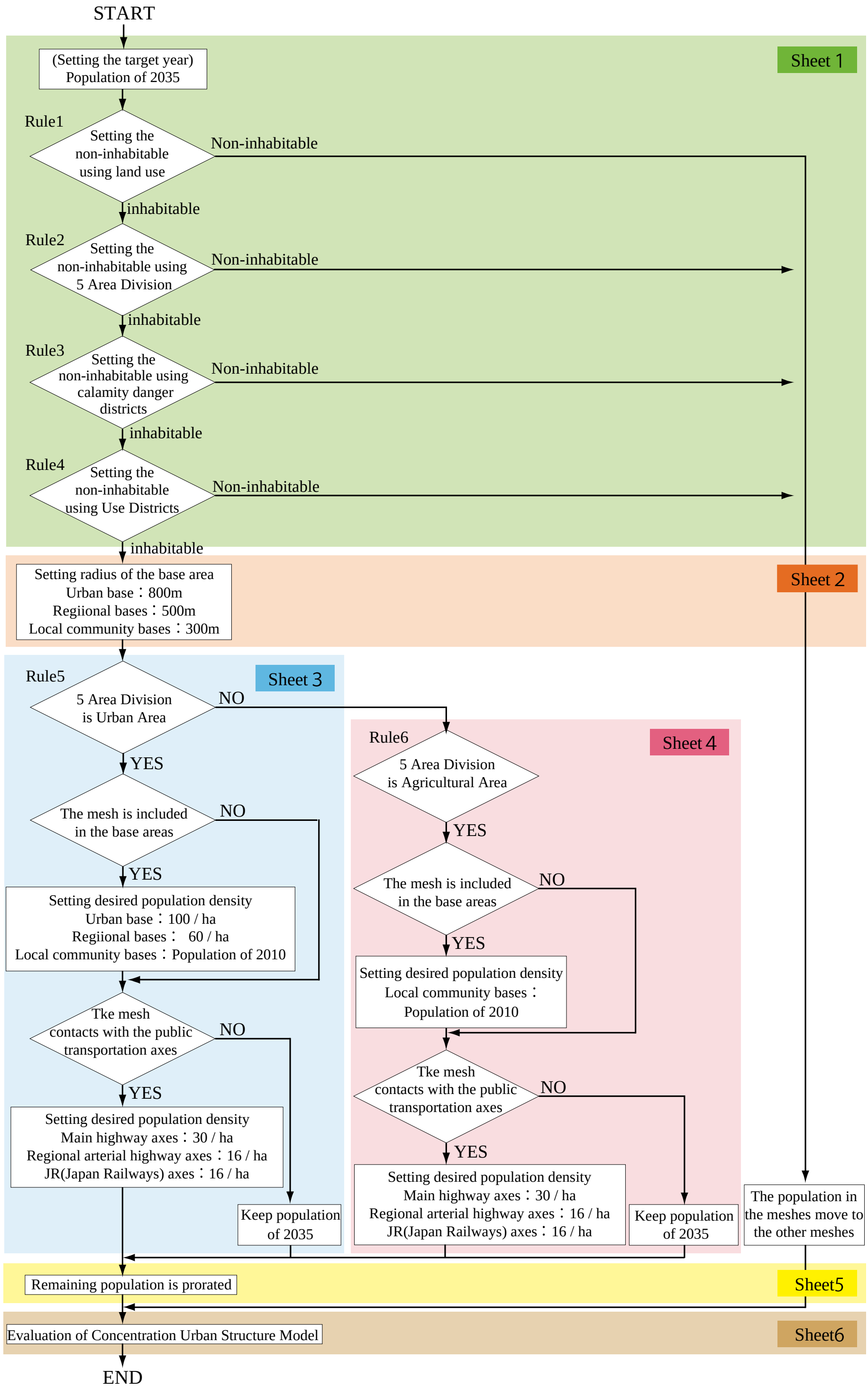

Figure 9. Flow chart of rules of population concentration

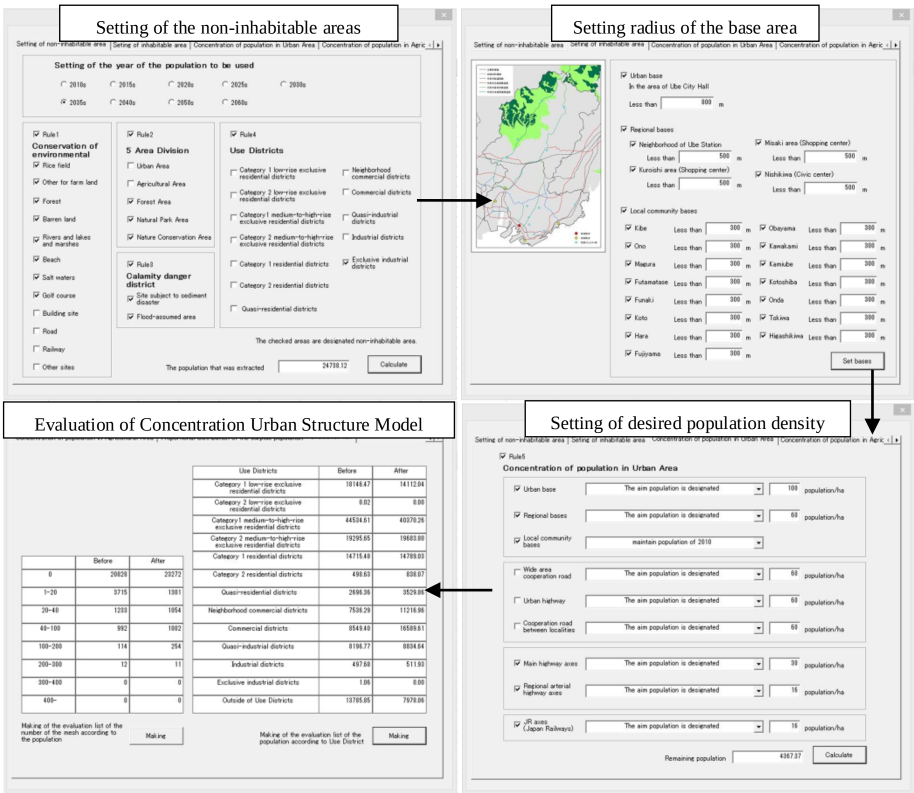

Figure 10. Interface images of the simulation

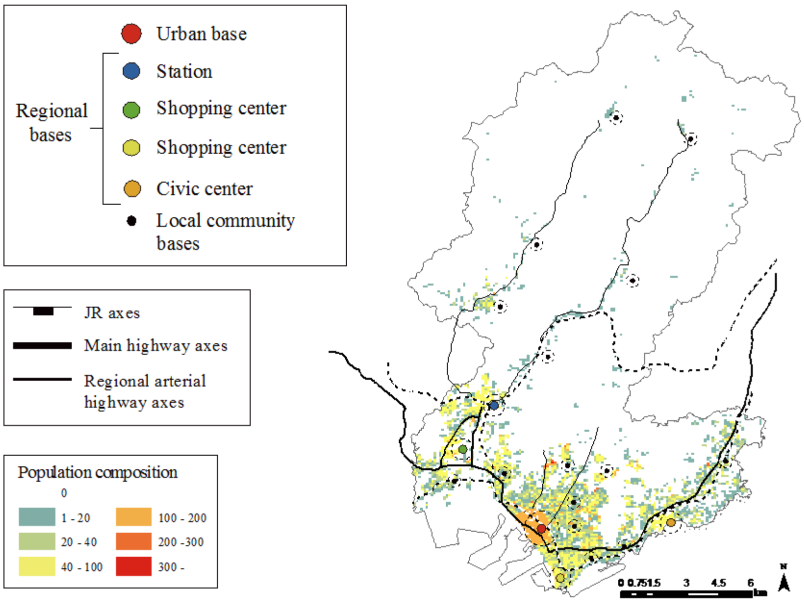

Figure 11. Concentration Urban Structure Model

4. EVALUATION OF THE CONCENTRATION URBAN STRUCTURE MODEL

4.1 Evaluation by population composition

From the results of the evaluation of the Concentration Urban Structure Model using population composition as a measure, meshes of “0 population” and of “100—200 populations” increased, while meshes of less than “20 populations” decreased when comparing the population distribution of 2010 with that of 2035. In addition, as a result of having considered population distribution on the basis of 40/ha, which was the population density of the standard of DID, meshes of high population density were concentrated around the city center.

Table 4. Population composition comparison

Population of meshes	2010s		2035s		Concentration Urban Structure Model	
	Number of meshes	Composition ratio (%)	Number of meshes	Composition ratio (%)	Number of meshes	Composition ratio (%)
0	20,710	77.0	20,828	77.4	23,272	86.5
1 - 20	3,442	12.8	3,715	13.8	1,313	4.9
20 - 40	1,229	4.6	1,233	4.6	1,023	3.8
40 - 100	1,297	4.8	992	3.7	1,018	3.8
100 - 200	197	0.7	114	0.4	255	0.9
200 - 300	17	0.1	12	0.0	12	0.0
300 -	2	0.0	0	0.0	1	0.0
Total	26,894	100.0	26,894	100.0	26,894	100.0

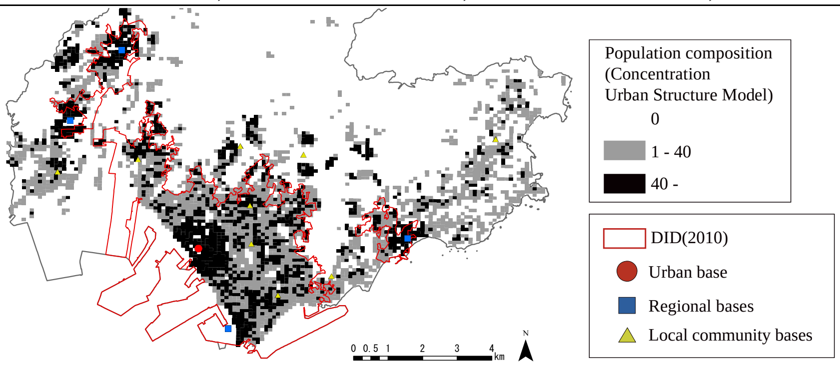

Figure 12. Population distribution on the basis of 40 people per ha

4.2 Evaluation by Use Districts

From the results of the evaluation of the Concentration Urban Structure Model by Use Districts, the population increased around commercial use districts. These areas are designated for intensive land use along the railway lines and highways around city.

4.3 Evaluation by lifestyle and convenience

From the perspective of lifestyle and convenience, we evaluated the Concentration Urban Structure Model using indexes about public transportation and the distance from three community service facilities.

4.3.1 Evaluation by distance from medical facilities

From the results of the evaluation about the Concentration Urban Structure Model by distance from medical facilities (hospitals and clinics), it was shown that there are few meshes with high population density that are far from those facilities. There are many meshes with populations of more than 60 or more than 100 in areas that are closely located those facilities. Therefore, medical facilities are located near the city area where the population is concentrated. Based on these factors, accessibility to medical facilities improves, and therefore, the number of people using these facilities increases. However, meshes of “0 population” increased around areas that are far from medical facilities as many facilities are located in areas that have been designated as non-inhabitable areas.

Table 5. Correlation of distance from medical facilities and population density (2035s)

Population density of meshes(people per ha)	Number of meshes according to The distance from medical facilities				Total of number of meshes
	0 - 500 (m)	500 - 800 (m)	800 - 1000 (m)	1000 - (m)	
0	1335	1412	986	17095	20828
1 - 20	1588	542	290	1295	3715
20- 40	958	170	49	56	1233
40 - 60	506	64	24	32	626
60 - 80	195	23	16	18	252
80 - 100	84	5	6	19	114
100 -	111	4	1	10	126
Total of number of meshes	4777	2220	1372	18525	26894

Table 6. Correlation of distance from medical facilities and population density (Concentration Urban Structure Model)

Population density of meshes(people per ha)	Number of meshes according to The distance from medical facilities				Total of number of meshes
	0 - 500 (m)	500 - 800 (m)	800 - 1000 (m)	1000 - (m)	
0	2161	1817	1201	18093	23272
1 - 20	711	192	86	324	1313
20- 40	821	123	41	38	1023
40 - 60	396	51	21	27	495
60 - 80	359	28	15	16	418
80 - 100	76	5	6	18	105
100 -	253	4	2	9	268
Total of number of meshes	4777	2220	1372	18525	26894

4.3.2 Evaluation by distance from welfare facilities

From the results of the evaluation of the Concentration Urban Structure Model by distance from welfare facilities, there are few meshes of high population density in areas that are located far from those facilities. There are many meshes with high population density that are located near those facilities. As seen from these results, accessibility to welfare facilities improves, and the number of people utilizing those facilities increases. However, meshes of "0 population" increased near areas that are from welfare facilities. These results are similar to the results of the evaluation conducted for medical facilities.

Table 7. Correlation of distance from welfare facilities and population density (2035s)

Population density of meshes(people per ha)	Number of meshes according to The distance from welfare facilities				Total of number of meshes
	0 - 500 (m)	500 - 800 (m)	800 - 1000 (m)	1000 - (m)	
0	1748	1866	1326	15888	20828
1 - 20	1703	716	298	998	3715
20- 40	907	215	53	58	1233
40 - 60	474	101	34	17	626
60 - 80	215	26	7	4	252
80 - 100	81	21	7	5	114
100 -	110	14	1	1	126
Total of number of meshes	5238	2959	1726	16971	26894

Table 8. Correlation of distance from welfare facilities and population density (Concentration Urban Structure Model)

Population density of meshes(people per ha)	Number of meshes according to The distance from welfare facilities				Total of number of meshes
	0 - 500 (m)	500 - 800 (m)	800 - 1000 (m)	1000 - (m)	
0	2639	2400	1561	16672	23272
1 - 20	770	242	78	223	1313
20- 40	762	165	46	50	1023
40 - 60	374	77	28	16	495
60 - 80	377	31	6	4	418
80 - 100	76	17	7	5	105
100 -	240	27	0	1	268
Total of number of meshes	5238	2959	1726	16971	26894

4.3.3 Evaluation by distance from commercial facilities

From the results of the evaluation of the Concentration Urban Structure Model by the distance from commercial facilities (facilities with an area of more than 1,500 square meters), it is shown that many meshes have a population of more than 60 or more than 100 in areas that are close to those facilities. These results show that accessibility to commercial facilities improves, and the number of users of those facilities increases. However, in comparison with the evaluation by the distance from medical facilities and welfare facilities, there are many meshes that have high population density in areas that are far from commercial facilities. This relationship shows that commercial facilities are located in the suburbs.

Table 9. Correlation of distance from commercial facilities and population density (2035s)

Population density of meshes(people per ha)	Number of meshes according to The distance from commercial facilities				Total of number of meshes
	0 - 500 (m)	500 - 800 (m)	800 - 1000 (m)	1000 - (m)	
0	375	390	290	19773	20828
1 - 20	526	340	198	2651	3715
20- 40	357	206	137	533	1233
40 - 60	183	91	64	288	626
60 - 80	85	43	28	96	252
80 - 100	35	17	3	59	114
100 -	51	11	4	60	126
Total of number of meshes	1612	1098	724	23460	26894

Table 10. Correlation of distance from commercial facilities and population density (Concentration Urban Structure Model)

Population density of meshes(people per ha)	Number of meshes according to The distance from commercial facilities				Total of number of meshes
	0 - 500 (m)	500 - 800 (m)	800 - 1000 (m)	1000 - (m)	
0	663	564	421	21624	23272
1 - 20	195	166	90	862	1313
20- 40	226	182	120	495	1023
40 - 60	95	89	51	260	495
60 - 80	215	64	35	101	415
80 - 100	30	18	3	57	108
100 -	188	15	4	61	268
Total of number of meshes	1612	1098	724	23460	26894

4.3.4 Evaluation of the correlation with public transportation convenience area

From the results of the evaluation of the Concentration Urban Structure Model using the population coverage rate of public transportation convenience area (i.e., the area in which it is convenient to use public transport), the population coverage rate of the area rose by 8% in the Concentration Urban Structure Model in the comparison of the population distribution of 2010 and that of 2035. However, it is necessary to relocate the positions of bus stops and increase the frequency of the bus services in order to realize a more efficient system of public transportation.

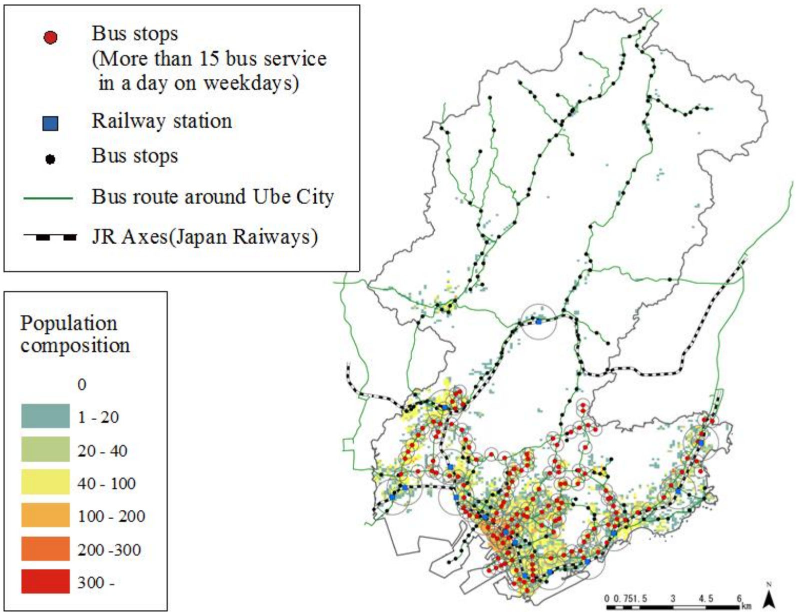

Figure13. Public transportation convenience area and Concentration Urban Structure Model

Table 11. Public transportation convenience area

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="3">Bus</td></tr>
<tr><td colspan="2">300m range from the bus stop</td><td rowspan="2">More than 300m range from the bus stop</td></tr>
<tr><td>More than 15 bus service in a day on weekdays</td><td>Less than 15 bus service in a day on weekdays</td></tr>
<tr><td rowspan="2">Railway</td><td>Less than 800m range from the station</td><td colspan="3">Public transportation convenience area</td></tr>
<tr><td>More than 800m range from the station</td><td></td><td>Public transportation inconvenience area</td><td>Public transportation blank area</td></tr>
</table>

Table 12. Correlation of public transportation convenience area and population distribution

	2010s	2035s	Concentration Urban Structure model
Population of each year	173,978.03	138,454.27	138,454.27
Cover population of public transportation convenience area	111,587.08	88,830.06	99,228.88
Population cover rate of public transportation convenience area (%)	64.14	64.16	71.67

5. CONSIDERATION OF THE AREA DESIGNATION OF RESIDENCE INSTRUCTION AREA

We extracted candidate sites for the Residence Instruction Area from the evaluation of the Concentration Urban Structure Model that was built.

The sites extracted as candidate sites for Residence Instruction Area are as follows:

(1) In the Concentration Urban Structure Model, these are meshes that belong to an urban base or a regional base, or around public transportation axes, and there are no meshes of “0 population.”

(2) In the Concentration Urban Structure Model, these are meshes that have a population of 40 or more.

(3) In the Concentration Urban Structure Model, these are meshes that have a population of 20 or more, and belong to areas within 500m from three life service facilities.

Meshes which correspond to either (1), (2), and (3) should be designed, if these are located within public transportation convenience area.

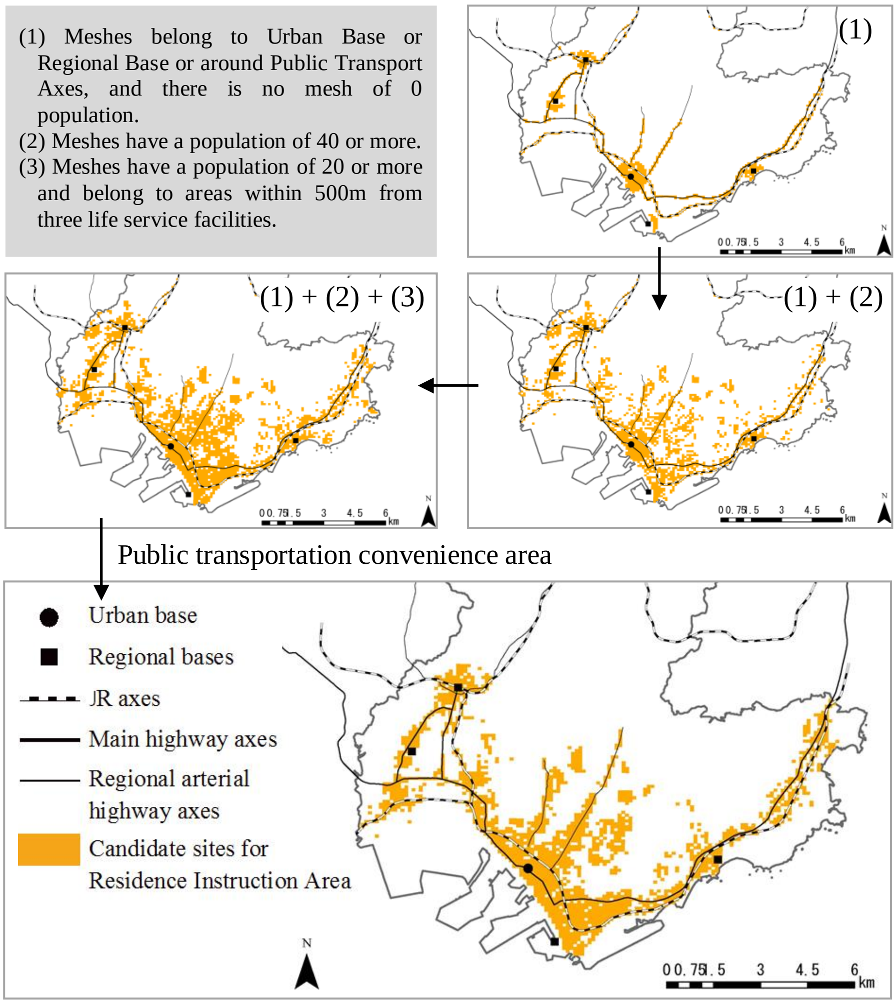

Figure 15. Extraction process of candidate areas for Residence Instruction Area

6. CONCLUSION

The results of this study are as follows:
(1) In Ube City, the population has decreased and spread out to the suburbs. By examining the future population distribution for 2035, it was shown that meshes of low population density will increase around the city center.
(2) From the results of the evaluation of the Concentration Urban Structure Model, meshes of high population density were shown to increase around the urban base, while population decreased in the suburbs. From this, the Concentration Urban Structure Model reflected a compact city structure where population was concentrated around the urban base.
(3) From the results of the evaluation of the Concentration Urban Structure Model in terms of lifestyle and convenience, meshes of high population density increased in areas that were near to life service facilities, and the population coverage rate of public transportation convenience areas also rose. From this, it was shown that accessibility improved.
(4) Based on the evaluation of the Concentration Urban Structure Model, we suggested candidate areas for Residential Instruction Area that could be formed by bases, population density, areas of life service facilities usage and public transportation convenience area.

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Designing economic models for the energy transition at the territorial scale

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Key words: economic model, business model, energy transition, cities, externalities

Abstract: Climate change mitigation and sustainable development is increasingly defining urban projects. High energy performance building standards imply high project extra costs at inception or through retrofitting solutions in urban renovation of buildings and urban infrastructure. However the weak economic climate and outlook is making it hard for investors to justify the additional investments in the absence of a market. Efficacity, the Institute for energy transition in the urban environment proposes an 8-stage methodology in order to identify relevant externalities of an energy efficiency project, determine relevant monetary values and to design suitable partnerships likely to convert them into economic flows. This article reviews this method as applied in a first instance to the specifications of a new building block project based on the use of potential synergies with local facilities (geothermal drilling and nautical centre). A second example reviews the potential economic effects on a district heating network when implementing non-concerted sustainable policies (building energy efficiency actions and waste minimisation policies). The application of this methodology proves it is useful for identifying and valuing externalities. The development of tools for use in partnerships through innovative contractual agreements and transactions intends to integrate the value of externalities in the overall project evaluation and is the main objective pursued by this project.

1. BACKGROUND

Energy efficiency investments have by and large been limited to energy-intensive industries ‘contribution to climate change mitigation (Grubb et al., 2014). In urban projects energy efficiency is les concerted and explicit.

With new large urban projects encouraged to integrate climate change mitigation through high energy performance standards, the impact on project costs is considerable. From the additional conception costs to all the other additions in terms of equipment, facilities and infrastructure, energy efficiency implies a considerable increase in costs when constructing a new housing, office buildings or transport infrastructures. This is even more significant in the case of urban renovation (Guennec et al., 2009, Nösperger et al., 2015). However the poor economic outlook is making it hard to justify this additional investment in the absence of a market for these ambitious projects. Yet, social and environmental co-benefits related to energy efficiency are now apparent (Tirado Herrero et al., 2011; Ürge Vorsatz IEA 2014). How can these contradictions between benefits and costs be solved in order to make projects viable? We shall attempt to solve this paradox by addressing a number of questions:

- When assessing the economic opportunity of an urban project, how can it be ensured that the socio-environmental benefits related to improved energy efficiency are taken into account? How are these benefits qualified from the perspective of different stakeholders and monetised, when relevant?
- What types of partnerships, agreements or contracts exist which ensure an equitable distribution or sharing of the economic value stemming from the identified co-benefits? Is this value sufficient to make the energy efficiency investment viable?

Today’s energy production facilities are either highly centralised (power plants) or highly decentralised (e.g. photovoltaic panels installed on roofs). What can learn from business models developed for transport (Uber) and internet (Google) that can integrate the multi-scale territorial perspective that characterises the diversity of actors and object in the area of energy efficiency, for example through smart grids.

EFFICACITY, the institute for energy transition in the urban environment, has been addressing these questions in a thematic program with the aim of delivering operational tools for use by stakeholders involved in urban projects (local authorities, energy and water suppliers, developers, etc.).

Following a literature review (part 2 of this article), a methodology for a broadened economic assessment was developed by EFFICACITY (presented in part 3) .This methodology was applied in two urban projects to test its validity, which is the subject of sections 4 and 5 of this article. We then end with a concluding section.

2. LITERATURE REVIEW

Environmental externalities have been studied in numerous projects and research articles and provide a solid basis to help identify broad families of externalities within the framework of an energy efficiency project (Amann, 2006), such as health impacts (Loftness et al., 2003), biodiversity protection (Ürge Vorsatz et al., 2009), and greenhouse gas reduction (IEA, 2014). In the case of environmental externalities, it should be noted that some States set "shadow values" that is to say, the value of the external costs when evaluating public infrastructure projects (Quinet 2008, Quinet 2013, CESD "socio-economic assessment" ...). The positive impact on local economic development (2014 Guennec et al IEA. 2009) or productivity (Loftness et al., 2003) are also revealed. This literature review has been synthesized in a reference book (Effiacity 2014) and an accompanying database (under development).

The following table provides some examples of the co-benefits of energy efficiency in the case of buildings.

Table 1. Examples of an integrated analysis of building functions and impacts (Source: Efficacity Externality reference tool and Nösperger & al., 2015)

Impact or externality category	**Impact Description**	**Stakeholder**
Health	Occupant health improvement thanks to comfort improvement	Occupier Occupying company
	Improved health thanks to facility (cycle boxes, shower facility, pedestrian paths…) allowing environment-friendly mobility (bicycling, walking)	Occupant
Productivity	Occupant wellness related productivity improvement thanks to comfort improvement (temperature, natural lighting)	Occupying company
	productivity improvement thanks to building-related positive corporate communication	Occupying company

		Inhabitants
Territorial facilities support	Building's ability to store rainwater (avoiding the need for additional drainage facilities)	Territory
Potable water savings	Improved potable water using equipments which optimizes the sizing of the waste water treatment facility)	Territory
Emissions and pollution	Energy-related CO_2 emissions due to comfort equipment such space heating	Occupier Territory World population

Asset value improvement ("green value")	Improved asset value (reduced vacancy period) due to advanced building indoor flexibility and adaptability	Owner
	Improved asset value due to reduced vacancy period or improved nominal rents thanks to advanced energy and environment labeling	Owner
Territorial economic development	New industry creation or reinforcement through the selection of technical solutions involving local firms	Local authority Local firms Inhabitants
Territorial facilities support	Building's ability to store rainwater (avoiding the need for additional drainage facilities)	Territory
Potable water savings	Improved potable water using equipment which optimizes the sizing of the waste water treatment facility)	Territory
Emissions and pollution	Energy-related CO_2 emissions due to comfort equipment such space heating	Occupier Territory World population

In fact, the main difficulty, when evaluating a well-defined energy efficiency project, lies in adapting locally these general externalities. While the enlarged economic evaluation of such urban energy efficiency projects can rely on proven methods (ISO 15686-5, Joumni 2009), or contrary to conventional evaluation methods such as Cost Benefit Analysis, where the State arbitrates between winners and losers, local energy efficiency projects require defining externality values which find endorsement by stakeholders for them to be then be inclined to contribute to a project on a voluntary basis.

The valuation of externalities is thus linked to the creation of economic models able to integrate those actors, traditionally absent or underrepresented, in current economic transactions around building projects.

In fact, beyond the business model, which is a monetary translation, the business model implies (du Tertre 2011 Nösperger et al, 2015.) gathering the following prerequisites:

- A basis for value creation and distribution (capturing) between the actors;
- The basis and formal structure of relationships between actors (contracts, formal or informal partnerships, "cooperative" society ...);

- Sources of mutual investment or financing operations;

- The nature of work performed by these players: skills, qualifications, activities produced independently or co-constructed (co-production).

The methodology presented in the next section proposes to address simultaneously the issue of externalities / co-benefits to consider and business models suited to their actual transformation into a monetary or non-monetary value.

3. METHODOLOGY

EFFICACITY developed an 8-stage methodology intended to assist in identifying relevant externalities of an Energy Efficiency project, determine relevant monetary values, and design suitable partnerships likely to convert them into economic flows (financial or non-financial):

Phase 1: Local context identification and definition of alternative solutions (stages 1-3):

- Step 1: Background and overview of the initial situation (nature of the project, scope) and identification of the sets of actors involved in the project.
- Step 2: Identification of technological and organizational solutions in energy efficiency adapted to the situation (and envisaged in the EFFICACITY relevant programs). Who do they concern and to what extent?
- Step 3: Classification and selection of a range of solutions

Phase 2: Externalities and benefits identification, selection and monetization (stages 4-6)

- Step 4: Identification and selection of externalities related to selected solutions.
- Step 5: Estimated market and non-market economic values
- Step 6: Arbitration of possible strategies to optimize resource allocation.

Phase 3: Identification of relevant partnerships/ contractual relationships and business model design (stages 7-8).

- Step 7: Design the business model adapted and sensitivity tests
- Step 8: Evaluation of the implementation conditions of the selected strategies: economic and contractual conclusions

4. 8-STEP METHOD APPLIED TO THE CONSTRUCTION OF AN URBAN BLOCK

4.1 Step 1: context

The planned urban block being subject to evaluation is located in a neighbourhood in the Paris basin shared with new buildings of a university campus, an architectural school, a Regional Express Railway station (RER), college halls of residence and a university canteen. This mixed urban block consists of 4000m² of offices and 13,500 m² student residences. The local authority is also considering building a large nautical centre (2000 m² Basin). The project is in an area with special status, a "new town", managed by a public development agency named EPA (Etablissement Public d’Amenagement).

EPA owns the grounds of the planned urban block and intends to sell it to the property developer who will commission and manage the project and supervise other contracted project managers such as for the halls of residence and the office buildings. This project is the subject of a single contract of Design-Build-Operate & Maintenance of which the incumbent manages the various components having already identified a number of subcontracting partners. EPA intends the cluster located in its district to be competitive internationally against other campuses.

Local energy resources include: an aquifer (120 m deep, 14° C), solar radiation, biomass (subject to demand by the local authority), and fatal heat from the nautical centre. A system composed of 5 wells was installed for the university building, with a discharge well back to the aquifer.

The energy balance of the territory points to:

- Net demand for heat from the student canteen in the campus, the building block and nautical centre. The net heat requirement of the building block is due to the predominance of residential housing (and high domestic hot water needs)
- Net cold requirements from the university building. This building will therefore significantly use a cooling tower before releasing water above or below the temperature of aquifer. However, the low flow rate of the aquifer will heat up the aquifer in the absence of additional uses for the waste heat.

4.2 Steps 2 & 3: Alternative energy solutions

The reference project, for calculating the additional cost of the energy efficiency solution, is a building block powered by a gas boiler and air-conditioning from adiabatic air coolers. The reference block is 30% more efficient than new period buildings.

The comparative analysis that follows, with respect to this reference solution, takes an energy efficient starting point (baseline).

In the context of this article, we will develop only the most promising alternatives, especially from the perspective of their intensity of use in a context of basically very efficient buildings. It is noteworthy that all of these alternatives include installing photovoltaic sensors whose production will be sold at a fixed feed-in tariff for 20 years.

The energy concept 1 of the building block is based on combining multiple sources of energy: gas, electricity, solar photovoltaic, and wastewater. Energy recovery from the grey waters is more robust (reliable and cost-effective) than solar thermal sources because it is simpler and requires no maintenance. Energy systems are centred on a thermorefrigeratingpump (TFP) that is not able to supply in a balanced way the hot and cold needs of the block. As a result there is a systematic loss of refrigo-calories (cold) having to be released back to the aquifer. This solution could be quite effective from a functional and energy standpoint in theory; unfortunately the temperature rise of the aquifer requires a search for alternatives. Indeed, while the energy balance of Bienvenüe university building wells, on the one hand, and the building block V1 on the other (which are located at a distance) could compensate "partially", the very low flow rate of the aquifer does not allow this "compensation" to be effective.

The Energy Concept 2 relies on the Mutualisation of the abstraction from the aquifer. The thermorefrigeratingpump on this aquifer uses the same wells used for the university building. This solution has the advantage of partially addressing the problem of excess heat emitted annually into the aquifer by the Bienvenue Building (due to an overall cooling need for the year) that leads to its gradual warming (because of the low rate of flow of the aquifer preventing heat to disperse). The decision to adopt this solution is based on the assumption that coupling the university building and the building block is sufficient to balance the needs and reduce very significantly the heat discharge to the aquifer. The innovative character of these buildings with high performance outer casings accentuates the risk of a mismatch between the simulated and observed behaviour. The coupled system “Building block – University building” may still be out of balance with an annual heat surplus, which would still contribute to the gradual warming of the aquifer.

The Energy Concept 3 relies on the Mutualisation of the abstraction from the aquifer and on the addition of a nautical leisure park.

The policy targets set by the local authority requires it to meet 50% of the heat demand of the nautical centre with renewable energy, in this case with solar thermal panels. The surface of these panels is downsized to avoid overheating.

Assuming that the “super-block” made of the projected building block and the university building to be in net heat excess in the summer (releasing water at 35° C), this balance could be used by the nautical centre to further reduce its summer minimal heat demand and consequently the surface needed for the solar panels. Before such considerations the surface area of the solar panel stood at 2900 m². Investment savings are therefore foreseeable.

4.3 Identifying externalities and co-benefits

We have to reason differentially (instead of reasoning on the comparison of absolute life cycle costs of each alternative) with respect to a high performance reference solution. The alternatives will not be compared with the baseline reference with respect to comfort, health, and mobility, which are independent of benefit from the mutualisation of the aquifer energy source. The real-estate value should also not be impacted. Most of the co-benefits discussed here therefore are focused on the impacts of the mutualised aquifer energy/cooling source. These are treated in Section 4.4.

4.4 Estimating the market and non-market values

4.4.1 Cost elements (tradeable goods and services)

The following table shows the cost elements related to the tradeable goods and services as compared with the reference solution.

Table 3: Financial results of the three concepts in relation to the reference (costs and market benefits

	Extra investment	Impact on the yearly energy	Impact on annual	Electricity sales from solar

	costs	bill	maintenance costs	panels
Concept 1	+58€/m²	-0.8€/m²	+0.8€/m²	-1.1€/m²
Concept 2	+69€/m²	-0.9€/m²	+0.95€/m²	-1.1€/m²
Concept 3	+72€/m²	-0.9€/m²	+0.95€/m²	-1.1€/m²

4.4.2 Monetising non-market benefits

The previous financial balance must be completed with the assessment of monetized non-market benefits.

4.4.2.1 Fighting climate change

The following table shows the cost elements related to market goods and services, always by difference with the reference solution.

Table 3: Financial results of three concepts in relation to the reference (costs and market benefits)

	Gas Consumption (final energy)	Electricity consumption. (final energy)	Primary energy consumption	CO_2 Emissions
Concept 1	-18.8 kWh/m²	+4.6 kWh/m²	-6.9 kWh/m²	-3.7 kg/m²
Concept 2	-22.7 kWh/m²	+6.7 kWh/m²	-5.4 kWh/m²	-4.3 kg/m²
Concept 3	-22.7 kWh/m²	+6.7 kWh/m²	-5.4 kWh/m²	-4.3 kg/m²

The three concepts outperform the reference in terms of GHG balance. This difference is greater for the concepts 2 and 3, with the reliance on the thermorefrigerationpump with a coefficient of performance (COP) greater than 3. We used the shadow price of carbon used in public investment evaluations (Quinet, 2013). This value is 52 € / t in 2015 with an escalation rate of 4.5%, equivalent to the discount rate used in public investments under the law of Hotelling (Quinet, op.cit.).

4.4.2.2 Environment, biodiversity and semiotics

While the project global warming attenuation capacity is indisputable, there may be an impact on biodiversity and the natural environment from the warming of the aquifer. Without corrective action, because of Darcy's velocity (flow rate) of the aquifer and hardness of the water, we could expect this warming over 15 years to result in two consequences:

- The development of algae and amoebae,
- Blockage and instability of the release well from the thermorefrigeratingpump at the university building (already installed). The use of cooling towers in the university building slows the phenomenon but does not suppress it.

Preventing the warming up of the aquifer improves the overall robustness of the system (at a 15 year horizon). The alternatives (concepts 2 and 3) for mutualising and compensating the heating and cooling needs reduce the warming of the aquifer. Furthermore, each alternative would give the territory a "showcase" of an innovative university campus, and fulfil the ambition of international renown mentioned above given the university’s focus on energy transition and sustainable development. However, this effect is much more significant in the case which includes the water leisure park (concept 3).

The monetization of impacts related to the aquifer was carried out by the method of costs of damage (Pearce et al., 2006). The main physical consequence is the impossibility of using a geothermal heat pump for the university building at a 15-year horizon. The assessment of that damage may be based on the discounted residual value of the equipment, valued at € 24 / m² (relative to the surface area of the planned building block) prior to discounting. The discounted value will be chosen to monetize the efforts for preventing the warming of the aquifer in the case of concepts 2 and 3.

In addition, EPA announced it would cover 50% of the investment cost associated with these three concepts in recognition of its innovative nature and international renown.

4.4.2.3 Operating savings of the university building

The expected synergies between the building block and the university building should reduce the release of cold effluent into the aquifer, enabling both improved energy efficiency of the cooling towers of the Bienvenüe building and decrease the use intensity. Thus, it is predicted that the overall operation of these towers is expected to fall between 20-60%!

This is accompanied by reduced maintenance and operating costs and longer service life of the equipment, a notable reduction of the operating costs. This represents an externality to the extent that it constitutes a cost or a benefit to either party, without it being valued economically. This externality is positive as the action of agent A (the use of the aquifer by the building block) results in improved well-being of another, agent B (a decrease in operating costs of the university building) without the latter having had to pay the price (Efficacity 2015).

In the absence of a partnership linking the two parties, the university building is outside the economic reasoning of the actors of the building block.

Based on the information provided, the operational savings from the cooling towers permitted by mutualisation between the university building and the building block (concepts 2 and 3) were estimated at € 0.1 / m² (based on the surface area of the planned building block).

4.4.2.4 Solar panel investment savings for the nautical centre

By broadening the mutualisation to include the nautical centre the synergies allow a reduction in the surface area of the solar thermal panels (see above) of approximately 10%.

As above, this benefit may be associated with an externality. Based on the information provided, 10% investment savings in solar panels represents € 180,000, or 10.3 € / m² (based on the surface of the building block).

4.5 Step 6: Arbitration of the strategies for optimising the allocation of resources

The table below shows the results of the evaluation in overall cost and extensive global cost (ISO 15686-5) of the different variants relative to the reference solution, performed over a period of 20 years with a discount rate of 3% (as per the EN 16627 standard). A negative value indicates a gain relative to the reference solution.

Table 4: Calculation of total cost (simple and extended) of the different concepts (€ / m²)

	Additional investment costs	Impact on annual energy costs	Impact on annual maintenance costs
Initial investment	58.0	69.0	72.0
Operating costs for energy and water	-10.9	-12.4	-12.4
Maintenance costs	11.5	13.1	13.5
Residual value for subtraction	-1.7	-2.0	-2.1
Social costs CO2/ period	-4.2	-4.9	-4.9

Production PV	-15.7	-15.7	-15.7
Benefits related to the operating savings for Bienvenüe building	0.0	-1.5	-1.5
Investment savings for the nautical centre	0.0	0.0	-8,7
Environment and semiotic benefits	-28.2	-42.7	-44.7
Extended evaluation	8.9	2.9	-4.5

It appears that the energy savings will not even cover the additional maintenance costs and the competitiveness of all three concepts depends on the value of the external effects. However, at a 20-year horizon, only e Concept 3 is economically competitive with respect to the reference solution. Choosing this path requires to engage in negotiations involving numerous partnerships.

4.5.1 Step 7 and 8: Designing of an appropriate economic model and Evaluation of the deployment of the selected strategies

Up to Step 6, we were in a cost/benefit logic proceeding by an itemised accounting (costs / market and non-market benefits). It must be formalised by the development of relevant partnerships following a logic of contributing actors and economic flows from one actor to another.

Partnerships can be bi-lateral or multilateral (for instance in the case of a "mutual fund" drawing contributions for different benefits or to supervise the bilateral exchanges). There's an apparent need for "systems of rules that bind the actors together, and are developed and adopted during the project" (Pasquelin, 2015). Beyond this governance, the success of such an economic model hinges on genuine cooperation between actors, who share an interest in each other's activities and how they interaction towards achieving a common goal (du Tertre, 2013). This instance illustrates, within acceptable technical and economic conditions, the possibility for an assembly comprising the three parties (the university building, the building block and the nautical centre) in the context of a shared willingness to showcase the exemplarity of the project.

5. THE METHOD IN THE CASE OF A DISTRICT HEATING NETWORK

The second application of this methodology was carried out on a district heating project (steam provided by an incineration plant). The sensitivity analysis of the sector-specific economic models (taking into account identified externalities) has been carried out for each actor's decisions. The two scenarios under study are the retrofitting of building to make them energy efficient, and the application of household waste minimisation policies. The externalities associated with these policies leads us to imagine new configurations of player games that redistribute earnings (profits) and losses for the most beneficial outcome. This constitutes a new way to build an all-encompassing cost approach by establishing new contract arrangement.

5.1 Scenarios and simulations

We are interested in all the actors' up- and down-stream of the two scenarios:

- Users of the heating network (households) recipients of the final energy bill and its share of domestic income;
- The incineration plant as heat supplier, and the contribution of heat sales to its operating margin (net of investments);
- The operator of the district heating system, who adapts the billing of its domestic customers according to the energy source and thus maintains its operating margin.

Three parameters are modified independently and simultaneously to develop various scenarios and assess the economic effects associated with the choice of its actors. These three parameters are:

- The percentage of waste incineration: today several local policies target waste minimisation preferring to maximize recycling to the detriment of incineration.
- The percentage of the renovated buildings on the district heating network: building standards improve efficiency and reduce energy consumption. The renovation policy targets a blanket application of new building standards.
- The percentage of residential housing connected to the district heating network. Recent policy orientations, national and local, have made heating network a key policy tool for attaining energy transition objectives.

5.2 Results

The fall in volumes of waste incinerated expected from waste minimisation policies may impact significantly the earning of partner stakeholders in a district heating network. The first concerned is the operator of the incineration plant, who sells less heat and therefore reduces its earnings. The plant operator must compensate by increasing prices to be able to purchase an alternative source of energy (gas) and fulfil its contractual obligations with downstream users of the district heating network. Beyond a certain threshold of waste reduction the operator of the heating network must install a booster station, increasing its operating costs. Its margin is decreased but is not erased, since it passes most of the additional cost to its users.

5.3 Arrangement of players games

The resilience of the heating network needs rethinking, without compromising either the environmental or economic objectives pursued in the two policies.

In the case of a fall in the volume of waste incinerated, it seems more difficult to remove the losses for all players, but still we can try to maintain the profitability of the system. In such a case, and to maintain a satisfactory level of renewable energy in the energy mix of the network, the thermal renovation of buildings should be encouraged (assuming it will reduce use and cost of fossil fuels to users). However, such action does not compensate the losses for the heating network and incineration plants. We can, in this case imagine a mutually beneficial compromise to encourage thermal renovation for users and to compensate the district heating operator and incinerator for the loss of business (including downsizing the furnaces to reduce operating costs).

The reduction in waste is not necessarily negative for the system; it is possible to "downsize", through public financing, all elements of the chain. The decrease in the production of household waste results in lower operating costs for the community. These savings could be redirected to finance this upgrade, and then proceed with a gradual decrease in user-fees for managing household waste.

The scenarios with variations of multiple parameters showed that:

- It is possible to compensate for the effects of one of the parameters by those of the other.

- We need to rethink about how to define the energy strategy of the urban area in an integrated way: you have to consider actions on consumption, production and distribution simultaneously. A player should have the supervisory role in planning and upholding the general interest.

6. CONCLUSION

The application of this methodology turns out to be effective for identifying and valuing externalities. A key point is the building of new economic models able to convert the identified economic value into financial flows (or equivalent) between stakeholders. These models will rely on a formal basis (innovative partnership, contracting) but especially on informal ties (trust between actors, organizational relevance…). The development of relevant formal and informal resources can be delegated to a trusted third-party. To help the latter achieve this complex work, operational tools still need to be developed. These may include:

- a comprehensive reference document covering externalities (literature-based review) to assist in the complex dialogue between stakeholders on the value of externalities;
- a global life-cycle costing calculation tool including externalities valuation;
- interviews, support guides for the negotiation between stakeholders (benefiting from positive externalities) and who have the willingness to contribute to the project in order to ensure that it become viable;
- specific contracting and partnership supporting tools in the areas of building renovation and district heating.

The development of such tools is the main objective being pursued by Efficacity in the framework of this project.

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Effects of rescue activities by local residents considering property damage and wide-area evacuation immediately after an earthquake

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Key words: Rescue activity, Local resident, Property damage, Wide-area evacuation, Casualty, Densely-built wooden residential area

Abstract: In order to reduce human casualties, rescue activities by local residents play an important role in the chaotic time immediately after an earthquake occurs. In this paper, we incorporated the following aspects into the wide-area evacuation simulation model which we had previously developed: (1) people trapped in a building and on a street; (2) rescue activities by local residents; (3) behaviour of people who get over rubbles of collapsed buildings; (4) the difference of evacuees' attribute. Using this simulation model, first, we demonstrated the effectiveness of rescue activities by local residents in densely-built wooden residential areas in the aftermath of a large earthquake. Next, we attempted to describe the relationships among elapsed time from an earthquake occurrence, property damages, human casualties and people engaged in rescue activities.

1. INTRODUCTION

The survival rate of people trapped inside buildings after a large earthquake is higher if they are rescued and transported immediately. However, in the chaotic time immediately after an earthquake occurs, fire-fighters and members of local fire brigades must first deal with the multiple fires that break out at the same time in different places, while police officers must deal with traffic control and other duties. Nor can one rely on the Self-Defence Forces or support workers from undamaged areas immediately after the earthquake. Therefore, rescue activities by family members or neighbouring residents are extremely important.

Table 1 presents a summary of the outlines in previous studies of rescue activities after a large earthquake. Many such studies to date were based on the investigative reports (Kuwata and Takada, 2000; Murakami, Takemoto, et al., 2000; Iwasaki, 2000; Tadokoro, Takamori, et al., 2000) of the 1995 Great Hanshin Awaji Earthquake (Hyogo-ken Nambu Earthquake). According to the report (Murakami, Takemoto, et al., 2000), most people were relieved from collapsed buildings not by public services (fire service, police, Self-Defence Forces, etc.) but by family members or neighbouring residents after an earthquake occurred. However, most of the studies targeted the rescue activities of public services, and very few dealt with rescue activities by local residents. Also, although these were valuable surveys for knowing the actual status of rescue activities at a large earthquake, issues were mainly qualitative.

A key issue for future disaster policies and measures is to make use of these valuable results to model the process of rescue activities by local residents, and to carry out simulations to obtain useful knowledge. Among previous rescue operation simulations, the RoboCup-Rescue Project (Tadokoro, Kitano, et al., 2000; Takahashi, 2007; Arai, Sang, et al., 2012; López, Suárez, et al., 2003), which employs a virtual city, is particularly well known. It allows interdisciplinary and international undertaking by replacing rescue operations immediately after large earthquakes with standardized problems. However, it is impossible to directly verify effects of rescue operations in actual cities. There are also studies based on actual urban-area GIS data that contribute to the estimation of human damage or drawing up local disaster prevention plans (Furuya and Sadohara, 2004; Tani, Yamamura, et al., 2004; Ueda, Seo, et al., 2007). However, there are not quantitatively enough discussions on the effects and risk of rescue activities by local residents based on the numerical analyses. More specifically, it is necessary to consider the influence by property damages that can cause danger to the rescue participants themselves and by wide-area evacuation behaviour to keep their safety as well as rescue activities.

In this paper, we incorporate the following aspects into the wide-area evacuation simulation model which we have previously developed (Osaragi and Oki, 2012; Oki and Osaragi, 2014; Oki and Osaragi, 2016): (1) people trapped in a building and on a street; (2) rescue activities by local residents; (3) the behaviour of people who get over the rubble of collapsed buildings; (4) the difference of evacuees' attribute (*Figure 1*).

Using this simulation model, first, we demonstrate the effectiveness and risk of rescue activities by local residents in densely-built wooden residential

Table 1. Previous studies of rescue activities by local residents following large earthquakes

Authors	Outline
Surveys and reports on Great Hanshin-Awaji Earthquake	
Kuwata and Takada (2000)	1) Conceptual model proposed to compute final number of rescued people from number of those who must be rescued after a large earthquake, rescue capacity of rescue workers, and survival rate for each day following disaster occurrence. 2) Suggests that rescue capacity is important factor to increase the number of rescued people.
Murakami, Takemoto, et al. (2000)	1) Rescue of survivors was mainly by family members or local residents. 2) Total time for rescue depends on structure of building trapping people needing rescue, the number of people who need to be rescued, the number of rescue workers, and the number of days since earthquake occurrence.
Iwasaki (2000)	Assertion that communities such as residents in the neighbourhood, town associations, and towns play important roles/functions in each of the stages of rescue activities, operation of evacuation centres, and reconstruction following earthquakes.
Tadokoro, Takamori, et al. (2000)	1) Presents a summary of rescue process, search for trapped people, uncovering process, treatment of uncovered trapped people, and the views of fire department personnel who partook in the rescue operations. 2) Assertion that the initial several hours after disaster occurrence are important, and that the efficiency of the search for trapped people greatly affects the efficiency of the entire rescue operation.
RoboCup-Rescue Project (RCRP)	
Tadokoro, Kitano, et al. (2000)	Introduction of RCRP
Takahashi (2007)	Introduction of RCRP and verification of the effect of rescue operations.
Arai, Sang, et al. (2012), López, Suárez, et al. (2003)	Example of the use of a Task Allocation Model based on Combinatorial Auction Mechanism to minimize human damage (number of victims)
Simulations of rescue activities by family members or local residents in actual urban areas	
Furuya and Sadohara (2004)	1) Construction of models of people trapped inside building, evacuation, moving to entrapment site, rescue operations, and request for support. 2) Assertion that it is important to increase the local community awareness through case studies of increased probability of participation in rescue activity, or when the search range for trapped people in the neighbourhood is expanded.
Tani, Yamamura, et al. (2004)	1) Modelling activities to rescue trapped people by family members and by professional rescue teams 2) Although the parties are attributed different abilities of rubble removal, suggestion made that family members may play a large role overall. 3) Analysis and discussion of cases when the number of fire department personnel or rescue teams changes, or the effects when rubble removal speed is increased by training.
Ueda, Seo, et al. (2007)	One of the few examples in which simulation of rescue operation is carried out by taking into account the property damage after large earthquakes in actual urban areas.

areas in the aftermath of a large earthquake. Additionally, we attempt to describe the relationships among elapsed time from an earthquake occurrence, property damages, human casualties and people engaged in rescue activities.

The originality of our study can be summarized as follows. Firstly, our simulation model takes property damages (such as building-collapse, fire-spread and street-blockage) and interactions among local residents into account. Secondly, the simulation which incorporates rescue activities with wide-area evacuation behaviour is executed for large real cities.

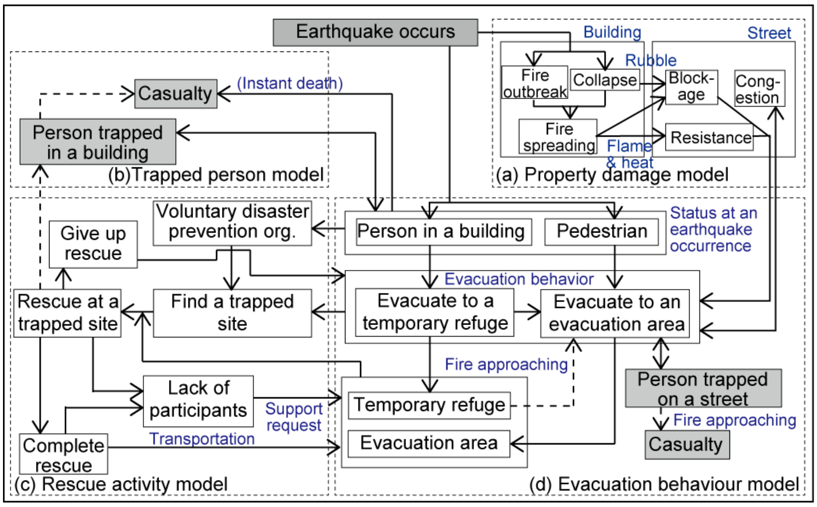


Figure 1. Overview of our simulation model

2. WIDE-AREA EVACUATION SIMULATION MODEL

2.1 Property damage model

The property damage model consists of building-collapse, fire-breakout, fire-spread, rubbles of collapsed buildings, flame during fire-spread, street-blockage by heat from fires, etc. The models of building-collapse, fire-breakout, fire-spread and street-blockage by rubbles was explained in the previous paper (Oki and Osaragi, 2016). Also, for the purpose of describing street-blockage by fires in detail, we set the timing when a street faced to a fire-catching building is blocked and becomes passable again (*Table 2*). In this paper, we refer to the model for available time of a street by type of buildings along the street and street-width, on the basis of radiation heat that evacuees are received (Iwami, Hagiwara, et al., 2006). Herein, the buildings where a fire breaks out are determined randomly based on the probability of fire-breakout, and are assumed to start burning according to the timing shown in *Figure 2* (Fire Prevention Committee of Tokyo Fire Department, 2015).

Table 2. How to describe street-blockage by fires

Construction type	Fire-resistant	Semi-fire-resistant	Fire-proof	Naked wooden
Time from catching-fire to street-blockage [minute]	30 (for $W \geq 4$) $10+5W$ (for $W<4$)		8	5
Time from when a building is burnt down to when a street gets available again (= ‘cancelled blockage’ in *Figure 10*) [minute]	60	110	70	

* *W* is the width of a street in front of a burning building.

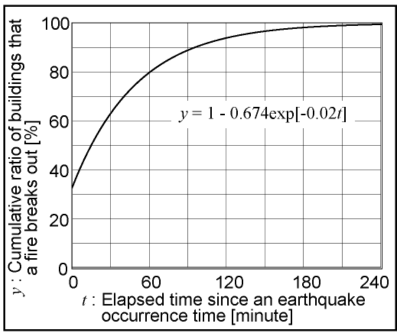
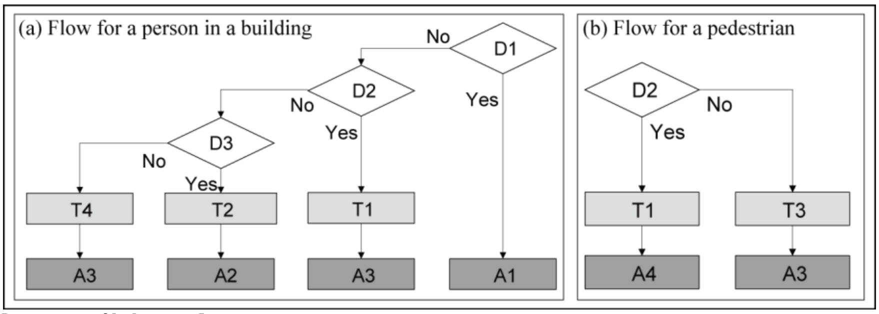


Figure 2. Timing of fire-breakout

2.2 Decision of starting action for people inside a building and pedestrians

The spatial distribution of people in cities immediately after a large earthquake occurs is estimated based on the Person-Trip (PT) survey data for Tokyo Metropolitan Area conducted in 2008. Using the PT data, we can estimate the location of each person with the detailed attribute (such as gender, age, etc.) and the staying/moving purpose by each building/street for anytime (Osaragi, 2009; Osaragi and Hoshino, 2012; Osaragi, 2015). In this paper, people in a building and pedestrians inside the analytical area are considered because we focus on wide-area evacuation behaviour and rescue activities by local residents in the small area surrounded by wide streets. Therefore, people moving by train or by car, returning home on foot, and coming into the analytical area from outside are excluded.

Figure 3 shows the decision flow of the timing (T1 – T4) of starting action and the type (A1 – A4) of behaviour for people in a building and pedestrians. Basically, people in a building are assumed to follow the Poisson distribution (λ=3.35) and pedestrians are assumed to start evacuation just after an earthquake occurs. In case that a fire approaches to a building within 150 m, people in the building are assumed to start evacuation in five minutes. Moreover, 1.7% of people out of the whole local residents are randomly extracted as the members of voluntary disaster prevention organization.



[Decision of behaviour]
D1: Trapped in a building or not D2: A fire approaches within a radius of 150 m or not
D3: A member of voluntary disaster prevention organization or not
[Timing that a person starts the action]
T1: In five minutes T2: In 15 minutes
T3: Immediately T4: Follow the Poisson distribution (λ=3.35)
[Action type]
A1: Not started any actions yet A2: Rescue activity (Find a trapped site)
A3: Evacuate to a temporary refuge A4: Evacuate to an evacuation area
* Even if a person decides the timing of starting action following the Poisson distribution, he/she starts any action in five minutes in case that a fire approaches before the timing.
* The parameter of the Poisson distribution refers to the previous study (Osaragi and Oki, 2012).

Figure 3. Timing that a person starts the action and decision of behaviour

2.3 Modelling a person trapped in a building

On the basis of the results of building-collapse simulation using the property damage model, a part of people in a building at an earthquake occurrence time is considered as “person trapped in a building” (*Figure 4*). Excluding people who die immediately in a building, the timing of escaping from a collapsed building is stochastically set to each person based on the survey (Takeda, Murakami, et al., 2001) (*Figure 5(a)*). Also, the level of injury and the timing of death are stochastically set to each person based on another survey (Ohta, Koyama, et al., 2001) (*Figure 5(b)* and *Table 3*). More specifically, people trapped in a building are assumed to be relieved when the total activity time by rescue participants (five people per a building in maximum) reaches 222 minutes (Takeda, Murakami, et al., 2001), or to become victims before escaping by himself/herself. The timing of death follows the earlier one of “remaining life span” based on the life-span-characteristics-function by the level of injury (Ohta, Koyama, et al., 2001) and the time required for the building catches a fire.

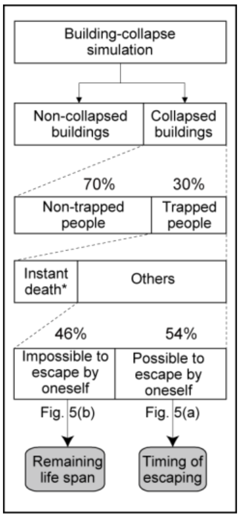


Figure 4. How to determine people trapped in a building

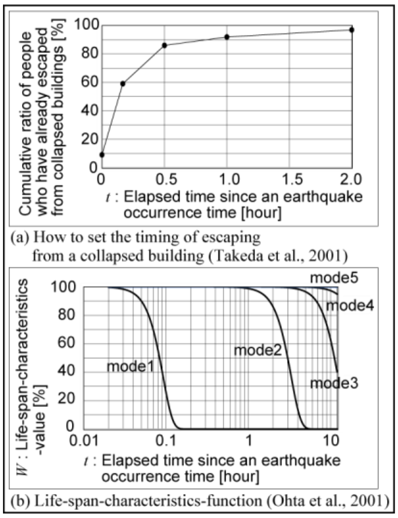


Figure 5. How to set the timing of escaping from a collapsed building and "remaining life span"

Table 3. Parameter and composition ratio by level of injury in the life-span-characteristics-function (Ohta, Koyama, et al., 2001)

Mode			Level of injury	Parameter *a*	Composition ratio in Kobe city in the Great Hanshin-Awaji Earthquake
1	Choke	Choke	Death / Dying	0.092	2%
2	External	Head / Breast	Serious injury	3.324	11%
3	wound	Abdomen	Medium injury	12.3	23%
4		Arms / Legs	Slight injury	26.59	30%
5		Uninjured	Uninjured	66.48	34%

* Life-span-characteristics-function: $W = \exp[-(t / a) \wedge m]$, $m = 3.71$ (const.)

* (Number of people who die instantly) = (Number of collapsed buildings) x 0.045 (Furuya and Sadohara, 2004)

2.4 Rescue activity model

We consider that rescue activities consist of the five phases as follows: (1) movement to a trapped site; (2) rescue at a trapped site; (3) support request; (4) transport of a relieved person to a temporary refuge; (5) patrol by the members of voluntary disaster prevention organization to find a trapped site. Hereinafter, People in the above phases are defined as "rescue participants".

Excluding the case that a person finds a trapped site within a radius of 20 m during evacuation, people besides the members of voluntary disaster prevention organization are assumed to determine whether he/she accepts the support request from another rescue participants or not, on the basis of participation rate in rescue activities (*Figure 6*). Herein, some elderly people cannot participate in rescue activities in a trapped site referring to "The physical fitness and athletic performance tests" (MEXT, 2013) (*Table 4*). The maximum time assigned for rescue activities is assumed not to be limited, and rescue participants are assumed to finish the activities in case that: (1) a fire approaches to a trapped site within a radius of 10 m; or (2) there are no other people trapped in the previous site after transporting the relieved person to a temporary refuge. However, in case that a person finds another trapped site on the evacuation route after finishing the activity, he/she joins the rescue activity again.

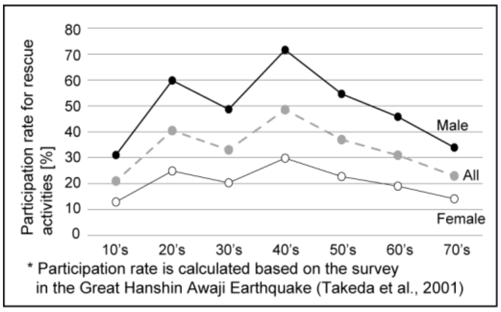


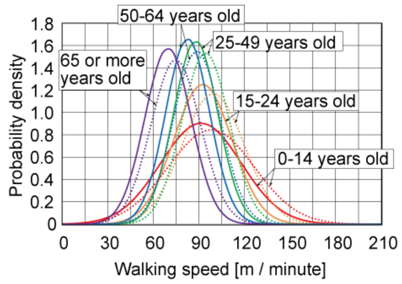
Figure 6. Participation rate for rescue activities by gender and age

Table 4. Modelling the handicap of elderly people

Gender	Age	Maximum height of rubbles that a person gets over 0.5m	1.0m	Ratio of people that cannot engage in rescue activities at a trapped site
	65 – 69	1.4%	29.7%	14.0%
Male	70 – 74	2.9%	35.6%	16.2%
	75 – 79	7.6%	44.3%	21.2%
	65 – 69	5.0%	35.1%	43.7%
Female	70 – 74	4.8%	41.0%	49.0%
	75 – 79	10.1%	53.9%	61.1%

2.5 Evacuation behaviour model

We consider the following aspects related to people's wide-area evacuation behaviour: (1) place where he/she is at an earthquake occurrence time (home / building besides home / outside the building); (2) person's attribute (gender / age); (3) timing when a person starts evacuating (follows the Poisson distribution / when a fire approaches); (4) evacuation route (depends on fire-spread and street-blockage); (5) walking speed (depends on the density of evacuees and rubbles); (6) two-stage evacuation[1)]. The probability distribution for walking speed is considered to be different according to gender and age (Willis, Gjersoe, et al., 2004) (*Figure 7* and *Table 5*).



(1) The standard walking speed s_0 for each person, which is the speed without the influence of density and rubbles, is determined by using a random number and the probability density function.
(2) The coefficient c according to the density d [person / m^2] of a street is determined based on *Table 5*.
(3) The walking speed s considering the density is calculated as follows: $s = s_0 \times c$
(4) The walking speed s' during getting over rubbles is assumed to be 10 [m / minute] uniformly.
(5) The speed s or s', whichever is slower, is used.

* Solid line = Female, Dotted line = Male

Figure 7. Walking speed considering person's attribute, density of people on a street and rubbles

Table 5. Density *d* and Coefficient *c* in *Figure 7*

Density d [person / m^2]	Coefficient c
$d < 1.5$	$c = 1.0$
$1.5 \leq d < 6.0$	$c = (-800 \times d + 5200) / (4000 / 60)$
$6.0 \leq d$	$c = (400 \times 6 / d) / (4000 / 60)$

2.6 Model for person getting over rubbles of collapsed buildings and trapped on a street

There are few studies on the estimation of the height of rubbles on streets, the possibility of getting over rubbles, and the time and number of people required for removing rubbles. Therefore, in this paper, we attempt to model people getting over rubbles of collapsed buildings and trapped on a street as follows:

(a) As well as the previous study (Oki and Osaragi, 2016), we assume that rubbles with the width equal to the height of a collapsed building spread around the building.
(b) Referring to the previous study (Mabuchi, Kaneko, et al., 2012), a person is assumed to get over rubbles whose height on the opposite borderline of the street facing the collapsed building is lower than two meters. The height is estimated on the basis of the width of the collapsed building (*Figure 8*).
(c) To be on the safer side, it is assumed not to be able to remove rubbles.
(d) The walking speed while a person is getting over the rubbles is uniformly set to 10 m per minute.
(e) Referring to the results of "The physical fitness and athletic performance tests (MEXT, 2013)", the maximum height of rubbles that some elderly people can get over is considered to be lower comparing with other people (such as 0.5 m / 1.0 m) (*Table 4*).
(f) People trapped on a street are assumed to continue evacuation behaviour (moving around) as much as possible. However, when a person notices that he/she has nowhere to go, he/she stops moving. Furthermore, when he/she is involved in fire-spread, we treat him/her as "casualty".

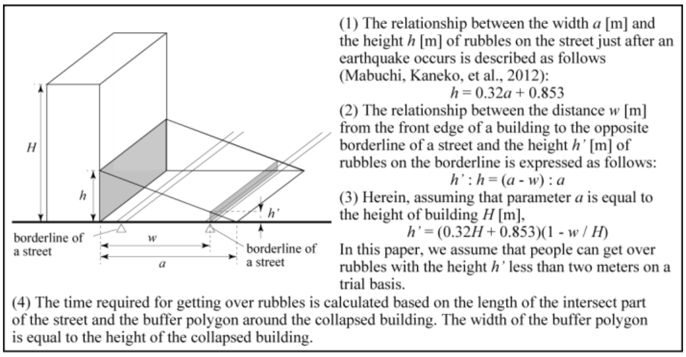


Figure 8. Model of getting over rubbles of a collapsed building

3. EFFECTS OF RESCUE ACTIVITIES BY LOCAL RESIDENTS

3.1 Analytical area and simulation method

We extract the analytical area surrounded by wide streets in Kita-Senju, Adachi Ward, Tokyo, where there is the high risk of building-collapse and city-fire in case of a large earthquake (*Figure 9*). The simulation is executed for 500 patterns of property damages, and rescue activities by local residents is supposed to be performed or not to be performed (totally 1000 times). Each trial is carried out just after an earthquake occurs till 12 hours passed. An earthquake is supposed to occur at 1:00 AM, when the largest number of people inside the analytical area during the day (*Table 6*).

3.2 Number of casualties whether to perform rescue activities or not

Comparing the frequency distribution of the number of casualties whether to perform rescue activities or not (*Table 7*), the difference between two cases is approximately 40 people (13.7% out of the all). It suggests that rescue activities might result in reducing the number of casualties in the whole analytical area.

From the viewpoint of the cause of death (*Table 8*), it might be possible to greatly reduce the number of casualties inside buildings from fires and injury (cause 1 and 3). The number of casualties on a street from fires (cause 4) is less in the case that rescue activities are performed than not performed. However, there are rarely the casualties from fires after arriving at a temporary refuge (cause 5). Cause 6 consists of the following two cases: (1) the case that a person is performing a rescue activity without noticing that

Table 6. Assumptions of simulation

Seismic intensity	Stronger 6 (6.0 – 6.5)
Seismic acceleration	739 – 1,354 cm/sec^2
Earthquake occurrence time	1:00 AM on a weekday in winter
Number of fire-outbreak buildings	Based on the damage estimation published by Tokyo Metropolitan Government (2012)
Weather condition	Sunny with 8 m/s north wind
Comparison scenario	Rescue activities by local residents are performed / not performed
GIS data	Data from surveys of the present situation of land use and buildings in 2011 (TMG)

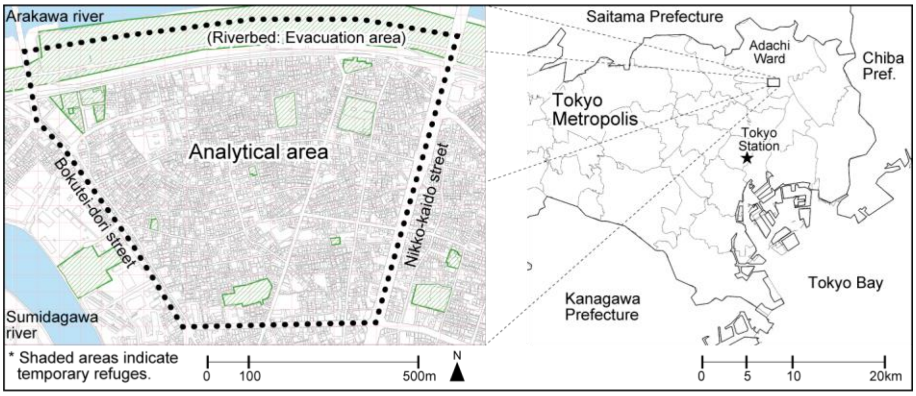
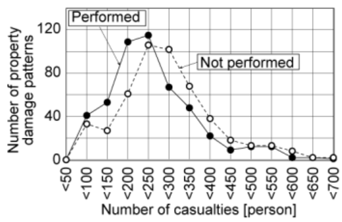


Figure 9. Analytical area (surrounded by the dotted line)

Table 7. Frequency distribution of the number of property damage patterns (by the number of casualties)



Unit: Person	Performed	Not performed
Average	243.6	282.4
Standard deviation	134.5	140.9
Maximum	1,204	1,283
Minimum	60	74

he/she is trapped on a street; (2) the case that a person is involved by fires at a temporary refuge after finishing rescue activities. Looking into the result in more detailed, the latter tends to cause more diverse severe damages.

3.3 Temporal transition

In this section, aiming at acquiring knowledge on the important timing for wide-area evacuation and rescue activities, we focus on the temporal transition of property damage (collapsed buildings, fire-catching buildings,

Table 8. Number of people by the causes of death (1 – 6)

Unit: Person	1. Person trapped in a building (Death by fire)		2. Person who cannot pass through a front street (Death by fire)		3. Person trapped in a building (Death by injury)	
	Performed	Not Performed	Performed	Not Performed	Performed	Not Performed
Average	28.8	51.8	21.6	21.6	64.1	89.3
St. dev.	4.7	15.7	16.5	16.5	20.7	21.1
Minimum	16	15	0	0	31	48
1st quartile	26	42	11	11	50	75
Median	29	53	18	18	61	86
3rd quartile	32	63	28	28	72.3	99
Maximum	47	95	99	99	171	199
Unit: Person	4. Person trapped on a street (Death by fire)		5. Person at a temporary refuge (Death by fire)		6. Person after engaging in rescue activities (Death by fire)	
	Performed	Not Performed	Performed	Not Performed	Performed	Not Performed
Average	93.4	101.3	15.1	18.3	20.2	0
St. dev.	62.7	75.2	62.0	75.9	32.5	0
Minimum	0	0	0	0	0	0
1st quartile	56.8	58	0	0	5	0
Median	84.5	87	0	0	11	0
3rd quartile	119	127	0	0	22	0
Maximum	560	615	716	907	486	0

* Shaded colour indicates the superior one of ‘Performed’ and ‘Not Performed’.

burnt-down buildings and blocked streets) and the number of evacuees, people engaging in rescue activities, casualties and people trapped in a building. The transition is based on the average number obtained by the simulation under the assumption in *Table 6*.

3.3.1 Temporal transition of property damage

Figure 10 shows the temporal transition of property damages. After several hours pass since an earthquake occurred, the number of buildings that newly catch a fire gets nearly equal to the number of buildings that are newly burnt down. Also, the number of blocked streets almost becomes constant.

3.3.2 Temporal transition of people engaging in rescue activities

The temporal transition of the number of people engaging in rescue activities is shown in *Figure 11*. Many people who have started the actions immediately after an earthquake occurred participate in rescue activities. About 400 people in average and more than 1,000 people in maximum engage in rescue activities at a trapped site. When about an hour elapses since an earthquake

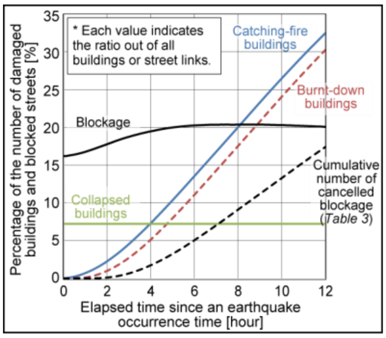


Figure 10. Temporal transition of property damages

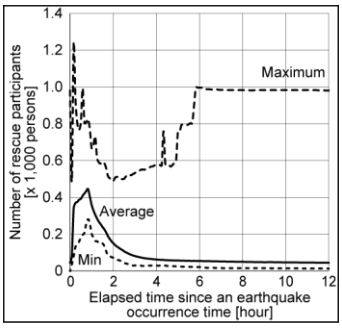


Figure 11. Temporal transition of rescue participants

occurred, people who finish a rescue activity at a trapped site move to a temporary refuge or an evacuation area accompanying a saved person. The number of people engaging in rescue activities gradually decreases because many people remain at a temporary refuge or an evacuation area after arriving there. Finally, only the members of voluntary disaster prevention organization continue to move around, looking for people trapped in a building.

3.3.3 Temporal transition of casualties and people trapped in a building

Looking at the temporal transition of the number of people trapped in a building (*Figure 12*), the number rapidly decreases because there are many people who escape from a building by himself / herself in 30 minutes since an earthquake occurred. In case that rescue activities are not performed, the number of people trapped in a building varies little after 2.5 hours later since an earthquake occurred. Meanwhile, the increase speed of the number of casualties becomes about twice as fast as the one in 2.5 hours after an earthquake occurred (*Figure 13*). On the other hand, in case that rescue activities are performed, the relief and transport of people from a collapsed building to a temporary refuge gradually start after about an hour later since an earthquake occurred till five hours later. However, the number of people who are newly saved gets lower and becomes nearly zero when six hours elapse since an earthquake occurrence time. In average, 11.7 people are still trapped in a building after 12 hours pass since an earthquake occurred, which is equivalent to about one twelfth of the number in case that rescue activities are not performed (140.6 people in average). Furthermore, the increase speed of the number of casualties is comparatively slower. As a result, even though there are some people who are relieved after their death or die after being rescued from a collapsed building, the average number of casualties after 12 hours elapse since an earthquake occurred can be reduced by 40 people (*Figure 13*).

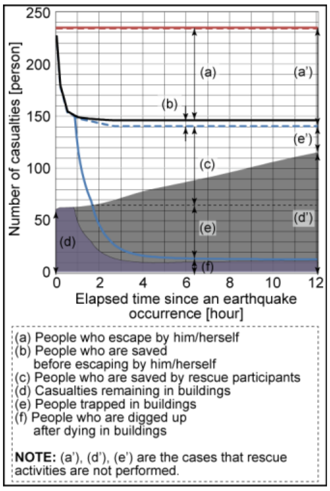


Figure 12. Number of people trapped in buildings

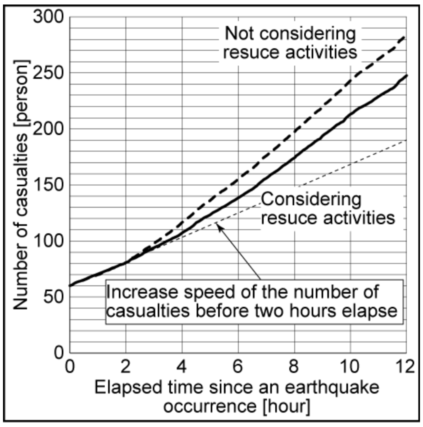


Figure 13. Increase of casualties

4. CONCLUSIONS

People trapped in a building and on a street, rescue activities by local residents, the action that people get over rubbles by collapsed buildings, and evacuees' attribute were newly incorporated into the wide-area evacuation simulation model that we had developed in the previous research. Using this model, the effects of rescue activities by local residents were demonstrated based on the simulation in densely-built wooden residential areas in case that rescue and fire-fighting activities by public organizations could not be expected because of property damages after an earthquake occurrence. Furthermore, we analysed the relationships of elapsed time since an earthquake occurrence with the number of property damages, rescue participants, people relieved from collapsed buildings, and casualties.

The longer elapsed time from an earthquake occurrence time, the higher possibility that people engaging in rescue activities themselves are involved in fire-spread and become victims. Also, the effects of rescue activities are gradually reduced. People who are not relieved from a collapsed building in 12 hours might be trapped where few others pass around because of the building location and rubbles of collapsed buildings. Therefore, there might be low possibilities that such people are relieved while they are still alive even if local residents continue rescue activities.

For future works, we are planning to discuss when rescue activities by local residents should be finished according to the difference of an earthquake occurrence time, damage situation of each building, activity ability of rescue participants, spatial characteristics, etc. Also, fire-fighting activities by local residents performed immediately after a fire breaks out will be incorporated into the simulation model developed in this paper.

5. NOTE

1) Two-stage evacuation is an evacuation method, which people firstly evacuate to the closest temporary refuge (small park, school, temple/shrine, etc.) for each person, and after that escape to an evacuation area (university campus, riverbed, etc.) in a group when a fire approaches to temporary refuges. It is recommended by Tokyo Metropolitan Government for preventing the congestion caused by evacuees on streets.

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Modeling Bounded Rationality in Choice Behavior

Relative Utility vs. Random Regret Models

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Key words: Bounded Rationality, Context Dependency, Relative Utility, Random Regret

Abstract: To better understand individuals' decision behavior, bounded rational decision models are getting increasingly more attention. This paper reviews relative utility and random regret models, which both assert that the performance of the considered alternative is dependent on the attributes of one or more foregone alternatives in the choice set. This property of the models is called context dependency. Differences and similarities between the models are outlined, new developments and applications are presented and finally future improvements are discussed.

1. INTRODUCTION

Last decades have witnessed a vast growth in applications of discrete choice models (DCMs) across different domains, including urban planning and transportation planning (e.g., McFadden, 1978; Ben-Akiva and Lerman, 1985; McFadden, 2000; Train, 2009). Traditionally, DCMs have been developed based on the principle of random utility maximization (RUM), which can be seen as an example of a theory of rational decision-making. In that sense, RUM models usually assume that individuals have specific goals, infinite knowledge and consistent preferences all the time (Simon, 1955). However, an increased number of studies pointed out the existence of bounded rationality and proposed alternative theories and models (e.g., Kahnmena and Tversky, 1979; Tversky and Kahneman, 1992; Loomes and Sugden, 1982, 1986; Bell, 1982, 1985).

Rasouli and Timmermans (2015a) reviewed the development and application of bounded rational decision models under condition of certainty. They defined bounded rationality as a "decision-making process and choice behavior in which individuals do not seek the optional choice and/or consider only a subset of the potentially influential attributes, and/or in comparing choice alternatives do not differentiate between asymptotically small differences in attribute/alternative values, and/or do not consider all alternatives in the choice set". Among the bounded rational models reviewed, (random) relative utility maximization (RRUM) models and random regret minimization (RRM) models have attracted much interest. Considering their similarity in some assumptions and model specifications, this paper aims to compare the differences and similarities between RRUM and RRM models, discuss improvements of these models to further elaborate the review and provide additional insights into these models that to date have largely been discussed in isolation.

RRUM models (Zhang et al., 2004) assume that judgments about choice alternatives are made relative to one or more reference points, while RRM models (Chorus et al., 2008; Chorus, 2010) assume that choice behavior is driven by avoiding negative emotions rather than the maximization of some form of payoff. Regret (i.e. negative emotion) occurs when one or more non-chosen alternatives outperform the chosen alternative in terms of one or more attributes. Therefore, it is straightforward that the bounded rationality underlying these models lies in the context-dependency of the decisions that individuals make, which tend to be compromise decisions.

After some seminal work in the middle 1980s and early 1990s, little effort has been spent on models, which attempt to specify context effects in terms of the utility of the choice model. Rather, the vast majority of studies have concentrated on the error terms, making assumptions about variables that are unknown. RRUM models and RRM models believe that in the context of applications of choice models in urban and transportation planning, modeling error terms might be not very effective. Rather, it might be more productive trying to capture the causes of the context effects, trying to find specifications in which the error terms represent pure error.

Nevertheless, there is still no generally accepted definition of context, and many scholars proposed their own definitions (e.g., Oppewal and Timmermans, 1991; Simonson and Tversky, 1992). As to RRUM and RRM models, they only consider alternative-specific context (choice set composition), which takes one or more non-chosen alternatives and their attributes in a choice set into account.

2. MODEL SPECIFICATIONS

2.1 RRUM models

The RRUM models were put forward by Zhang et al. (2004), who argued that utility was meaningful only relative to some reference points and that individuals had different interests in each alternative. The model specification can be described as follows:

$$RU_i = r_i \sum_{j \neq i} \left(u_i - u_j\right) = RV_i + \varepsilon_i = r_i \sum_{j \neq i} \sum_m \left[\beta_m \left(x_{im} - x_{jm}\right)\right] + \varepsilon_i \tag{1}$$

where RU_i indicates the random relative utility of alternative i; $RV_i = r_i \sum_{j \neq i} \sum_m \left[\beta_m \left(x_{im} - x_{jm}\right)\right]$ indicates the observed term of RU_i, β_m is the parameter with respect to mth attribute; ε_i indicates the unobserved term of RU_i; u_i and u_j indicate the utilities of alternative i and j, respectively; r_i is relative interest parameter, which indicates the weight of alternative i; x_{im} and x_{jm} indicate the level of mth attribute of alternative i and j, respectively. Assuming different distributions of ε_i, a new family of choice models can be developed.

Considering that the relative utility is actually defined at the attribute level, Zhang et al. (2013) generalized the RRUM model as follows:

$$RU_i = f\big(g(x_{im} - x_{jm}), r_i, w_{ij} \mid j \neq i\big) \tag{2}$$

where RU_i indicates the random relative utility of alternative i; r_i is relative interest parameter; w_{ij} is a weight parameter reflecting the influence of alternative j on the choice of alternative i; x_{im} and x_{jm} denote the level of the mth attribute of alternative i and j, respectively. Using different function forms of $f(\cdot)$ and $g(\cdot)$, different types of RRUM models can be developed and context dependency can be flexibly represented.

2.2 RRM models

Similar to the concept of relative utility, Chorus et al. (2008) proposed the concept of random regret minimization, which is rooted in regret theory (Bell, 1982; Fishburn, 1982; Loomes and Sugden, 1982). Contrary to RUM models, RRM models claim that choice behavior is driven by minimizing regret. In the original specification, the context effect is reflected in the comparison of the considered alternative and the best foregone alternative in a choice set. The systematic regret of alternative i can be written as follows:

$$R_i = \max_{j \neq i}\left\{\sum_m \max\left\{0, \beta_m\left(x_{jm} - x_{im}\right)\right\}\right\} \tag{3}$$

where R_i denotes the systematic regret of alternative i, which acts as the observed term in random regret; β_m is the parameter with respect to the mth attribute; x_{im} and x_{jm} denote the level of the mth attribute of alternative i and j, respectively.

Later, Chorus (2010) proposed another version of the RRM models based on the following considerations: first, the original RRM model postulates that regret is only experienced with respect to the best foregone alternative rather than all other alternatives in the offered choice set; second, the specification's likelihood function in the original RRM model is non-smooth, which creates difficulties in model estimation. To distinguish these two versions of the RRM models, in the remainder the authors refer to the one proposed in Chorus et al. (2008) as the original RRM model, and the one proposed in Chorus (2010) as the new RRM model. The specification of the new RRM model can be written as follows:

$$R_i = \sum_{j \neq i} \sum_m \ln\left\{1 + \exp\left[\beta_m\left(x_{jm} - x_{im}\right)\right]\right\} \tag{4}$$

where R_i denotes the observed term in random regret of alternative i; β_m is the parameter with respect to the mth attribute; x_{im} and x_{jm} denote the level of the mth attribute of alternative i and j, respectively. Replacing the inner max operator in Eq. (3) with a logsum, its likelihood function becomes smooth, which facilitates model estimation. Replacing the outer max operator in Eq. (3) with a summation, all other foregone alternatives in the offered choice set are taken into consideration equally.

3. THEORETICAL COMPARISONS

In this part, we will discuss the differences and similarities between RUM, RRUM and RRM models. Note that for the RUM model we assume the utility function has a linear-additive form. Model specifications are presented in Eq. (1), (3) and (4).

Conclusion 1: the RRUM model is mathematically equivalent to the RUM model if all the relative interest parameters are equal.

This conclusion is also known as the Relative Utility Theorem, whose proof can be found in Appendix A of Zhang et al. (2004). This conclusion emphasizes the importance of the relative interest parameter in RRUM model. Without the relative interest parameters, the RRUM model is nothing but a standard RUM model.

Conclusion 2: RRUM model reduces to the RUM model if the choice set is binary.

Consider a binary choice set $\{1,2\}$. Assume relative utility of alternative 1 and alternative 2 are defined as $RV_1 = r_1 \sum_{m=1}^{M}[\beta_m(x_{1m} - x_{2m})]$ and $RV_2 = r_2 \sum_{m=1}^{M}[\beta_m(x_{2m} - x_{1m})]$, respectively. Therefore, the difference in the relative utilities of the two alternatives equals:

$$\begin{aligned} RV_1 - RV_2 &= r_1 \textstyle\sum_{m=1}^{M}[\beta_m(x_{1m} - x_{2m})] - r_2 \sum_{m=1}^{M}[\beta_m(x_{2m} - x_{1m})] \\ &= r_1 \textstyle\sum_{m=1}^{M}[\beta_m(x_{1m} - x_{2m})] + r_2 \sum_{m=1}^{M}[\beta_m(x_{1m} - x_{2m})] \\ &= (r_1 + r_2) \textstyle\sum_{m=1}^{M}[\beta_m(x_{1m} - x_{2m})] \\ &= (r_1 + r_2)(V_1 - V_2) \end{aligned} \tag{5}$$

where V_1 and V_2 indicate the standard utility of alternative 1 and alternative 2, respectively. According to Eq. (5), it is intuitive that the RRUM model reduces to the RUM model if the choice set is binary.

Conclusion 3: the original RRM model is mathematically equivalent to the RUM model if the choice set is binary.

Consider a binary choice set $\{1,2\}$. Assume that $\beta_m(x_{2m} - x_{1m}) \geq 0$, $m \in \{1,2,\dots,m_1\}$, while $\beta_m(x_{2m} - x_{1m}) < 0$, $m \in \{m_1+1, m_1+2,\dots,M\}$. Therefore, the systematic regret of the two alternatives equals:

$$\begin{aligned} R_1 &= \textstyle\sum_{m=1}^{M} max\{0, \beta_m(x_{2m} - x_{1m})\} = \sum_{m=1}^{m_1}\beta_m x_{2m} - \sum_{m=1}^{m_1}\beta_m x_{1m} \\ R_2 &= \textstyle\sum_{m=1}^{M} max\{0, \beta_m(x_{1m} - x_{2m})\} = \sum_{m=m_1+1}^{M}\beta_m x_{1m} - \sum_{m=m_1+1}^{M}\beta_m x_{2m} \end{aligned}$$

Therefore, the difference in systematic regret of the two alternatives is equal to:

$$\begin{aligned} R_1 - R_2 &= \left(\textstyle\sum_{m=1}^{m_1}\beta_m x_{2m} - \sum_{m=1}^{m_1}\beta_m x_{1m}\right) - \left(\sum_{m=m_1+1}^{M}\beta_m x_{1m} - \sum_{m=m_1+1}^{M}\beta_m x_{2m}\right) \\ &= \left(\textstyle\sum_{m=1}^{m_1}\beta_m x_{2m} + \sum_{m=m_1+1}^{M}\beta_m x_{2m}\right) - \left(\sum_{m=m_1+1}^{M}\beta_m x_{1m} + \sum_{m=1}^{m_1}\beta_m x_{1m}\right) \end{aligned}$$

$$= \sum_{m=1}^{M} \beta_m x_{2m} - \sum_{m=1}^{M} \beta_m x_{1m} = -(V_1 - V_2) \tag{6}$$

Since regret uses the rule of minimization while utility uses the rule of maximization, Eq. (6) shows that the original RRM model reduces to the RUM model when the choice set is binary.

Conclusion 4: the new RRM model reduces to the RUM model if the choice set is binary.

The proof of this conclusion can be found in Appendix 2 of Chorus (2010). It is interested to see that all models reduce to RUM models in the case of binary choice set. This is might because that in DCMs, utility (or regret) itself is a relative concept, and this relativity lies in the pairwise comparison. So when the choice set is binary, RRUM models and RRM models are identical to RUM models.

Conclusion 5: both RRM models are special cases of the RRUM model.

This conclusion can be drawn easily from Eq. (2). The only difference is their specific function forms of $f(\cdot)$ and $g(\cdot)$: Eq. (1) takes a linear form with a relative interest parameter, and considers all foregone alternatives in a choice set; Eq. (3) takes a non-smooth polyline form, and only considers the best foregone alternatives in a choice set; Eq. (4) takes a smooth exponential form, and considers all foregone alternatives in a choice set.

4. RECENT DEVELOPMENTS

After Zhang et al. (2004), some further work was done using the concept of relative utility, especially the attempt to link it to prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1992). Given the property of loss aversion, a model that integrates the concepts of relative utility and prospect was proposed (Zhang et al., 2010; Zhang et al., 2013). This model takes the form of the value function in cumulative prospect theory and evaluates the relative utility in gains and losses separately. The specification of this model can be expressed as follows:

$$RV_i = r_i \left\{ \sum_{j \neq i} \left[\sum_k \left(\gamma_k^+ \left(d_{ijk}^+ \Delta x_{ijk} \right)^{\alpha} - \gamma_k^- \lambda \left(-d_{ijk}^- \Delta x_{ijk} \right)^{\beta} \right) \right] \right\} \tag{7}$$

where RV_i indicates the observed term in the random relative utility of alternative i; r_i is relative interest parameter; γ_k^+ and γ_k^- are coefficients that need to be estimated; λ, α and β are parameters in the value function of CPT, which are fixed to simplify model estimation; d_{ijk}^+ and d_{ijk}^- are dummy variables, d_{ijk}^+ is set to 1 if Δx_{ijk} is non-negative, otherwise 0, d_{ijk}^- is set to 1 if Δx_{ijk} is negative, otherwise 0; $\Delta x_{ijk} = x_{ik} - x_{jk}$, which defines the attributes difference between two alternatives.

Several applications of RRUM models can be found, such as choices of destinations and stop patterns (Zhang et al., 2004), influence effect of travel information on modal choice (Zhang & Fujiwara, 2004; Fujiwara et al., 2004), choice set generation (Zhang et al., 2005), departure time and route choice (Zhang et al., 2010; Zhang et al., 2013). In addition, a review of RRUM models was presented (Zhang, 2015).

Unlike few developments and applications in RRUM models, the RRM models first introduced by Chorus et al. (2008) have attracted much more attention. After the original RRM model and the new RRM model, several other versions of RRM models have been developed and some critical problems have been discussed.

The generalized RRM model (Chorus, 2014) has been developed from the new RRM model considering model flexibility, which lies in its ability to capture and distinguish the taste for an attribute and the non-linearity of the attribute's regret function. This model is created by recasting a fixed constant (i.e. 1) into an attribute-specific regret weight parameter. Its specification can be written as follows:

$$R_i = \sum_{j \neq i} \sum_m \ln\{\gamma_m + \exp[\beta_m(x_{jm} - x_{im})]\} \tag{8}$$

where γ_m denotes regret weight parameter. If $\gamma_m = 1, \forall m$, then it is intuitive that generalized RRM model will reduce to the new RRM model. Typically, $\gamma_m \in [0, 1], \forall m$. The recent μRRM model (van Cranenburgh et al., 2015) derived from the new RRM model by arguing that the latter is not scale-invariant and allowing the variance of the error term of random regret to be estimated. Its model specification can be described as follows:

$$RR_i = R_i + \varepsilon_i = \sum_{j \neq i} \sum_m \ln\left\{1 + \exp\left[\frac{\beta_m}{\mu}(x_{jm} - x_{im})\right]\right\} + \varepsilon_i, \ -\varepsilon_i \sim i.i.d.EV(0, \mu) \tag{9}$$

where μ is scale parameter. This μRRM model with different values of μ comes to different models: if μ is insignificant different from one, then it becomes the new RRM model; if μ is arbitrarily large, then it comes to RUM model; if μ is arbitrarily close to zero, then it comes to the pure RRM model, which has the following model specification:

$$R_i = \sum_m \beta_m x_{im}, \quad where \quad x_{im} = \begin{cases} \sum_{j \neq i} \max(0, x_{jm} - x_{im}), if\ \beta_m > 0 \\ \sum_{j \neq i} \min(0, x_{jm} - x_{im}), if\ \beta_m < 0 \end{cases} \tag{10}$$

Ten choice sets were applied to show the μRRM model's better model fit than the new RRM model and RUM model.

Jang et al. (2016a) assumed a perception effect that attribute-level regret is proportional to attribute's magnitude. Therefore, they proposed new forms of regret function by replacing $(x_{jm} - x_{im})$ with $\left(\frac{x_{jm}-x_{im}}{(x_{im})^{\vartheta_m}}\right)$ in the original RRM model and the new RRM model. The model specifications are presented as follows:

$$R_i = \max_{j \neq i}\left\{\sum_m \max\left\{0, \beta_m\left(\frac{x_{jm}-x_{im}}{(x_{im})^{\vartheta_m}}\right)\right\}\right\} \tag{11}$$

$$R_i = \sum_{j \neq i} \sum_m \ln\left\{1 + \exp\left[\beta_m\left(\frac{x_{jm}-x_{im}}{(x_{im})^{\vartheta_m}}\right)\right]\right\} \tag{12}$$

ϑ_m is a parameter valued between zero and one to capture the perception effect. If ϑ_m is smaller than one, then the perception effect is diminished in some degree; if ϑ_m is equal to zero, then these models comes to the original RRM model and the new RRM model. Two data sets (one concerned stated preference and the other concerned revealed preference) were applied to test the model fit, and results revealed that these models' performance were better.

Besides these new forms of RRM models, some hybrid models were also developed, such as the hybrid model of regret and utility (Chorus et al., 2013; Kim et al., 2016), the hybrid model of regret and disappointment (de Carvalho et al., 2016).

Beside from these developments in model specification, some studies focus on empirical comparison of different versions of RRM models. As already mentioned above, the difference between the original RRM model and the new RRM model lies in two aspects: first, the original RRM model postulates that regret is only experienced with respect to the best foregone alternative while the new RRM model deals with all other alternatives in the offered choice set; second, the specification's likelihood function in the original RRM model is non-smooth whereas the new RRM model's is smooth. According to that, Rasouli and Timmermans (2015b) proposed another form, which defined regret as max attribute-level regret between chosen alternative and all foregone alternatives (denoted as RRsum model):

$$R_i = \sum_{j \neq i} \sum_m \max\{0, \beta_m (x_{jm} - x_{im})\} \tag{13}$$

Comparing the model fit of Eq. (3), (4) and (13) in the context of shopping destination choice, they found that the original RRM model performs best, and the new RRM model worst. Similar results were found by Jang et al. (2016a), which was in the context of shopping center choice and travel model choice. It seems that the property of user friendliness of the new RRM model sacrifices its model fit. Recall the curves of attribute-level regrets of the original RRM model and the new RRM model (see Chorus, 2010), their difference might lie in the predictive ability of small difference (around zero). In addition, taking all foregone alternatives equally into consideration is not defendable either.

In addition, Jang et al. (2016b) paid their attention to measurement error of RRM models. Given the different function forms between RUM models and RRM models, their study argued the assumption of i.i.d error term in RRM models should be critically assessed. Although it is acknowledged that biased estimation results from measurement error exist in both types of models, uncertainty tended to accumulate in RRM model since comparisons of alternatives are involved. By comparing the biased estimation results of RUM model and the original RRM model in some different context, this study found that bias caused by the original RRM model specification is higher than in the RUM model. In addition, an approach to deal with this problem was also presented.

5. FURTHER IMPROVEMENTS

Although some studies confirmed the advantages of RRUM models in capturing individuals' bounded rational choice behavior, this model largely went unnoticed. However, over the last few years, so-called reference-based models have attracted increasing attention. Examples include regret-based models, disappointment-based models, etc. It seems timely to re-address the relative utility models as it can be shown that regret-based models and the other mentioned models are nothing but special cases of RRUM models. The remainder of this section discusses several potential improvements of RRUM models as well as in RRM models.

First, the recent elaborations of regret models could also be investigated for relative utility models, and vice versa. Second, although Eq. (2) mentioned that $f(\cdot)$ and $g(\cdot)$ could have varied function forms, only linear-additive form was tested in RRUM models. Therefore, other different forms could be investigated and compared with linear-additive form. Third, Rasouli and Timmermans (2015b) argued that taking all foregone alternatives equally into account may not be defendable on some choice domains. Therefore, inspired by Eq. (2), one might consider giving each foregone alternative a weight w_{ji} to measure their influence to the considered alternative. Such model can be expressed as follows:

$$R_i = \sum_{j \neq i} w_{ji} \sum_m \max\{0, \beta_m(x_{jm} - x_{im})\} \tag{14}$$

Fourth, to date only the alternative-specific context was discussed in the contexts of RRUM models and RRM models. Alternative-specific context includes the number of alternatives and their attributes, the correlated structure of attributes and the availability of alternatives. However, Zhang (2015) defined another two different types of context: the time-specific and individual-specific context. The time-specific context refers to the individuals' previous and future choice behavior. The individual-specific context refers to the choice behavior of others' in individuals' social network. It is interesting and relevant to examine relative utility and random regret models that include these comparisons or a combination of the three types of contexts.

Fifth, although theoretical comparisons of RRUM and RRM models are presented in Section 3, empirical results of comparisons of these models in different context of different domains are still needed. Sixth, here only RRUM and RRM models under condition of certainty are discussed. However, uncertainty (or risk) is a more common factor in the real world. Therefore, one might be interested in the comparison of these models in terms of theoretical and empirical aspects and their applications under condition of uncertainty.

6. CONCLUSIONS

In this paper, we reviewed the basic concepts underlying relative utility and random regret models, compared their differences and similarities, discussed their new elaborations and applications, and argued their potential improvements. Basically, RRUM models and RRM models take into account context dependency, which reveals individuals' bounded rationality. Several conclusions may be drawn: 1) RRUM model comes to RUM model if all relative interest parameters are equal; 2) the RRUM model reduces to the RUM model if the choice set is binary; 3) the original RRM model turns into the RUM model if the choice set is binary; 4) the new RRM model reduces to the RUM model if the choice set is binary; 5) both RRM models are special cases of RRUM models; Future research could focus on the combination of RRUM models and RRM models, model developments in time-specific context and individual-specific context and model applications and comparisons under condition of uncertainty.

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To dig or not to dig: How to determine the number and location of test trenches

A Case Study

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Key words: decision-making, test trenches, excavation, excavation damages

Abstract: To confirm the exact location of underground utilities, engineers can rely on maps of underground systems at the excavation polygon, as well as technologies, such as Ground Penetrating Radars (GPRs). However, differences may exist between maps and reality. As a result, it is necessary to confirm the exact location of the underground systems by digging test trenches. This article focuses on the analysis of currently used strategies to determine the location of test trenches. Data were gathered through a literature review and interviews conducted at several companies in the Netherlands. Results indicate that companies devise their own particular, and often ad-hoc, strategies to decide. All of them are based on the drawings received from the Cables and Pipes Information Agency. The preliminary results hint at several "best practices", which are elaborated. Weaknesses are identified and discussed. These findings serve as input for our current (follow-up) research on strategy improvement to obtain the maximum amount of information out of the minimum number of test trenches.

1. INTRODUCTION

The underground space is becoming increasingly busy. Many kinds of cables and pipes are buried under the ground. Excavation has become challenging for today's engineers. They have to schedule operations in a way that will not cause damages to the existing networks. Since several of the pipes and cables were buried a long time ago, the actual location does not always match the position according to the drawings. New technologies such as ground penetrating radars and 3D visualization (Schall, Junghanns, & Schmalstieg, 2010) are used to help to confirm the exact location of the underground utilities. However, radars are costly and do not give complete certainty. As a result, test trenches are used to confirm the exact location of underground networks in many countries such as Canada (test holes), USA and UK (trial holes), Australia (potholing), Netherlands ("proefsleuven"). Drawings and radars are merely supporting tools which help to decide where shallow trenches are necessary. Several guidelines about damage prevention are in place in those countries. These guidelines present rules about the dimension and distances between test trenches. In the Netherlands, the underground network extended over approximately 2 million km in 2013 (GPKL-Het Gemeentelijk Platform Kabels en Leidingen, 2013). This will probably only increase in the coming years. During the same year 40,000 damages to the Dutch underground network were reported (GPKL-Het Gemeentelijk Platform Kabels en Leidingen, 2013). The number presumably decreased slightly over the last two years thanks to the national Underground Networks Information Exchange Act, commonly referred to as WION (WION, 2008) and the improvement of the Klic application, implemented by the Cables and Pipes Information Agency (Cadastre). The legislation act describes the rules about activities that must be accomplished before, during and after excavation. Once an excavation request is sent to Cadastre, the excavator will receive information about the existing networks in the area. *Figure 1* presents a schematic overview of Klic.

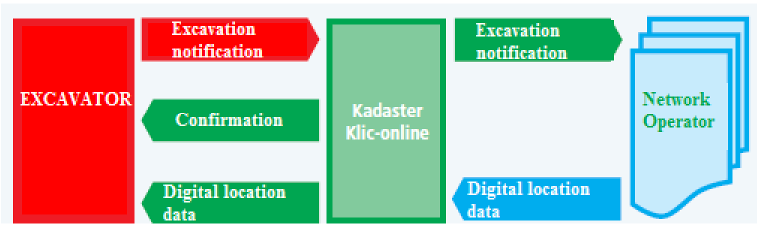

Figure 1. The functional description of KLIC - online (Groot, 2008)

Before breaking the surface, it is necessary to confirm the exact location of the underground networks. Due to legal requirements (WION) and technological limitations of electronic devices, confirmation of underground system locations has to be done by digging test trenches. The decision process about determining the location and number of test trenches is not easy and often appears to be random, resulting in many damages to underground systems. What is more, every excavation, even the hand digging, can cause damages. In an ongoing project[1], we aim to develop a decision support tool which will make the decision process easier and more reliable.

This article presents findings from the preliminary stages of this project, and in particular focuses on the analysis of strategies used to select test trench location. Data were gathered through literature review and interviews conducted at several companies in the Netherlands. Interviews with representatives of several companies were conducted. Before each interview, the representative was asked to prepare an example of a project where they had to decide about the number of test trenches and their location. Each case was discussed during the interview. Other examples were also shared what gave the opportunity to compare the strategies depending on the situation. That results of this first stage are described in this article.

The structure of this article is straight forward. Section 2 outlines background information on decision-making processes in general and excavation procedures in the Netherlands. The research method is described in section 3. Results are in section 4. Finally, conclusions are presented in section 5.

2. BACKGROUND

2.1. Decision-making process

Sometimes decisions are easy, and at other times difficult. Sometimes the decision entails heavy responsibilities, and at other times it is not as important as we first thought (for example, which dress to wear for an important meeting). Depending on their character, people can make, independent decisions, but often the decision, at least in part, based on preferences from authority figures. Consider as an example, the relation between bosses and a workers. Workers might always agree with their bosses, just because they consider them to be smart and more important.

To make the decision means to make use of information and choose an option among the best available possibilities (Ishibushi & Nii, 2000). A

[1] University of Twente, Reggefiber and other partners created the ZOARG program (Dutch: Zorgvuldige Aanleg en Reductie Graafschade). This program is realized to promote careful approaches in construction and maintenance of the underground infrastructure, by investing in the development of new methods and technologies that prevent excavation damages (Reggefiber & University of Twente, 2015). The analysis of strategies currently used to select the location of test trenches is part of a PDEng (Professional Doctorate in Engineering) project entitled “Improved strategies, logic and decision support for selecting test trench location”.

decision-making process can be thought of as consisting of 4 phases: (1) intelligence phase, (2) design phase, (3) choice phase, and (4) implementation phase. These major phases are known as Simon's rational decision making model (Turban & Aronson, 2001). The model is presented in *Figure 2*.

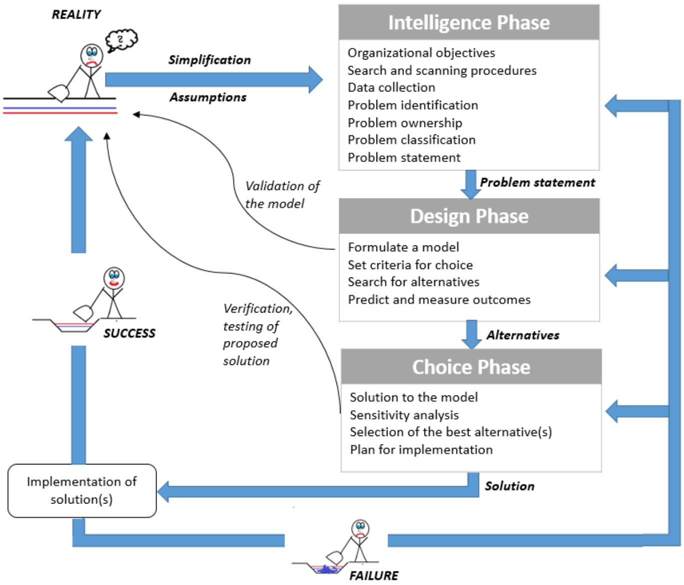

Figure 2.The decision-making process as (Simon, 1977) adapted by (Turban & Aronson, 2001)

The Intelligence Phase is the first phase of a decision process and it focuses on the data collection, case investigation and subsequently problems' identification, classification and statement. If the decision-makers are experienced persons, in the ideal situation, they will follow general work practices. Nevertheless, the problems, which will have an impact on decisions, may appear while the work is proceeding. If the problems will be correctly identified the accurate decision can be made.

The Design Phase is focussed on finding the possible solution(s) for the problem(s). In other words, it is the treatment phase. The decision-maker needs to understand the problem and provide the solution that will lead to a successful problem solving. One of the methods used to find the solutions consists of the creation of an accurate model of the identified problems. The model will frame the scenarios, which decision-makers consider that can happen. Afterwards, it will guide them for the accurate paths during searching for alternatives.

During the Choice Phase the decision about the solutions is made. The decision is preceded by selection of the best alternatives, analysis of sensitivity and model testing.

The solution is implemented during the last step of the decision process named Implementation Phase.

The decision-making in civil engineering project impose heavy responsibilities on the decision-makers (Turskis, G., Kalibatas, & Barvidas, 2007). The question: '*Where and how many test trenches should I locate in the excavation polygon?*', is a good example of such responsibilities. The test trenches are the shallow trenches dug to confirm the exact location of the underground utilities. If the decision-maker choose not enough amount of test trenches to the case, the risk of damage to the underground systems will increase. Contrarily, if too many test trenches are dug that will expose the contractor to higher costs of the process. Depending on the case the decision-makers will have to choose the best option from the possible alternatives by taking into account the information that they have already possessed. To choose the correct solution from the variety of alternatives the Decision Support tool can be used. (Omar F.M., 2009).

This kind of tools can have the form of computer-based systems. The decision-makers very often have to rely on their experience, judgments and intuition which in case of failure, can have significant consequences. The types of Decision Support Systems (DSSs), that are used to support complex problems are as follow (Druzdzel & Flynn, 2002):

- Database management systems (DBMS): are used to store the data. The user can analyse them and provide the relevant solutions to the problem.
- Model-base management system (MBMS): the data that were stored by DBMS can be easily transformed into the information that will support the decision-maker.
- Dialog generation and management system (DGMS): are used to manage the dialog (interface) between the user and Decision Support System.

2.2. Excavation procedure in the Netherlands

Excavation damages are defined as mechanical damages to underground networks which result from the contact with an object. (Technology Subgroup of the Operations&Environment, 2011). Their magnitude depends of the shape of the object together with the provided power. Damages can be made to the external coating of pipe or cable and other network equipment, but they can also take another form such as dents, scrapes, cuts or punctures (Technology Subgroup of the Operations&Environment, 2011). Damage can occur in every phase of the utilities life cycle. What is more, damages are not always discovered during excavation and can occur in the future. Durability of utilities decrease when the coating gets injured and other factors such as corrosion, pressure, fluid stream, intrusion can have higher influence on them. As a result, catastrophic failure can appear when is least expected.

In the Netherlands, an excavation notification must be sent to Cadastre by Klic-online application before any excavation works. The excavator has to ensure that an investigation has been performed into the exact location at the excavation polygon. It is important to send the notification on time (at least three but not earlier than twenty working days before the beginning of the work). Cadastre will send the data within two days. The excavator has to ensure that the area information received from the Agency are presented at the excavation polygon.

It is also necessary to check if any extra precautions are needed. In a positive case, the additional precautions will be indicated and the user will be asked to contact the network operator. Pipes and cables can be found even 1,00 m away from the position indicated in the plots. Because of that inaccuracy, it is necessary to determine their exact location on site. In case a deviation in the position of the pipes is detected, this information should be reported to Cadastre. The length of test(trial) trench is approximately 1,00 m on both sides of the theoretical location (CROWN, 2000). There can be a reason to deviate from standard dimensions described in the guidelines (Groot, 2008). In some situations additional rules must be applied, for example in case of pipes with dangerous content (such as gas or chemicals) or in case of utilities with a high value (such as major communication lines). The information about the precautions for networks can be found in the Klic-viewer application. The excavators have to contact the network operator to receive information about how the work must be carried out. The network operators have to ensure precautions (if necessary) within 3 working days from that time. It is important that network operators ensure all precautions, so it is necessary to make that clear in the agreement with them. Any doubts should be consulted with the them to avoid the possibility of damages.

So, when the test trenches are necessary? The test trenches are necessary for open excavation when the theoretical horizontal position of network's elements is situated wholly or partly (Groot, 2008):

- Within the planned excavation profile or monitoring area;
- Within the horizontal distance of 1,50 m on both side of the planned excavation.

For vertical drilling, sounding or installation of piles or sheet piles when the theoretical horizontal position of network's elements is situated wholly or partly (Groot,2008):

- Within the location of the diameter of drilling or probing or at the location of projected piles installing;

- Within the horizontal distance of 1,50 m from the outer diameter of the projected ground drilling, probing, projected piles or sheet piles.

When are test trenches NOT necessary? Test trenches are not necessary for open excavation, vertical drilling or probing or installing piles and sheet piles when the theoretical horizontal position of network's elements is situated (Groot,2008):

- Completely outside of horizontal distance of 1,50 m on both side of planned excavation;
- Completely outside of 1,50 m from the outer diameter of the projected ground drilling, probing, projected piles or sheet piles.

In case of trenchless techniques it is necessary to contact the network operator and consult how to proceed to determine the exact location of the network and determine the necessary precautions. For vertical drilling, probing or installing piles and sheet piles it is necessary to contact the operator as well in order to confirm proceeding, in case the horizontal position of networks components is expected to be more than 1,50 m below ground level. When the excavation takes place with shallow ground water level, it may be not possible to proceed work by using test(trial) trenches in order to determine the exact location of network. For that situation the excavator has to contact the network operator. If the excavators will no adhere to the procedures they will have to pay a fine.

3. RESEARCH APPROACH

Guidelines are available to help decide about test trenches location. These support the excavator on technical issues (Groot,2008), (Crow, 2013). However, the technical guidelines are not enough to make reliable decisions. It is necessary to look into the decision consequences resulting from previously made decisions (Bennet & Bennet, 2008). We have conducted interviews with the units involved in the decision-making process about test trench location to examine currently used strategies. The goal of the first round of interviews was to get familiar with currently used strategies, identify the problems and investigate how to obtain the maximum amount of information out of the minimum number of test trenches.

The Design Process Unit (DPU) approach (Becker & Wessel, 2013) was used to structure questions for the interviews (see *Figure 4*). DPU is part of other design method DfX (Design for eXcellence), as presented in *Figure 3*. DPU can be defined as the knowledge which is compulsory to design. The design parameters are properties of the artefact that can be manipulated to achieve the performance. Opposite, the scenario parameters describe the properties that cannot be changed and have to be considered in the design. The performance is pulling both the design and scenario and it assesses the quality of the analysis (Becker & Wessel, 2013). There are 5 categories of DfX methods: (1) Guidelines, (2) Checklists, (3) Metrics, (4) Mathematical models, and (5) Overall methods (Becker Jauregui & Wessel, 2011).

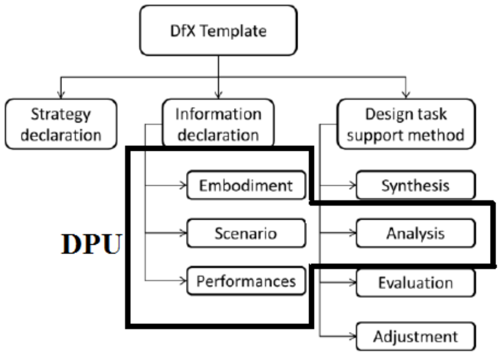

Figure 3. Taxonomy of the DfX template (Becker Jauregui & Wessel, 2011).

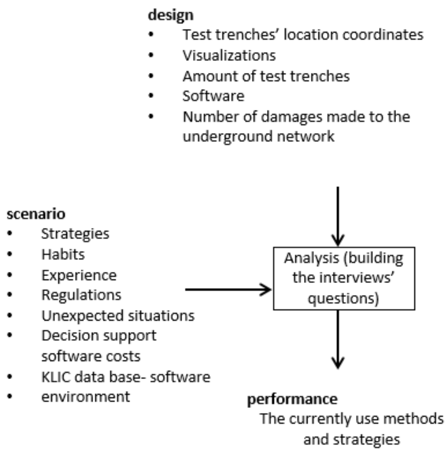

Figure 4. DPU model for interviews questions' analysis

The questions, as a result of the analysis, can be seen in *Table 1*. The design parameters represents the parameters which we can manipulate. Due to them, the questions are formulated. However, several scenario parameters must be taken into account as well. Companies have their own habits and it may be difficult to change their opinions about the strategies that they use. What is more, some of the rules, such as using Cadastre Klic-online system, are dictated by law.

Table 1. Interviews' questions result from DPU

Embodiment and Scenario that influent the question	Question
Design: location's coordinates; visualization (analysis of drawings); **Scenario:** user's experience, practice rules, Klic database and users itself	Where did you locate the test trenches? Why did you locate them there (grounds, reasons)? On which reasons did you base your decision?
Design: amount of test trenches **Scenario**: user's experience, practice rules, Klic database and users itself	Why did you choose that amount? What are distances between the test trenches?
Design: location's coordinates; visualization (analysis of drawings), amount of test trenches; **Scenario:** user's experience, practice rules, Klic database and users itself	What is your opinion about the idea of considering the shallow excavation as a test trench?
Design: software **Scenario:** user's experience, practice rules, Klic database and users itself	Did you use any aid to decide easier about number of test trenches or about the excavation? (software? Devices? Radars?)
Design: number of damages **Scenario:** user's experience, practice rules, Klic database and users itself	What were the results of your choices? Did any damage happen?
Design: software, number of test trenches; **Scenario:** user's experience, practice rules, Klic database and users itself	What do you think about the current information exchange system Klic? Do you like it? Is it helping you? Would you change something?
Design: visualization (analysis of drawings), software, number of damages; **Scenario:** user's experience, practice rules, Klic database and users itself	What do you think about the cooperation/communication at excavation place?
Design: location's coordinates; visualization (analysis of drawings), software, number of damages; **Scenario:** user's experience, practice rules, Klic database and users itself	Could you tell me what would you like to change in the current procedures? Do you have any ideas what would help you to decide easier about test trench location?

Ten interviews were conducted with excavation companies, network operators and government agencies. The representatives of this units differed in functions what helped to have a broad overview on the discussed problem. The function of interviewees in the company are presented in *Table 2*. The results of interviews are discussed in the Results section below.

Table 2 The functions of interviewees in the Companies

Interviewee	The function in the Company
1	WION Inspector
2	Manager in the Operational Information Management department
3	Asset Manager
4	Designer
5	Designer
6	GPRs Specialist
7	FttH Engineer
8	Specialist of software design
9	Coordinator
10	Group of Work Planners

4. RESULTS

The results will be discussed according to the phases of the decision-making process model presented in Figure 2 (see point 2.1). This section concludes with SWOT analysis of the currently used strategies.

4.1. Intelligence Phase

Firstly, all the excavators use the Klic-online system to receive information about underground networks which are buried on excavation polygons. In addition, the Klic-viewer and Klic-app are used to read the data. An example of a map received by using the Klic-online system is shown in *Figure 5*.

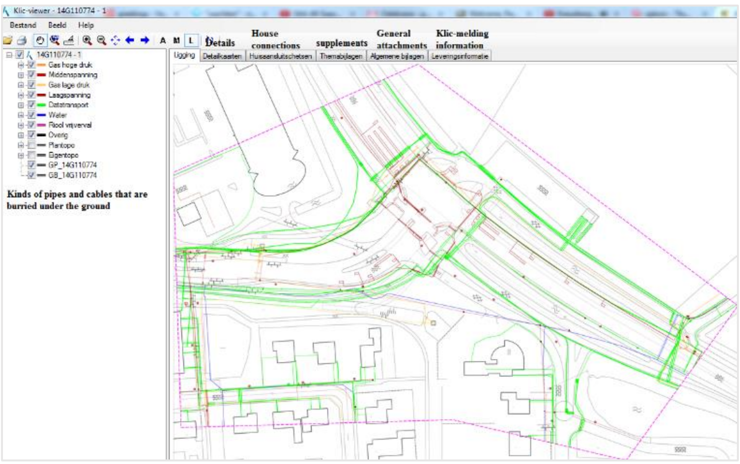

Figure 5. Example of map presented in the Klic-viewer

Secondly, during the first step of investigation all of the interviewees compare the received maps (and documents) with the design drawings. These help to detect the conflicts between the design and the situation under the ground. Following the detection of conflicts, the dialogue with the network operators begins and either the design can be changed or the utilities can be replaced.

The next important step is the analysis of the excavation area. Many obstacles can be noticed during the analysis of the surroundings, which may have an impact on the taken decisions. The factors that can influence a decision are: trees, paths, houses, rails, roads and so on. Some of the companies support their decisions by using Ground Penetrating Radars (GPRs). The frequency of use depends on the amount of money that the company can invest. Many times the GPRs are used only to calculate the depth and confirm the path of the networks which were already uncovered by test trenches. However, some representatives have doubts about the usefulness of digging test trenches. They justify their opinions that GPRs are non-invasive and as a result better to detect underground utilities. Nevertheless, the GPRs are costly and do not provide total certainty.

Steps described above help to identify the problems which can influence the decisions. The following factors can have an impact on making decisions:

- Kind of work that must be done: type of work, how deep is the excavation, what kind of technology is used to dig;
- Presence of hazardous underground networks on the excavation polygon, such as high-pressure gas pipeline;
- Presence of obstacles such as trees, roots, rails, houses, roads;
- Presence of house connections; the information about house connections is still updated in Klic system.

Some of the companies use internal databases, such as ArcGIS, to store all the data. The software helps in data comparison and makes the process easier when it is necessary to look into previously taken steps. What is more, the decision-makers have to consider that the situation under the ground can differ from the one which is presented on the drawings. For example, the amount of cables (they can be placed in one duct) or the pipes and cables can be wider because of joints (i.e. socket-welded and butt-welded joints).

4.2. Design Phase

Considering the factors and problems mentioned in the intelligence phase, the group of decision-makers (designers, coordinators, work planers and in case of necessity of precautions- network operators) decide about the number and location of the test trenches. They have to deal with an important question: '*how to get the maximum amount of information from the minimum number of test trenches, and at the same time avoid the danger and minimize the costs?*'.

Several good practices were noticed during the interviews. In order to obtain maximum information, the decision-makers:

- Compare the design with Klic's maps that help them to see which utilities can be affected by the execution of the design. The comparison and dialogue with network operators may result in decision changes or agreement with network operator about replacing the pipes or cables;
- Store data in the internal databases, as well as in applications like Klic-app (develop by GOconnectIT), which can help to analyse if similar cases were already considered in the past. The information about good practices but also about previous mistakes can help workers to improve their job. In addition, in case a damage is made to the network it is possible to look into steps taken and see what was done wrong. The database also supports the coordinators, to control the work that was made;
- Observe the surroundings in the excavation polygon to consider obstacles.

4.3. Choice Phase

A careful analysis helps to determine the number of test trenches and their location. However, the decision is changed many times after digging the first trial trenches. Sometimes, the experienced workers have the feeling that more test trenches should be done, for example, because they had already seen similar cases. In one example given during the interviews, three test trenches were planned, but finally fourteen were made and in the last one, it was found that the pipe was not placed linearly.

Results showed that when many contractors work on the excavation polygon, some misunderstanding can occur in the communication about who is responsible to make one of the test trenches. Finally, nobody carries out that work and, as a consequence, damage is made to the network.

A good practice, which was noticed during the interviews, is placing a cover on top of the pipes, as is shown in *Figure 6* . This cover warns the workers that the network is located under it and they should dig carefully. That warning sign can help in case any test trench has been planned at that precise spot and an unexpected network has been discovered.

Figure 6. Underground utilities together with the red cover in the test trench

4.4. Implementation phase

The choice made can result in success or failure. Success means that the work was executed without causing any damage, and failure means that a damage was made to the underground network. The interviewees admitted that sometimes the report of damage is not registered and the information about the damage after it was repaired was missed. During the interviews a database with information about damages in the year 2015 was presented. About 70% of the damages were completely registered by the Network Operators, and other 30% of them were only reported.

A report which describes the decision process for the test trenches location and details how the works were done is often not prepared.

4.5. Analysis SWOT of the current system.

SWOT analysis is the technique which is useful to present and analyse the Strengths and Weaknesses of the case under investigation. The SWOT analysis for currently used strategies to select test trenches location is shown in *Table 3.*

Table 3. Analysis SWOT of currently used strategies

Strengths	**Weaknesses**
Cadastre's Klic system; Comparison between drawings and maps; View on excavation area; Internal databases.	Databases are not obligated by law; Sometimes decision is based on judgments The databases are not often use; Reports about damages are not often registered; Misunderstandings;
Opportunities	**Threats**
Global database for proceeding the excavation; Educational meetings and guidelines	If the use of database is not required by law it will not be used.

The Cadastre's Klic-system is unarguably one of the strongest points of the currently used strategies. Digital maps together with documentation are received from one unit which work as a bridge between excavators, network operator and government agencies. The system provides the support for decision-makers in civil engineering. As a result, they are able to compare the drawings with maps. Afterwards they can confirm the information during inspections in the area and include observations in analysis (for example the presence of obstacles). In addition, some of the companies use internal databases as well as applications to store the information.

However the several weaknesses were observed as well. Klic-app is nowadays improved in addition functions. For example soon it will be possible to store the data about test trenches in the cloud. Nevertheless, the users are not obligated by law to use it. What is more, the internal databases are not used by every company and information about made decisions is many times lost. In case of some companies only comparison between drawings and maps is done, what seem to be insufficient. Moreover, the decisions are many times changed because of intuitions of the workers. The lack of support tool can influence the communication in the excavation place what result in misunderstanding about responsibilities. In addition, the reports are often not registered and afterwards it is not possible to analyse the mistakes.

To receive maximum amount of information from the minimum number of test trenches, all companies should use a global database. That can direct them towards the best practices, help to avoid the same mistakes, as well as confirm if other works were executed in that area in the past. Education meetings should be organized as well, and the guidelines should be published to make the excavators aware of the importance of test trenches. Nevertheless, a global database will not work if the information sharing is not required by law.

5. CONCLUSIONS

In this article we have reviewed current strategies to determine the number and location of test trenches on construction sites. Results indicate that careful data analysis and observation of the surroundings are needed. It is difficult to analyse large amounts of data. Moreover, information can be lost which result in faulty decisions. Arguably successful practices showed that database software, such as ArcGIS, facilitated informed decision-making. The database helped excavators to store data, analyse previously made decisions, avoid the same mistakes and also to control the work. What is more, the database would help to prepare a good report about the decision process which was applied to the case. In this report, the information about test trenches can be included. Currently, the quality of the reports about the decision process differs between companies (in some cases reports were even not prepared).

During some of the interviews, the interviewees showed doubtfulness about the necessity of digging the test trenches. Due to that, it might be important to prepare some meetings with the excavators to explain why the test trenches plays an important role in underground system confirmation, and what are the advantages compared to using only ground penetrating radars.

In some of the companies it was noticed that there is a lack of communication between the contractors. A database, with open access for all the units involved in the excavation works, can help to follow the work process. In addition, the good practice guidelines can help to solve this problem.

The subsequent interviews are directed at determining best strategies used to select test trench location, as well as to identify the problems that excavators are struggling with. Meanwhile, a possible new strategy will be developed and tested. The goal is to improve currently used strategies and make the decision process easier and more reliable !

6. ACKNOWLEDGMENT

The work is supported by Agentschap Telecom and Reggefiber. We would like to thank especially Frank van Bree and Robert-Jan Looijmans for supporting us with their knowledge and organize the interviews meetings in several companies.

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Using Cognitive Agent-based Simulation for the Evaluation of Indoor Wayfinding Systems

A Case Study

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Key words: Computer Aided Evaluation, Wayfinding, Signage System, Cognition, Agent-based Simulation, Visual Attention Modelling, Virtual Reality

Abstract: This paper presents a novel approach to simulate human wayfinding behaviour incorporating visual cognition into a software agent for a computer aided evaluation of wayfinding systems in large infrastructures. The proposed approach follows the Sense-Plan-Act paradigm comprised of a model for visual attention, navigation behaviour and pedestrian movement. Stochastic features of perception are incorporated to enhance generality and diversity of the developed wayfinding simulation to reflect a variety of behaviours. The validity of the proposed approach was evaluated based on empirical data collected through wayfinding experiments with 20 participants in an immersive virtual reality environment using a life-sized 3D replica of Vienna's new central railway station. The results show that the developed cognitive agent-based simulation provides a further contribution to the simulation of human wayfinding and subsequently a further step to an effective evaluation tool for the planning of wayfinding and signage.

1. INTRODUCTION

The architecture of public buildings like train stations and the provision of guidance information has important implications for people, regarding the quality of the provided services and constitute a major challenge for designing a consistent and accessible wayfinding and signage system. The locations for visual signs need to be selected carefully such that they do not compete with other signs or advertising, are readily viewable within an adequate time, are not partially obstructed, and can be seen within viewing distances of an average person. All these aspects of a wayfinding and signage system should be taken into account already in the planning phase. Wayfinding has to be treated as an integral part of the design process to create more intuitive architectural spaces where people navigate instinctively. Currently, there are no adequate tools available that allow an integration and assessment of such issues into the planning process.

Therefore we propose a new agent-based simulation model enabling a computer aided evaluation of wayfinding systems to identify weaknesses and gaps in the signage system of an infrastructure. In this work, we focus on the simulation of wayfinding of people who are unfamiliar with an infrastructure and are heavily dependent on available signage. As test scenario we used Vienna's new central railway station, as this provides a prototypical example for complex wayfinding problems with a focus on pedestrians. Train stations gradually evolve from transport hubs towards multi-functional environments combining mobility services with commercial areas for events, exhibitions, shopping or various other activities. This increases the complexity of the environment which can cause disorientation and discomfort.

The paper is structured as follows. In Section 2 the state of the art in pedestrian simulation, wayfinding and visual attention modelling is presented. Section 3 describes the developed wayfinding simulation with the different models and how they are cooperating. In Section 4 we describe wayfinding experiments where we gathered empirical data by means of a virtual reality (VR) environment. Then we compare the results from the agent-based simulation with the empirical data. The paper closes with concluding remarks and discussion on future challenges in Section 5.

2. RELATED WORK

2.1 Agent-based Pedestrian Simulation

Simulating pedestrian behaviour has recently gained a lot of attention in a variety of disciplines, including urban planning, transportation, civil engineering and computer science. Various kinds of models like cellular automata, fluid dynamics, discrete choice models, rule-based models and multi-agent models for simulating pedestrian behaviour have been suggested (Timmermans, 2009). Agent based microscopic modelling is an approach for simulating pedestrians as single individuals by supplying a detailed representation of their behaviour, including decisions on various levels and interactions with other pedestrians in the crowd with the goal to reproduce realistic autonomous behaviour. Pedestrian behaviours can be categorized as strategic, tactical and operational behaviour as referred to in (Bierlaire and Robin, 2010, Hoogendoorn, Bovy, et al., 2002, Hoogendoorn and Bovy, 2004, Kielar and Borrmann, 2016). Strategic behaviour describes destination choice and activity scheduling, tactical models characterize the pedestrians' route selection from the pedestrian's current position to a certain destination under which wayfinding can be understood. The operational behaviour relates to the manner of walking to the next visible intermediate goal of the route and interacting with other pedestrians and obstacles along the path.

Most currently available simulation models are based on the assumption that all pedestrians know the infrastructure perfectly and consequently all pedestrians choose the shortest path to reach their goal. However, for those pedestrians who are not familiar with the infrastructure a more realistic simulation of the wayfinding behaviour is needed.

2.2 Wayfinding Behaviour

In (Koh and Zhou, 2011) the important factors in a pedestrian's decision-making process during wayfinding include a pedestrian's sensory attention, memory, and navigational behaviours. Wayfinding through buildings like train stations can be considered as route following facilitated by signs, easily associable landmarks like shops and crossings connected by corridors and can be classified after the taxonomy in (Wiener, Büchner, et al., 2009) as aided wayfinding. Aided wayfinding is considered to be rather simple since it does not require considerable cognitive effort from the user. It is important only to provide all the relevant information at each decision point. Research on people’s wayfinding helped to establish practical guidelines on how to design public buildings and signage to facilitate wayfinding (Arthur and Passini, 1990). Large public buildings such as central railway stations fulfil various functions, which makes the design of signage and wayfinding systems very difficult and error-prone. Currently, there are no adequate tools available that allow the assessment of signage systems already in the planning stage.

The approach of applying computational cognitive models for understanding human cognition is relatively new and significant progress has been made in recent decades in advancing research on computational cognitive modelling. But, there is still a long way to go before we fully understand the computational processes of the human mind (Sun, 2008). There exist various computational cognitive models for wayfinding which are focussing primarily on the exploration of mental representations rather than on the information needed for wayfinding and neglect the processes of how people perceive and navigate through spatial environments (Raubal, 2001).

Therefore it will be necessary to carry out further studies to advance the understanding of human wayfinding behaviour. Recent developments in virtual reality head mounted displays and eye-tracking enable new innovative possibilities and will boost wayfinding research which will provide in-depth insights to human behaviour.

2.3 Visual Attention

Understanding the visual attention process of pedestrians during wayfinding tasks is an important prerequisite to successfully and realistically model their behaviour. Different important aspects of the process must be addressed: Visual attention needs to be understood and analysed as a result of both bottom-up and top-down processes.

Each visual scene has its own visual properties, and some visual patterns attract more attention than others. (Itti, Koch, et al. 1998) analysed different images and showed that visual saliency can be used to model human attention towards images. This approach provides a helpful bottom-up characterisation of the visual scene, but research has shown that it can only account for a low percentage of fixations (Rothkopf, Ballard, et al., 2007).

In order to fully address visual attention processes also knowledge-driven gaze control needs to be considered. (Henderson and Ferreira, 2004) provide a typology of the different levels of knowledge involved. Episodic scene knowledge deals with information about a specific scene that is learned over the short term (current perceptual encounter) and over the longer term (across multiple encounters). Scene-schema knowledge relates to information about the objects likely to be found in a specific type of scene (e.g. train stations typically contain guidance signs), and spatial regularities (e.g. guidance signs are frequently placed overheads). Task-related knowledge describes a general gaze-control strategy relevant to a given task. For the example of navigating in a busy train station such a strategy might be to periodically switch between fixating the immediate walking path for collision avoidance and scanning overheads for guidance signs.

Recently, empirical studies relating attention patterns with body movements, head motion and gaze direction in naturalistic settings have been conducted (Foulsham, Walker, et al. 2011). More specifically data addressing the problem of walking were the people need to navigate through the environment and avoid collisions has been conducted by (Jovancevic-Misic and Hayhoe, 2009). Furthermore, more and more detailed attention data from realistic scenarios outside the lab become available through the use of advanced scene reconstruction and eye tracking equipment (Paletta, Santner, et al. 2013, Schrammel, Mattheiss, et al. 2011). These data now can be used to improve the quality of attention models for pedestrians.

3. AGENT-BASED SIMULATION

3.1 Overview

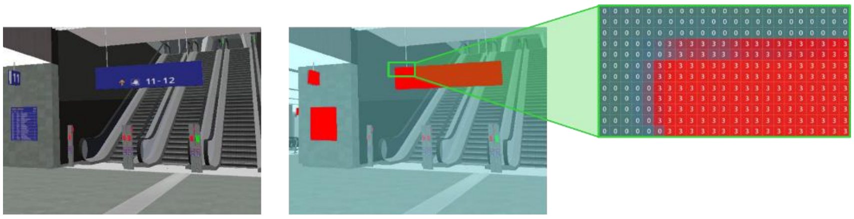
The main contribution of this work is a cognitive agent-based simulation which is tailored to the needs of persons unfamiliar with the infrastructure. To simulate human wayfinding in a plausible way, visual perception and cognition of guidance information need to be integrated. Therefore, the proposed wayfinding includes visual access to signage for directional information at decision points. It follows the Sense-Plan-Act paradigm (Gat, 1998) comprised of models for visual cognition of signage, navigation behaviour and pedestrian movement as explained in *Table 1* and described in the following sections.

Table 1. Basic algorithmic steps of the simulation loop.

Main Loop	
while target location is not reached:	# or the simulation time has run out
perceive surrounding;	# render agent view in the virtual reality environment
calculate attention	# calculate probabilities of the visual attention for each sign
select navigation behaviour;	# select appropriate navigation behaviour and action
execute the movement;	# check collision and update agent's location
end while	

3.2 Modelling of the Environment

The virtual environment of Vienna's new central railway station was used for the visual view of the simulated agent as shown in *Figure 1a*. To determine the areas covered from signage in the field of view additionally a mask is rendered containing the signage only (*Figure 1b*). For each pixel in this mask a unique identifier (ID) to the associated sign is assigned (*Figure 1*c). So all signs and covered areas that are visible to the agent can be determined an evaluated. Semantic information about type and information provided by each sign can be retrieved from a database using the unique ID. Therefore a 3D editor was developed which made it possible to explore the 3D model and to select and annotate the signs with semantic information.



(a) (b) (c)

Figure 1. Rendered agent view (a), areas containing signs (b) and per pixel sign id's (c).

3.3 Modelling Visual Attention

The field of view rendered from the 3D model serves as input to the attention model. On the basis of this image the attention model calculates the saliency in the visual range using a frustum model (Riche, Mancas, et al., 2013). The result is an attention distribution on the objects in the field of view (Schrammel, Regal, et al., 2014).

As illustrated in *Figure 2*, a function for identifying objects of interest was developed. The function consists of three modules to calculate (1) the dynamic field of view (Frustum, Fru), (2) bottom up saliency (Sal) and (3) task specific attention (Semantic, Sem). The function for calculating objects of interest receives an image of the agents view and a mask that assigns an ID to each object for identification as input parameters. For simulating the frustum, a Gaussian distribution (μ=0, σ=7) is combined with a Beta distribution (α=3, β=12), based on the data by (Foulsham, Walker, et al., 2011). The visual saliency is calculated by using the RARE 2012 algorithm by (Riche, Mancas, et al., 2013). For the task specific attention a semantic model of relevance of objects is used with three types of objects relevant for navigation: signage, train schedule information, and other objects belonging to the train infrastructure (i.e. ticket machine). Related to the task the estimated attention for each object is calculated, based on attention defined in the model. The output of the three modules is combined by using a weighted geometric mean. This allows to simulate different user characteristic by applying a weight factor to the output of each model. Weighting factors were set as wSa=wSe=wFr=1.

The integrated task based attention is calculated as

$$\sqrt[wSa+wSe+wFr]{Sal^{wSa} + Sem^{wSe} + Fru^{wFr}}.$$

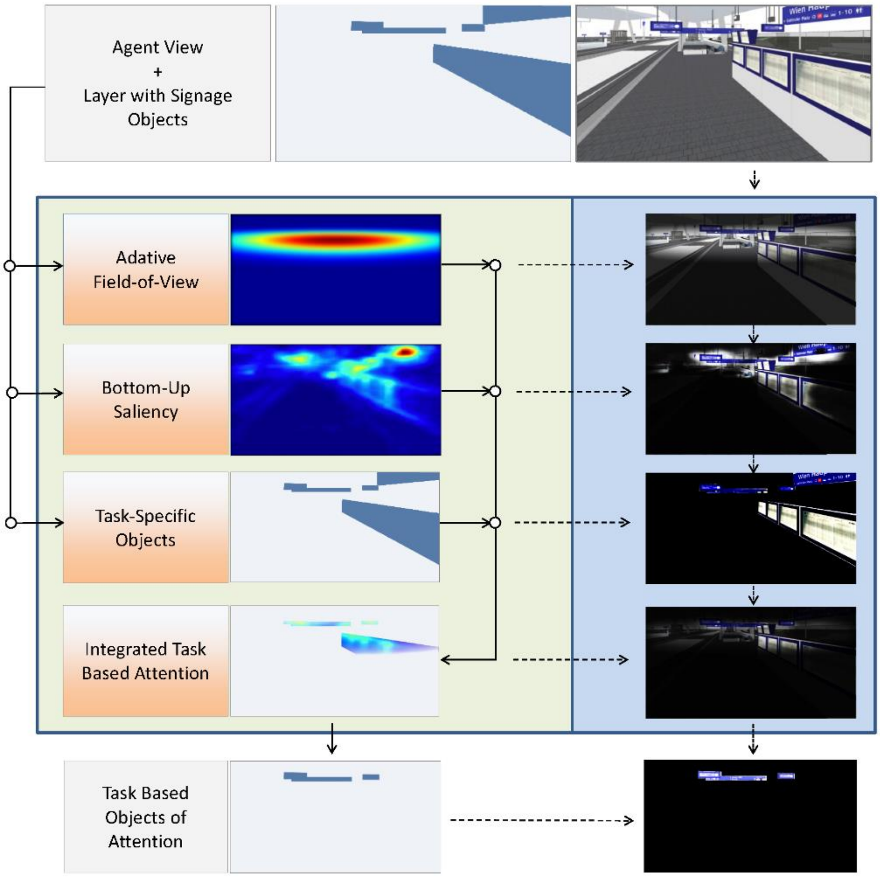


Figure 2. Task based visual attention model

Using the integrated task based attention, the most relevant objects are identified by calculating the attention for each object in the image separately. Therefore, the sum of attention of each point within an object is calculated and the objects are sorted by overall attention. The task based attention objects are provided as a sorted list to the agent navigation behaviour model.

3.4 Modelling Navigation Behaviour

The agent's behaviour is modelled based on the probability that each sign in the current field of view is seen and recognized, as calculated from the visual attention model. To enhance generality and diversity of the developed wayfinding simulation, stochastic features of perception are incorporated to reflect a variety of behaviours. Therefore, a fundamental aspect of the behaviour model is a *threshold(sign, agent)* function which defines the required attention threshold which must be exceeded in order to recognise the given sign. The value of this function is assigned randomly between 0 and 1 at the start of each simulation run for each agent/sign combination and remains constant during the simulation. For example, the same sign could have a threshold value of 0.3 for one agent and 0.8 for another. Signs with a good contrast in the centre of the agent's field of view have an attention close to 1 and the stochastic influence of this threshold can be neglected, whereas signs with a medium attention will only be seen by some agents.

When searching for a given target, the attention model calculates the attention for each sign in the field of view in regular intervals. If *attention(sign, agent)* ≥ *threshold(sign, agent),* the sign is added to the temporary set *S* of seen signs. The content of all seen signs is then matched with the given task and is classified into one of three categories: (1) The sign is directly at (or very near) the given target and it can be assumed that the agent knows the location of the target if he sees the sign. (2) The sign shows a clue in which direction to continue searching for the target (usually a direction arrow). (3) No suitable information can be found on the sign.

The signs are then sorted in terms of priority. Signs in category 1 are always preferred to signs in category 2, which in turn are preferred over signs in category 3. If there are multiple signs visible in the same category, the ones with a higher calculated attention are preferred. The final behavioural action is then inferred from the category of the sign with the highest priority. In case of (1), the agent is directly sent to the target and in case of (2), the agent is sent in the direction which is given by the sign. If only signs of category 3 or no signs at all could be seen, the agent continues searching for further information. This is currently done by sending the agent to certain base points which are manually placed in the infrastructure (green lines in *Figure 3)*. An overview of the general algorithm is given in the following *Table 2*.

Table 2. Decision algorithm of the behaviour model

```
bestSign = Ø                          # No sign selected as the best initially
S = get_signs_in_field_of_view(agent) # Get a set of signs which are in the field of view
for s ϵ S:                            # Each sign in field of view
   if attention(s, agent) < threshold(s, agent):
      continue                        # Sign does not grab attention

   if bestSign == Ø or s.category > bestSign.category or
         (s.category == bestSign.category and attention(s, agent) > attention(bestSign, agent)):
      bestSign = s                    # Select the sign, if it has higher category than the current,
                                      # or as a fallback a higher attention
if bestSign != Ø:
   goto_position(bestSign.goal)       # Go to the given goal (or direction) from selected sign
else:
   explore_area()
```

3.5 Modelling Movement

The agent proceeds to the next point of interest obtained from the behaviour model. Points of interest can either be the target itself when it was found, or e.g. a point at the end of a hallway if a direction arrow on a sign points along that hallway. If no target (or clue to the target) was found, points of interest are scattered around the infrastructure and selected sequentially to explore the area. In all cases, the goal is a specific position in the infrastructure which the agent needs to reach with a movement model to navigate among neighbouring agents and obstacles through the VR environment.

Pedestrian motion is handled on two different levels. First, a path to the next point of interest is found by building a regular grid of the infrastructure and searching for the quickest path using the Theta* algorithm (Daniel, Nash, et al., 2010) which yields obstacle free waypoints to get to the goal. Second, the movement to each waypoint is modelled by a simple social force model after (Helbing and Molnar, 1995) where opposing forces from other pedestrians and walls are combined with an attractive force that steers the agent towards the next waypoint.

4. EXPERIMENTS AND RESULTS

To evaluate the simulation results empirical data were collected from 20 participants by means of an immersive virtual reality environment using a life-sized 3D replica of Vienna’s new central railway station. The main hall of the railway station is approximately 150 m x 350 m wide und comprises of three levels, 22 escalators and six elevators. The signage consisted of about 290 signs and details of placements and graphics of the sign were provided by the architect. We defined typical use cases to test our cognitive agent-based simulation for the evaluation of indoor wayfinding systems.

4.1 Scenario Description

The scenario covered a wide area of the train station and took 15 to 20 minutes for each participant to find and walk along the way-points. The participants were put in a travel situation and instructed as follows (see *Figure 3*): *“You are at the central railway station in Vienna (Start 1) and want to visit the historic Belvedere Palace before traveling back home. To get there, first you have to buy a ticket at the ticket counter (waypoint 1 in Figure 3), then leave the luggage at the luggage lockers (waypoint 2). Afterwards go to the* *restroom (waypoint 3) and finally proceed to the stopping place of tram line D (waypoint 4).”*

To reduce the risk of cyber sickness the entire scenario was split into two parts. Each part was designed such that its completion was possible within 10 minutes under normal conditions. The first part starts at Start 1 and ends at waypoint 2 as shown in *Figure 3* by the red line, the second part starts at waypoint Start 2 and ends at waypoint 4 indicated by the orange line. An alternative route to the waypoint 4 using the escalators is also possible and can be seen in *Figure 3* by the orange dashed line. The green lines in *Figure 3* show intermediate goals where the agent is routed by direction arrows on the signs. If no sign could be seen the agent navigates from area to area to explore the infrastructure searching for signs or the target.

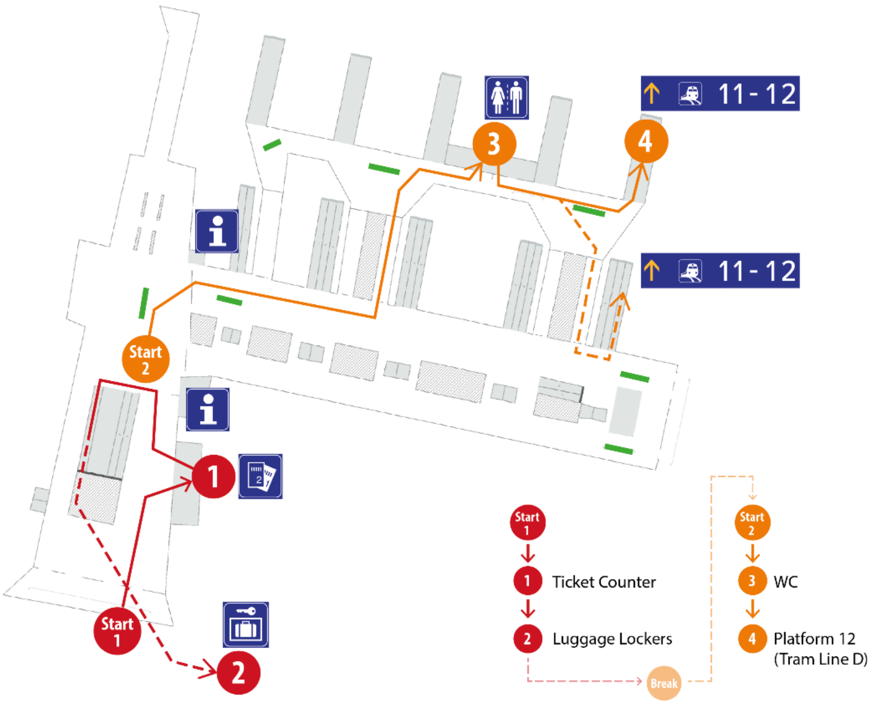


Figure 3. Waypoints and optimal route of the scenario for VR experiment and simulation

4.2 Virtual Reality Experiments

For the evaluation of our cognitive agent-based simulation, motion and visual attention data were collected in a controlled experiment using an immersive virtual reality environment in combination with a mobile eye tracking system for visual attention analysis (Schrom-Feiertag, Schinko, et al., 2014). After a short training session in the VR environment the participants were put in a travel situation and instructed with the scenario details. The experiment took place during the railway station's construction phase one year before its opening, therefore, no participant was familiar with the train station. For an enhanced immersion, virtual passers-by are simulated and an ambient soundscape was provided.

The validity of our VR environment for wayfinding research has been explored in (Bauer, Schneckenburger, et al., 2013) by conducting a case study with parallel test groups, exposing individuals to wayfinding exercises in the real world and the corresponding virtual world. The validation results showed that the perceived durations, egocentric distances and directions do not differ statistically significantly between the real and the virtual world.

From the experiments in the VR environment, we obtained accurate measurements on position, body orientation, viewing frustum and gaze of 20 participants (11 males and 9 females). These collected trajectories were used to evaluate the individuals' wayfinding behaviour and served for the validation of the simulation.

4.3 Simulation Results

Figure 4 and *Figure 5* show the correlation between the obtained trajectories from the VR experiments (a) and the routes generated by the cognitive agent simulation (b). *Figure 4* shows the results of the first part of our experimental scenario, which includes the tasks of buying a ticket and finding the luggage lockers. While the ticket counter could be found in the experiment and in the simulation, finding the luggage lockers revealed much longer paths in the simulation where the entire hall was searched and some agents were not able to finish the task. The reason is, that the lockers are in a different storey of the building and only a small, inconspicuous sign points towards the stairs leading to the storey with the lockers. In the experiment, people quickly asked for help at the information counter which was not implemented in the simulation.

(a) (b)

Figure 4. Trajectories of first part from VR experiment (a) and simulation (b).

Figure 5 depicts the results of the second part of the scenario which includes the tasks of finding the WC and then the station of tram line D. The paths towards the WC, waypoint 3 in *Figure 3*, show a high correlation between the experiments and the simulation and the signage system was sufficient in both cases. Finding the tram line D deemed much more problematic as it requires either leaving the building and walking outside or walking along the whole platform 12 to find the tramway station outside the building. Given this task, the simulation stopped as it could not find the clues leading towards the station but also the test persons in the VR environment could not find the tram line without asking explicitly for it. As a fall back, we sent the simulated agent towards platform 12 at waypoint 4 which again could be easily found using the signage. Similar to the experiment, some agents used the stairs while some used the escalator to get to the floor with the platform.

(a) (b)

Figure 5. Trajectories of second part from VR experiment (a) and simulation (b).

The similarities in wayfinding between the experiment and the simulation seem promising, while the usage of info points and asking others for help needs further research. It might be, that this option was overused in the experiments as the test persons were given explicit instructions that they could ask for help in the VR experiments, which could be seen as an encouragement.

Furthermore, no other people queued at the info points which might be different in reality and decreases the probability for asking there for help.

5. CONCLUSIONS AND FUTURE RESEARCH

In this work, we proposed a novel modelling approach combining models for visual attention, human navigation and motion behaviour to build a cognitive software agent for the evaluation of indoor wayfinding systems. The agent-based pedestrian simulation has been applied to simulate realistic wayfinding behaviour given the infrastructure of the central railway station in Vienna. Empirical data collected from experiments using a VR environment were used for behavioural modelling and to validate simulation results of the same wayfinding scenario. The similarities of the trajectories between the experiment and the simulation seem promising and confirm the validity of the model. The experiments showed that the VR environment offers an innovative way to perform an evaluation of signage systems already at the planning stage. Especially in combination with eye-tracking it is also possible to obtain more fundamental knowledge about the wayfinding behaviour which in turn can be used to improve the models for attention and wayfinding behaviour.

At the present state of development, the simulation is ready for use, but the models are still based on simplifications. More fundamental questions can only be answered using a VR environment but the simulation can be seen as a useful complement to VR experiments. Since the implementation of such experiments is very time-consuming, the simulation offers an optimal solution to test a variety of scenarios which would not be possible experimentally with comparable effort.

The conducted experiments revealed alternative wayfinding strategies, like asking for the way if people are not sufficiently supported by the signage system. The next step will be the investigation and incorporation of such strategies in the navigation behavioural model.

Future research will also involve deeper analysis of eye tracking data to review the developed attention model on empirical data. In particular the dependency of the viewing frustum regarding the motion velocity needs to be investigated. Furthermore the viewing frustum of the agent is currently rendered straight ahead in the direction of movement. For a realistic perception of the surrounding environment additionally eye and head movements need to be considered.

6. ACKNOWLEDGEMENTS

This work was part of the project MOVING and was funded by the research program line ways2go within the framework of the Austrian strategic initiative IV2Splus Intelligent Transport Systems and Services plus under the project number 835733.

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Morphological Change of Urban Spatial Structures Overviewed through Analysis on Tower Construction Trend in Tokyo

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Key words: Urban Development System, Urban Planning, Population Change, Skyscrapers

Abstract: In Japan, more than 50% of skyscrapers were built in three wards and these streams of tower construction were formed by socially established urban development systems. This study aims to identify the tendencies of the morphological changes through analysis of the tower construction conditions in three Tokyo wards. There have been four phases in the transition of the skyscrapers' distribution and applied urban development systems. The characteristics of the tower construction have clearly changed from a symbolic position of having one skyscraper to a symbolic area comprising a group of skyscrapers; three wards have used the different urban development systems according to their own regional characters, and this creates an effect on the building use and morphological changes of urban structures.

1. INTRODUCTION

1.1 Background

Skyscrapers, along with technological developments are one of the most important factors to form urban spatial structures globally. These trends began from North America and Western Europe, and moved to the growing cities in Asia. Japan is no exception. The urban paradigm has changed from the age of symbolic super high-rise buildings to the age of clustering super high-rise buildings that now form the urban spatial structure.

According to Building Statistical Yearbook of the Tokyo Metropolitan area in 2013, 1063 buildings taller than 60m were constructed in 23 wards. Moreover, 49.4%, or 525 buildings in all were concentrated in three wards (Chiyoda, Chuo, Minato). Additionally, 57.3%, or 301 buildings of the three wards were completed after the 2000s, which means that the urban structure and form were transformed.

The characteristics of urban development in the 2000s especially, were the clustering of skyscrapers based on the relationship between property owners and developers, which meant not an individual building development but several building developments that made up one urban form. It can be seen that these streams of tower construction were formed by urban development systems which are socially established, and it can be also noted that urban structures and characteristics, such as population change, are changed by these developments.

1.2 Objectives

This study aims to reveal the tendencies of the morphological changes through the analysis of actual tower construction conditions with the transition of the urban development system; it focuses on three wards (Chiyoda, Chuo, Minato) and clarifies the characteristics and effects on urban structures in each. The specific study objectives are described as follows.

1) To identify the transition of the tower construction (i.e., buildings taller than 60m) in relation to urban development systems and social issues since the 1960s.
2) To clarify the characteristics of the skyscrapers' distribution by overlapping the urban development system based on each ward.
3) To verify the relationship between the population change and tower construction through the analysis on the rate of population change over 10 years and the building use of the skyscrapers.

1.3 Methodology

This study reviewed the transition of urban development systems and planning after the 1960s through historical raw data surveys. We subsequently conducted the follow two activities in order to achieve the aims of the study.

First, we listed data of the 525 skyscrapers from three wards using the data of the Tokyo Metropolitan area, and extracted the coordinate system of each skyscraper via an address matching program. By conducting the address matching with an aerial photograph and Google Map, we extracted 462 buildings as a subject of study through excluding 63 buildings not completed until 2013 for example, and not found on the map.

Based on the 462 buildings, we identified the relationship between the skyscrapers and applied urban development systems by drawing the distribution map. Further, we verified the inter-relationships between the skyscrapers and population change via the change rate of workers from 1996 to 2006 based on the Business Place and Enterprise statistics survey data, and the change rate of the night population of a village unit from 2000 to 2010 based on accessible census data.

2. CHARACTERISTICS OF A TOWER CONSTRUCTION BASED ON URBAN DEVELOPMENT SYSTEMS

2.1 Trend of skyscrapers with urban development systems

The transition of skyscrapers in three wards can be characterized during four distinct periods in a comparative analysis between the yearly number of skyscrapers completed and the transition of urban development systems related to building a skyscraper (Table 1).

2.1.1 Phase I: The start of Tower Development (1961–1977)

Japan has experienced population growth since the 1950s. The concept of the Densely Inhabited District (DID) was introduced by a national census for the first time in 1960. New markets for tower construction were born for coping effectively with land use given an increasing population, and these were available after the official announcement of Technology Guidelines for High-rise Building Structures in 1964.

At first, as the urban development systems were related to the high-rise buildings, the Specific Block System (SBS) was established in 1961, and was based on city planning law. Since then, the High-intensity Use District System (HUDS) was established in 1969 with the enactment of urban redevelopment law, and the Total Design System (TDS) was established in 1970 based on building standards law. The government of Metropolitan

Tokyo especially, appropriated the permission outline of TDS in 1976, which relaxed the permission requirements for building a high-rise building. Thus, the urban development systems, which are necessary for the construction of high-rise buildings, were organized in this period against the background of post-war urban growth.

2.1.2 Phase II: Deregulation of large-scale development (1978–1986)

The minimum limit of the site area in TDS was relaxed by the amendment of the enforcement ordinance of building standards law in 1982. An urban residential area based on TDS used the relaxation of the housing volume enforcement in 1983 to promote increased residency in a downtown coping with the problem of the "doughnut" phenomenon. In addition, Redevelopment Policy Fitter Type-TDS in 1986 was enforced in order to induce a high volume of redevelopment by combining with the District Unit Plan System established in 1980. Thus, the urban development projects using various types of TDS were increased rapidly in this period.

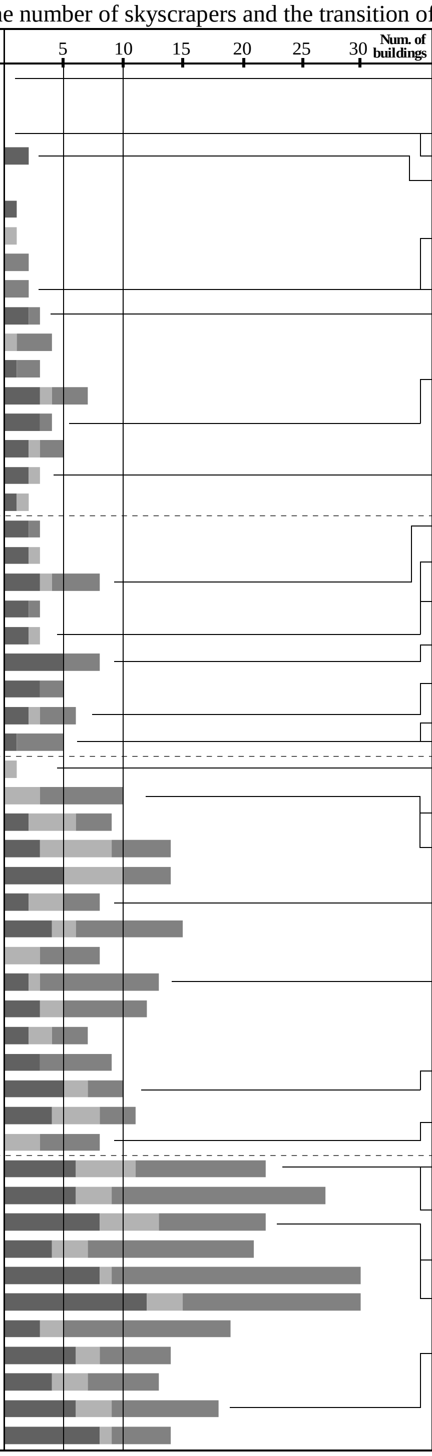
2.1.3 Phase III: Appearance of a system for clustering towers (1987–2001)

The Private Sector Resources Utilization Law in 1986 and the Act on Special Measures Concerning the Promotion of Urban Development in 1987 were established with the privatization policy of the Nakasone cabinet. In particular, the demands for development around the railway garage areas and brownfields were since the privatization of the Japan National Railway.

Against this background, an amendment of the city planning law established the Redevelopment District Planning System (RDPS) in 1988. This system aims at an integrated development of buildings with an infrastructure improvement targeted at unused or low-use land, which is different from SBS and TDS that focused on an individual site (Table 2). Thus, this system plays a role in clustering high-rise buildings such as the Roppongi hills (2003), Shiodome (2005), and Midtown (2007), after the 2000s.

The Urban Housing Mixed-TDS in 1991 and Urban Residential Type-TDS were established as measures to mitigate the problem of the doughnut phenomenon in the downtown area. In particular, the Obligation Outlines of Tower Construction Affiliated with Housing in the case of a certain size of building were appropriated by three wards (Chiyoda (1992), Chuo (1985), and Minato (1991)). These developments increased mixed-use skyscrapers in this period.

Table 1. The number of skyscrapers and the transition of urban development systems



Phase	Year	Transition of Urban Development Systems
Phase I(1961–1977) : The start of Tower Development	1961	• Establishment of Specific Block System(SBS) based on Fomer City Planning Law(1919)
	1962	
	1963	• Establishment of Volume District System • Abolition of Absolute Height Regulation
	1964	• Official Announcement of Technology Guidelines for High-rise Building Structures
	1965	
	1966	
	1967	
	1968	
	1969	• Anactment of Urban Redevelopment Law ↓ • Establishment of High-intensity Use District System
	1970	• Establishment of Total Design System(TDS) based on Building Standards Law(1950)
	1971	
	1972	
	1973	
	1974	• Establishment of Special Law on the promotion of supply of residential areas in metropolitan areas
	1975	
	1976	• Appropriation of the permission outline of TDS (Tokyo)
	1977	
Phase II(1978–1986) : Deregulation of large-scale development	1978	
	1979	
	1980	• Establishment of District Unit Plan System areas • Amendment of the enforcement ordinance of Building Standards Law
	1981	
	1982	↓ • Relaxation of the minimum limit of the site area in TDS
	1983	• Urban residential area based on TDS : Relaxation of the housing volume enforcement
	1984	
	1985	• Obligation Outline of Tower Construction Affiliated with Housing(Chuo ward)
	1986	• Redevelopment Policy Fitter Type-TDS • Private Sector Resources Utilization Law
Phase III(1987–2001) : Appearance of a system for clustering towers	1987	• Act on Special Measures Concerning the Promotion of Urban Development
	1988	• Amendment of City Planning Law ↓ • Establishment of Redevelopment District Planning System
	1989	
	1990	
	1991	
	1992	• Obligation Outline of tower construction affiliated with housing(Minato(1991), Chiyoda(1992))
	1993	
	1994	
	1995	• Establishment of Streetscape Induction District Plan System
	1996	
	1997	
	1998	
	1999	• Establishment of Important Cultural Property Special Type-SBS
	2000	
	2001	• Foundaation of Urban Regeneration Headquarters
Phase IV(2002–Present) : Grouping Type of Skyscrapers	2002	• Amendment of Urban Regeneration Special Equipment Law ↓ • Establishment of Urban Regeneration Special Zone System
	2003	
	2004	• Chiyoda ward:Specified Floor Area Ratio(1,300%) • Exceptional Floor Area Ratio applied by District System(Daimaruyu area in Chiyoda)
	2005	
	2006	
	2007	
	2008	
	2009	
	2010	
	2011	• Establishing the System of Company for promoting Urban Regeneration
	2012	

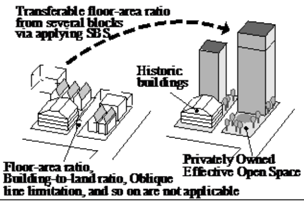
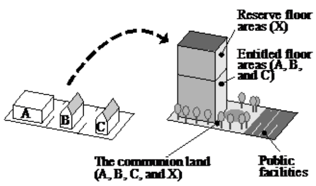
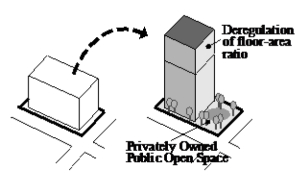
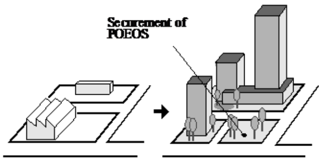
Legend
Chiyoda Chuo Minato

2.1.4 Phase IV: Grouping Type of Skyscrapers (2002–present)

The Urban Regeneration Headquarters was founded in 2001 and the Urban Regeneration Special Zone System (URSZ) based on urban regeneration special equipment law was established in 2002. This system has relaxed the regulation of a building's floor area ratio and the building-to-land ratio if the urban development improves surrounding land; this "public contribution" that includes underground or road and park spaces is enforced by local government in a conventional manner. Actually, this system has mainly been applied around the Tokyo metropolitan area while Chiyoda ward has only the specified floor area ratio (1,300%) and exceptional floor area ratio applied by the District System (2004) in the Daimaruyu area.

As mentioned above, the urban development plan among land owners has been discussed since the late 1980s, but many projects could not be realized because of the bubble economy collapse in the 1990s. In the 2000s, the land owners pursued a synergistic strategy to change the method of development from an individual development of building to a clustering type of development based on area. Thus, many types of grouping skyscrapers have been realized through the combination of various urban development systems.

Table 2. The characteristics of urban development systems

<table>
<tr><th>Specific Block System(1961)</th><th>High-intensity Use District System(1969)</th><th>Urban Redevelopment Project(1969)</th></tr>
<tr><td>
</td><td>
</td><td>- One of processing method in applying High-Intensity Use District System
- Construction business expenses are desided by the subsides, and the selling of reserve floor areas
- There are two type:
1)Rights Exchange Scheme
2)Land acquisition Scheme</td></tr>
<tr><td>- To create builings that based on a better environment and form
- To secure the Privately Owned Effective Open Space (POEOS[1])
- To relax the floor-area ratio in responding to the areas of EOS</td><td>- To promote an intensive use of land such as integrating the A, B, and C sites for the improvement of public facilities
- To secure the POEOS
- To relax the floor-area ratio in responding to the building coverage ratio</td><td>Urban Regeneration Special Zone System(2002)</td></tr>
<tr><th>Total Design System(1970)</th><th>Redevelopment District Planning System(1988)</th><td rowspan="2">- Relaxing the floor area ratio, and the building-to-land ratio was calculated based on the POPOS total area only; however, via the URSZS, improving the surrounding lands such as underground, road, and park spaces, so called "public contribution" became including in the calculation method.</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>- To improve an area' s environment via a site plan
- To secure the Privately Owned Public Open Space (POPOS[2]) in a site
- To relax the floor-area ratio in responding to the areas of POS</td><td>- To aim at an integrated development of buildings with an infrastructure improvement targeted at unused or low-use land
- To play a role in clustering high-rise buildings such as Roppongi Hills(2003)</td><td>(additional notes)
[1]POEOS(Privtely Owned Effective Open Space):
- It is an Open space that available to walk and use for Citizen all the time
- To use for SBS and RDPS
[2]POPOS(Privtely Owned Public Open Space):
- Similar difinition as mentioned -above EOS
- To use for TDS</td></tr>
</table>

2.2 The development process of skyscrapers

It has been determined that the process of tower construction can be divided into four distinct periods through a comparative analysis between the number of skyscrapers and the transition of urban development systems (Table. 1).

First of all, the tower constructions may have been built during the establishment of the systems (Phase I), whereas the deregulation was implemented to cope with the development pressure under an economic boom (Phase II). However, construction experienced a stagnant period because of the bubble economy collapse, even though a new urban planning system, which was not intended for individual sites but for integrated development based on the urban scale, was established (Phase III). In the 2000s, depending on the new policy for urban regeneration, the grouping of skyscrapers was increased according to the plans of land owners and developers (Phase IV).

According to the changes in numbers of skyscrapers, 39 buildings were built in Phase I, 45 in Phase II, 148 in Phase III, 230 in Phase IV. It is clear that 49.8% of skyscrapers were built after 2002 and the variation in tower constructions indicates the intimate relations between socioeconomic conditions and establishment of urban development systems.

3. DISTRIBUTION CHARACTERISTICS OF SKYSCRAPERS ACCORDING TO THE URBAN DEVELOPMENT SYSTEM APPLIED

3.1 Characteristics of three wards

This study targets three wards (Chiyoda, Chuo, Minato), which represent 49.4% of all skyscrapers in the Tokyo metropolitan area; the characteristics of the skyscrapers' distribution and the urban development system for their construction are as follows (Table 3).

3.1.1 Chiyoda ward

Chiyoda ward has 145 buildings (Phase I: 17, Phase II: 22, Phase III: 35, and Phase IV: 71). The most applied system is TDS, which applies to 28.3% (41 buildings), followed by SBS which applies 13.1% (19 buildings). Unlike other wards, Chiyoda ward has a comparatively high number of skyscrapers 37.9% (55 buildings) to which no systems were applied, and it is clear that the designation of the specified floor area ratio of 1,300% in Chiyoda ward has a big effect on this trend.

Based on the distribution of skyscrapers, it has been clarified that Daimaruyu area around Tokyo station has a high land use rate where blocks have utilized the systems since Phase I. In addition, the clustering of tower construction has developed in area such as those around Akihabara, Iidabashi, and Ochanomizu stations (Figure 1).

3.1.2 Chuo ward

Chuo ward has 82 buildings (Phase I: 6, Phase II: 5, Phase III: 40, and Phase Ⅳ:31). The most applied system is TDS which applies to 47.6% (39 buildings), followed by HUDS at 23.2% (19 buildings). In particular, among the 48.7% of skyscrapers completed in phase III (1987-2001), 57.5% (23 buildings) were built using TDS.

Based on the distribution of skyscrapers, it was determined that there are many the waterfront developments along Sumida river to which use TDS was applied in Phase III. The discussion for developing this area with TDS was started before the establishment of the RDPS (1987). Thus, the public space network between the blocks in the ground level was difficult, even though the clustering development occurred. In addition, URSZ designated five blocks along Ginzachuo-dori famous for as the Ginza main street. However, it was determined the height of buildings was limited to 56m by the rule of local associations in Kyobashi and the Ginza area, except for those over 100m in the Nihonbashi area located in the northern part of Ginzachuo-dori (Figure 2).

Table 3. The number and percentage of skyscrapers based on urban development systems

Urban Development systems	Chiyoda ward						Chuo ward						Minato ward					
	PI	PII	PIII	PIV	Total	Percent (%)	PI	PII	PIII	PIV	Total	Percent (%)	PI	PII	PIII	PIV	Total	Percent (%)
Number of Buildings	17	22	35	71	145		6	5	40	31	82		16	18	73	128	235	
Specific Block System	3	4	3	9	19	13.1	2	0	2	3	7	8.5	4	2	3	1	10	4.3
High-intensity Use District System*	0	0	1	7	8	5.5	0	0	8	11	19	23.2	1	3	0	13	17	7.2
Urban Redevelopment Project*	0	0	1	11	12	8.3	0	0	6	7	13	15.9	1	3	0	16	20	8.5
Total Design System	0	5	13	23	41	28.3	1	3	23	12	39	47.6	2	10	29	43	84	35.7
Redevelopment District Planning System*	0	0	0	4	4	2.8	0	0	7	6	13	15.9	0	0	6	38	44	18.7
Urban Regeneration Special Zone System	0	0	0	4	4	2.8	0	0	0	3	3	3.7	0	0	0	0	0	0
no systems applied					55	37.9					4	4.9					62	26.4

(note) PI : Phase I, PII : Phase II, PIII : Phase III, PIV : Phase IV

*: Means that the block is duplicated by other urban development systems.

3.1.3 Minato ward

Minata ward has 235 buildings (Phase I: 16, Phase II: 18, Phase III: 73, and Phase IV: 128). The most applied system is also TDS which applies to 35.7% (84 buildings) followed by, 62 buildings (26.4%) that had no systems applied; which these are concentrated in the Odaiba area, as seventh subcenter of Tokyo during the 1990s. The skyscrapers that had TDS and RDPS applied after Phase IV included 34.5% (81 buildings) of all skyscrapers and there are many skyscrapers relatively recently completed in this ward.

Based on the distribution of skyscrapers, it is clear that the large-scale grouping of skyscrapers, such as Shiodome Siosite, Shinagawa Intercity, Midtown and Roppongi hills famous as tourist spots were realized by using RDPS.

3.2 Comprehensive trends among three wards

As the common characteristic among three wards, the most applied urban development system is TDS, which accounts for 35.5% (164) of all buildings. On the other hand, it is apparent that the applied urban development system is different in the three wards. SBS is applied the most by Chiyoda ward, to 13.1% of the total, blocks along Naka-dori street in Daimaruyu area around Tokyo station. They have used SBS with the exceptional floor area ratio applied by the District System, which could extend the floor area ratio to another block in order to preserve historical buildings and manage the skyline according to local rules.

RDPS is applied the most by Minato ward to 18.7% of the total. In the case of Minato ward, the road has not been improved and its network is not a grid pattern, unlike Chiyoda and Chuo wards. Thus, there is a strong tendency to apply RDPS in Minato ward in order to repair the existing roads and public spaces; this has increased the number of skyscraper groups more than in other wards.

HUDS is applied the most to 23.2% of all skyscrapers by Chuo ward. It is apparent that Ginza, Kyobashi, and Nihonbashi areas in Chuo ward have used HUDS extensively to achieve effective utilization of land coping with the regional characteristics of an elongated site.

URSZ, established in 2002 is applied to only 1.5% or 7 buildings completed prior to 2012, although this is predicted to increase.

4. POPULATION CHANGE AND SKYSCRAPERS

4.1 Characteristics according to an overview of population change

We visualized the maps of three wards by using the location of skyscrapers with applied urban development systems and overlapping the change rate of both a night population based on a unit of area from 2000 to 2010, and workers from 1996 to 2006. The available data is shown in Figure 1, 2, and 3. Further characteristics of the three wards are described in the following sections.

4.1.1 Chiyoda ward

Many areas experiencing a change rate of the night population under minus 50% are distributed in Chiyoda ward, such as the areas around Tokyo station and Nagatacho station. On the other hand, there are many areas with a change rate of over 100% in the case of workers, such as Daimaruyu, Ochanomizu, Iidabashi, Akihabara, and so on. Thus, it is clear that the largest percentage of skyscrapers is specialized for business use in this ward. Inversely, there are few skyscrapers based on a residential function, which is caused by utilizing SBS much more than other wards.

When it comes to building use, the hotel mixed-office buildings have declined since Phase I. However, the university or hospital, commercial mixed-office buildings have increased since phase IV. For example, Daimaruyu area is designed not by individual site-based-skyscrapers but linkage between the sites to connect the lower parts of skyscrapers as a street such as Naka-dori, by introducing commercial facilities.

4.1.2 Chuo ward

We determined that there are many areas with a change rate of the night population of over 100%, such as Ginza and Nihonbashi area in Chuo ward, and also that there are many areas along Sumida river of over a 25% change rate of the night population during 10 years in the 2000s; this is a small effect because the skyscrapers mainly increased in the 1990s. The reasons why Chuo ward has a high change rate in the night population are that they used to utilize the Urban Residential Area based-TDS in order to cope with the problem of the doughnut phenomenon, and they introduced the Obligation Outlines of Tower Construction Affiliated with Housing (1985) earlier than the other two wards. From the 2000s, there is the tendency of skyscrapers to increase not only for residential use but also for residential and commercial mixed use.

On the other hand, when it comes to the change rate of workers, there are many areas under minus 25%, which means that Chuo ward has few tower constructions based solely on business use.

4.1.3 Minato ward

In the case of Minato ward, the areas based on the clustering skyscrapers have a high change rate in the night population. In addition, it is also apparent that the change rate of workers is high at over 50%. As mentioned above in Chapter 3, this ward has utilized RDPS more than other two wards, which makes it easy to develop clustering skyscrapers. It was determined that more than one residential building was placed essentially in the group of skyscrapers, such as Shiodome Siosite, Shinagawa Intercity, Midtown, and Roppongi hills.

In Phase IV, the total floor area of skyscrapers increased rapidly, which had an effect on the change rate of the night population and workers. Furthermore, it is clear that not only business-use based buildings but also various-use mixed building such as hotels, cultural, and commercial facilities were constructed.

4.2 Differences in building use among the three wards

As a result of determining the effects and characteristics of building use based on the change rate of the night population and workers, it was clear that there are distinguishable differences among the three wards and this characteristic has a close relation to how they use the urban development system.

SBS is used mostly by Chiyoda ward for constructing business-based buildings. That is why the density of night population in most areas of Chiyoda ward is small at under 50 persons/ha whereas the average in Tokyo is 143 person/ha.

Chuo ward has the outstanding characteristic of introducing the residential-use building by utilizing Urban Residential Area-based TDS. Although, Chuo ward does not have a high density night population compared to the other 23 wards, there are many with areas over 200 persons/ha, the density of night population, because of the effect on the waterfront development along the Sumida river in the 1990s.

RDPS is usually applied by Minato ward as they have the outstanding characteristic of clustering the development of skyscrapers, which are

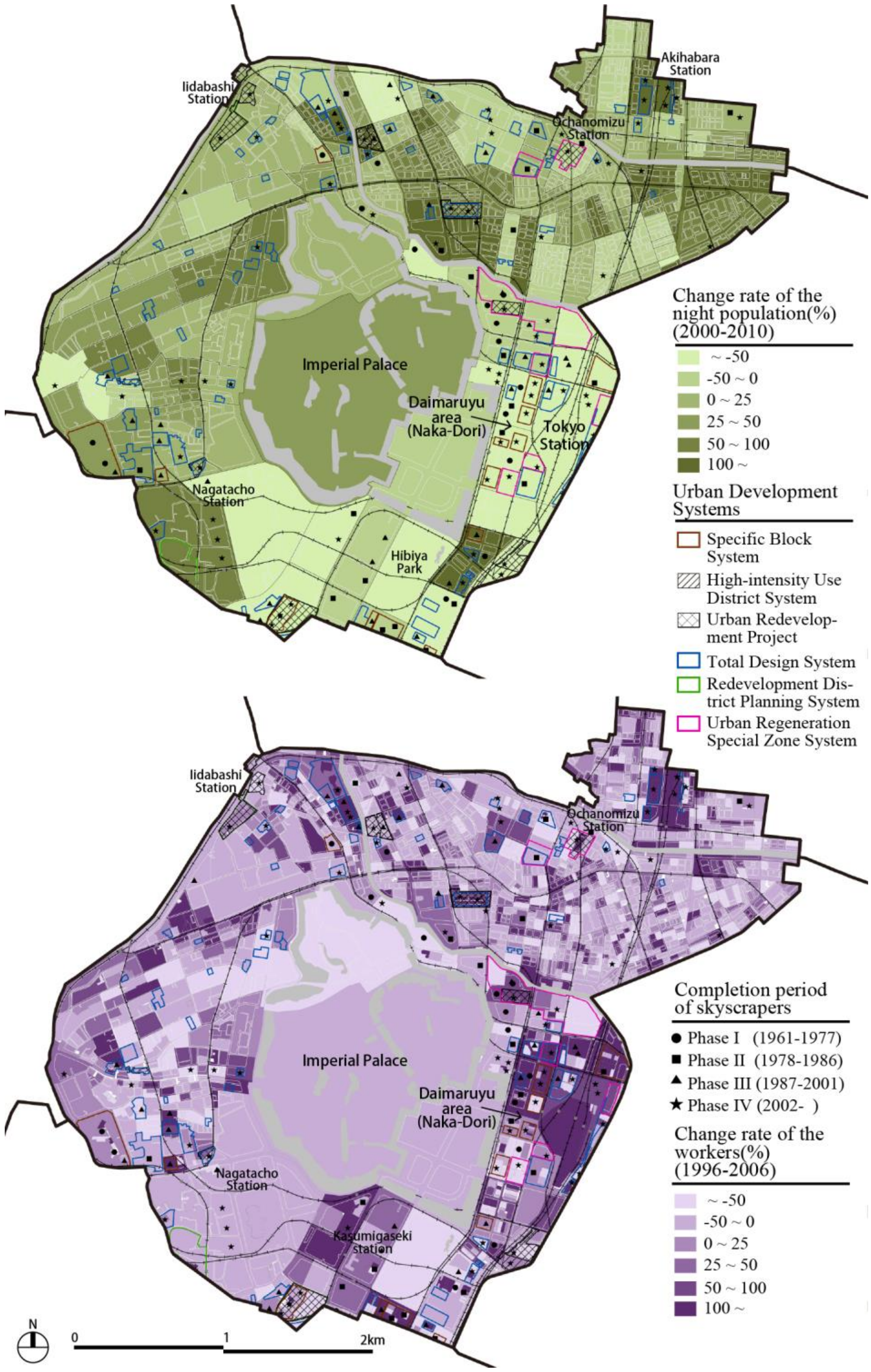


Figure 1. Population Change and Skyscrapers in Chiyoda ward

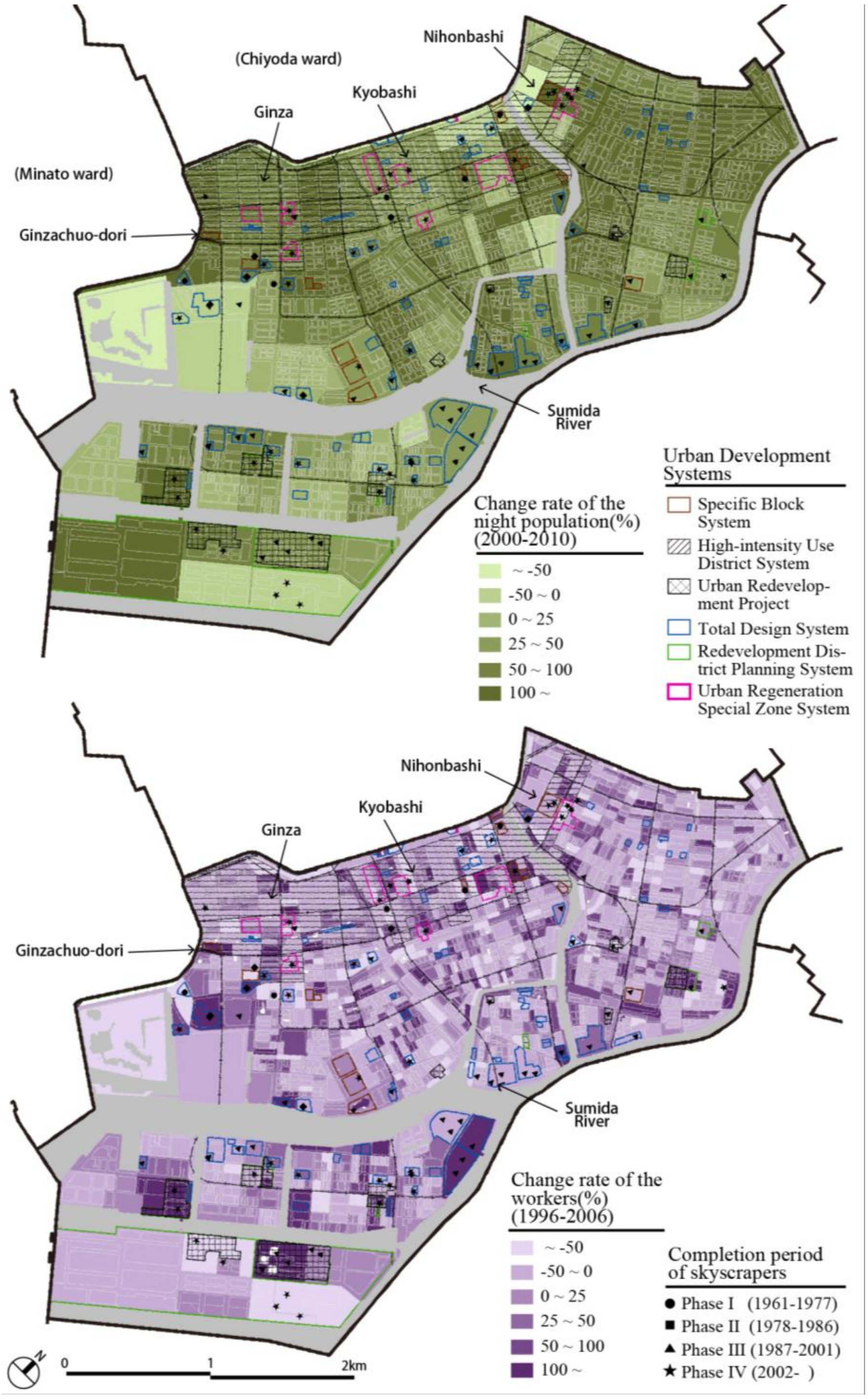


Figure 2. Population Change and Skyscrapers in Chuo ward

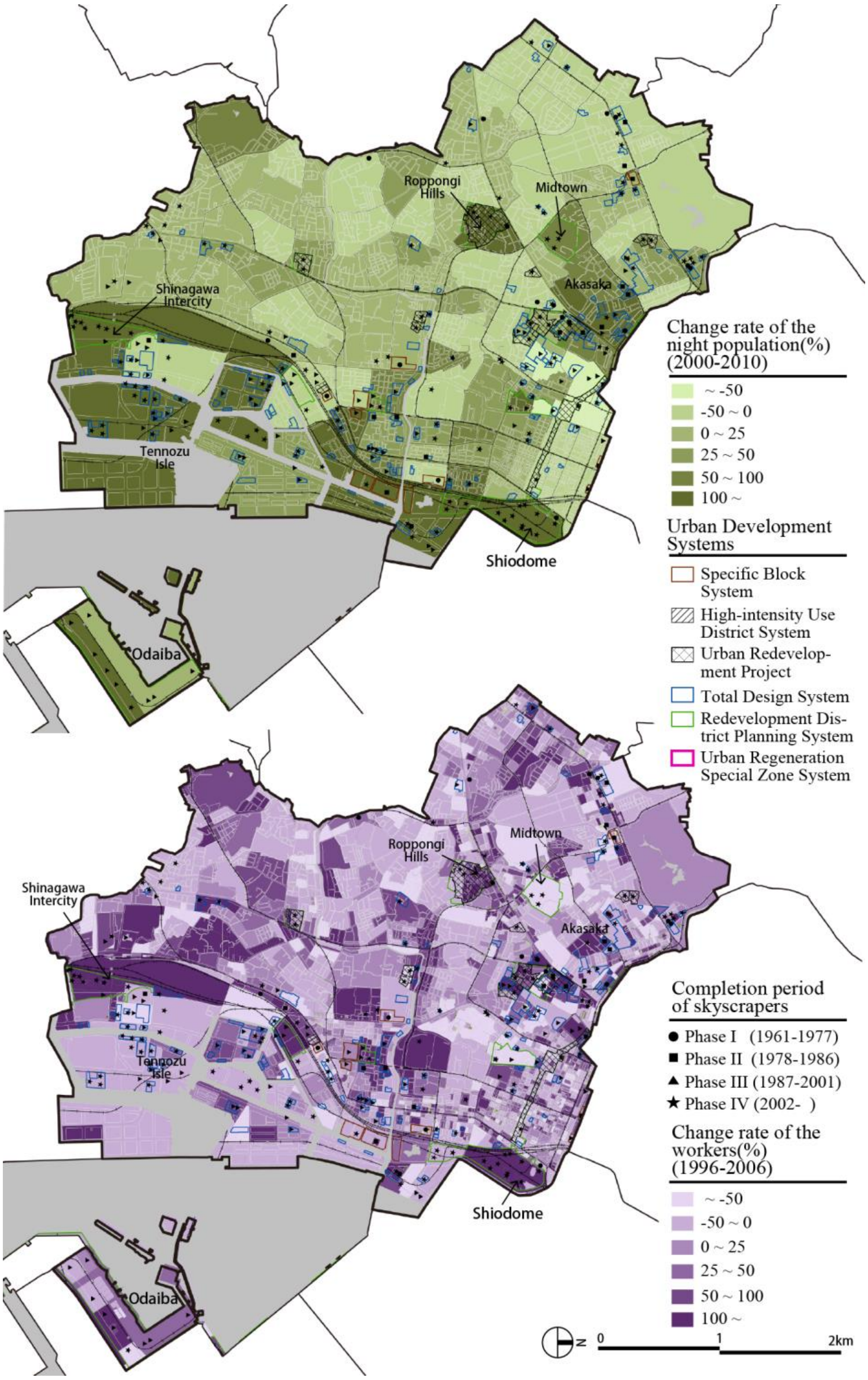


Figure 3. Population Change and Skyscrapers in Minato ward

categorized as ones involving not only business use but also residential use. It is apparent that the night population and workers in these groups of buildings have a tendency to increase what it called 'job-housing proximity' in the compact city.

5. CONCLUSION

This study reviewed the characteristics and trends of tower constructions by investigating all skyscrapers taller than 60m in order to clarify the morphological change of urban Spatial Structures in three wards.

There have been four phases in the transition of the skyscraper distribution and applied urban development systems: 1) the start of tower development (1961-1977), 2) deregulation for large-scale development (1978-1986), 3) appearance of a system for clustering towers (1987-2001), and 4) grouping type of skyscrapers (2002-present).

It has been ascertained that the characteristics of tower construction have from the symbolic position of having one skyscraper to having a symbolic area of skyscraper groups; this has progressed with the development of the urban development system, which also changed from a system applied to an individual site to a system for blocks or large-scale areas.

There are large portions of the business-use buildings based on SBS in Chiyoda ward, residential-use buildings based on TDS in Chuo ward, and mixed-use buildings based on RDPS in Minato ward. In other words, the three wards have used the different urban development system based on their own regional characters, which has an effect on the building use and the morphological changes of urban structure, such as the night population and workers. Minato ward is the most outstanding ward of clustering skyscrapers among three wards. This feature of the ward is closely related to regional characteristics. Minato ward has utilized RDPS for improving the infra structures with tower constructions.

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The effectiveness of the compact city plan of local government after abolishing the Area Division System

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Key words: Local city, Area Division System, Farmland conversion, Master plan, Concentration urban structure model,

Abstract: The Japanese population is decreasing, and declining birth rates and aging rates are increasing. From such problems, there is a need for construction of urban structures that adapt to changes in the demographics. Local Japanese cities are trying to form compact cities in harmony with the recent population changes. In this study, we compare sprawling urban structures with a concentration urban structure model, and aim to examine future planning issues.

1. INTRODUCTION

1.1 Background and purpose of this study

The Japanese population is decreasing. According to data (National Institute of Population and Social Security Research, 2012), the population of 2050 is calculated to the less than 100 million people (Table 1). Also, the estimate of the 2060 population is that those under 14-years will be less than 10%, while those over 65-years will be more than 40% (Table 2). The data shows that the declining birth rate and aging rate are increasing. From such problems, there is a need for construction of urban structures that adapt to changes in the demographics. Local Japanese cities are trying to form compact cities in harmony with the recent population changes.

In 1968, in Japan, Area Division System (ADS) of the city planning act was established to prevent unregulated urbanization. The ADS divides city planning areas into urbanization promotion areas which prevent unregulated urbanization, and urbanization control areas which promote planned urbanization. The system achieved good result when the population was growing. However, in local cities, applying the system has been one of the factors that interfere with the activation of the city when population declines.

In 2000, the city planning act was revised, the ADS became selectivity by the local government. By abolishing ADS, there are local governments who can control land use in accordance with the actual situation of each region.

In this study, we target Takamatsu city which abolished the ADS in 2004, as a case study. We examine changes in the urban structure before and after abolishing the ADS. Then, we build a future urban structure based on the master plan, and evaluate the compact city that the government intends to make. We compare the sprawling urban structure by abolishing ADS with the concentration urban structure model based on multiple master plans. From these comparisons, we aim to examine future planning issues.

Table 1. Future world and Japanese population (millions)

	2010 Population	2020 Population	2030 Population	2040 Population	2050 Population	2060 Population
World	6,916,183	7,716,749	8,424,937	9,038,687	9,550,944	9,957,398
Japan	128,057	124,100	116,618	107,276	97,076	86,737

Table 2. Age structure of 2010 and 2060 in Japan (millions)

	0–14	15–64	65–	Uncertain Age	Total
2010	16,803 (13%)	81,031 (63%)	29,246 (23%)	976 (1%)	128,057 (100%)
2060	7,912 (9%)	44,183 (51%)	34,640 (40%)	-	86,737 (100%)

1.2 Review of related studies

There are many studies about changes in urban structure caused by the ADS. For example, there are studies that have considered the need to operate the systems of the city for populations less than 100,000 (Ishimura, Ikaruga, et al., 2006), and have analysed the development trend of the non-area division city, and simulated the abolishing the ADS in other cities (Kobayashi, Ikaruga, et al., 2005).

Moreover, there are many studies about compact cities worldwide. For example, there are studies that have proposed the direction of urban regeneration (Jung Geun, Hyum-Chang, et al., 2014), have verified the carbon dioxide emissions (Gao, Ji, et al., 2013), and have verified compact cities according to public transport use (Boquet, 2014).

There are also many studies about compact cities in Japan. For example, there are studies that have verified the cost of the formation effects (Takahashi and Deguchi, 2007), have verified the carbon dioxide emissions (Uchida, Ujihara, et al., 2009; Kobayashi, Kobayashi, et al., 2010), and have verified the effects of consumer behaviour patterns (Yamane, Zhang, et al., 2007).

These studies examined sprawl in the suburbs of urban area caused by abolishing ADS, and the decreasing in CO_2 emissions and improving convenience when concentration urban structures are constructed. There is also the authors' study about support tools in the compact city (Tsuboi, Ikaruga, et al., 2015). In this study, we compare sprawl in the suburbs with a concentration urban structures, and point out the planning issues involved in the compact city.

1.3 Study methods

At first, we organize the transition of farmland conversion before and after abolishing the ADS. Then, we analyse the factors that affect farmland conversion before and after abolishing the system with quantification theory 1. In quantification theory 1, the object variable is the number of farmland conversions, and the explanatory variables are use district[1)], population, and distance from urban facilities. The analytic unit is a 250 sq m mesh data. Further, we calculate the predictive values of the number of farmland conversions with the category scores obtained from quantification theory 1, and, we consider sprawl by abolishing the system based on the predictive values of farmland conversion.

Next, we develop a “population concentration tool” for building of concentration urban structure with Expert System Theory based on the municipal government master plans made after abolishing ADS. The simulation unit is 100 sq m mesh data. Thus, we simulate urban structures that the government should aim for through using the tool to build a concentration urban structure model.

Finally, we compare sprawling urban structure to concentration urban structure model, and indicate the planning issues in the compact city.

2. SUMMARY OF THE TARGET AREA

Takamatsu city is a prefectural capital of Kagawa prefecture (Fig 1). The city abolished the ADS in May 2004. Figure 2 shows use of the district in the target area.

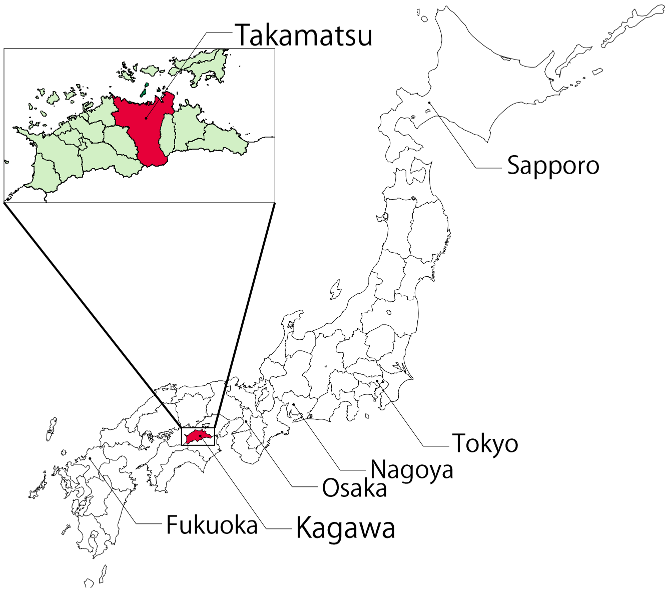

Figure 1. Study area on map

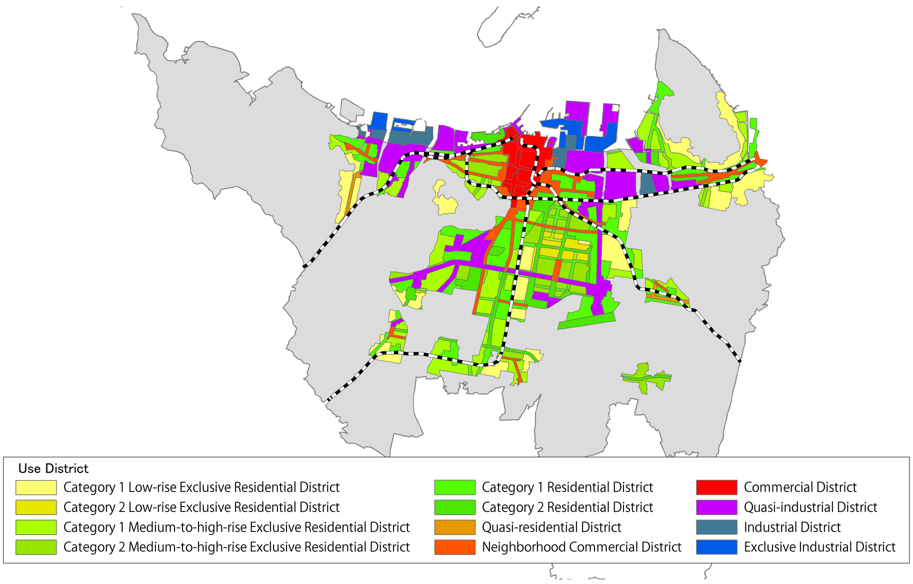

Figure 2. Use district

2.1 Population trend

Table 3 shows the population trend of the target area, and Figure 3 shows the 100 sq m mesh population distribution. The population under 65-years was decreasing, and over 65-years was increasing.

Table 3. Changes in population

Age structure	2000	2005	2010
0-14	50,178	48,458	45,630
15-64	224,000	218,885	200,586
65-	58,687	67,114	71,760
Total	332,865	334,457	317,976

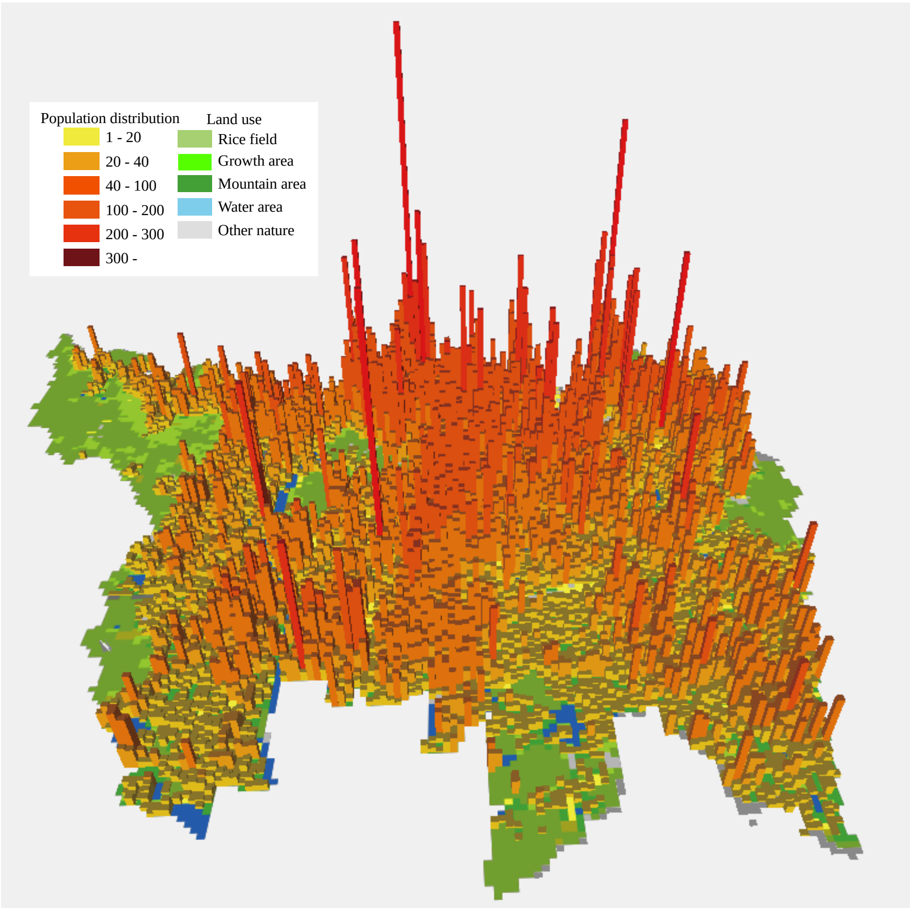

Figure 3. Population distribution

2.2 Farmland conversion trend

Table 4 shows the number of farmland conversions from 1999 to 2011 in Takamatsu city. Farmland of 9,351 (inside the use district was 4,218 and outside the use district was 5,133) had been converted. Also, the number of farmland conversions outside the use district increased after abolishing the ADS.

Figure 4 shows farmland conversion before abolishing the ADS, and Figure 5 shows farmland conversion after abolishing ADS. Before abolishing the ADS, much farmland was converted to inside the use district, and there are areas in which farmland conversion is concentrated. On the other hand, after abolishing the ADS, farmland conversion was distributed inside and outside the use district.

Table 4. Farmland conversion trend

	1999	2000	2001	2002	2003	2004	2005
Inside use district	415	423	387	391	469	396	371
Outside use district	330	385	417	333	354	533	567
	2006	2007	2008	2009	2010	2011	Total
Inside use district	297	291	237	161	192	188	4,218
Outside use district	499	438	335	333	309	300	5,133

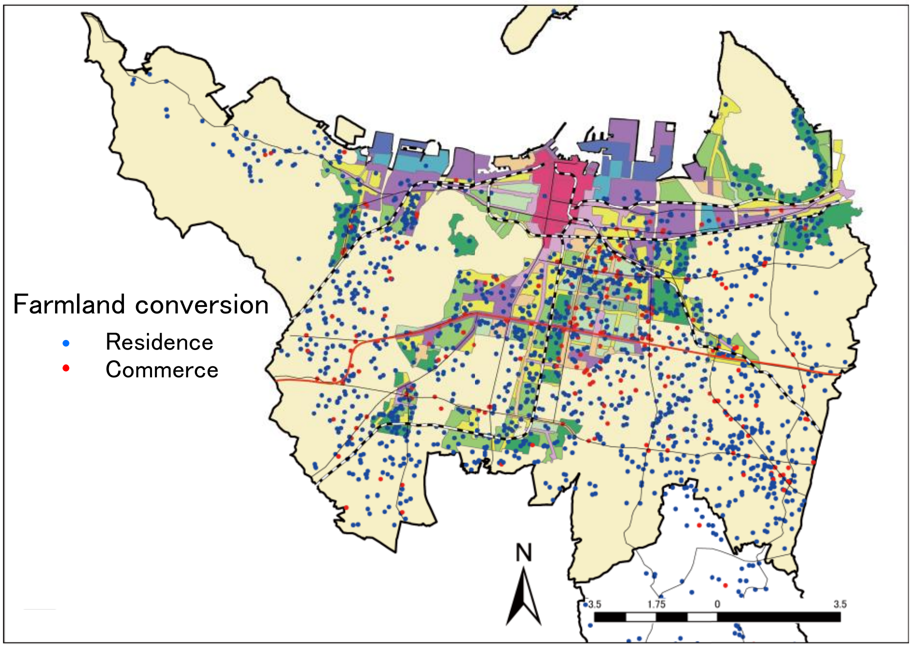

Figure 4. Farmland conversion before abolishing the Area Division System

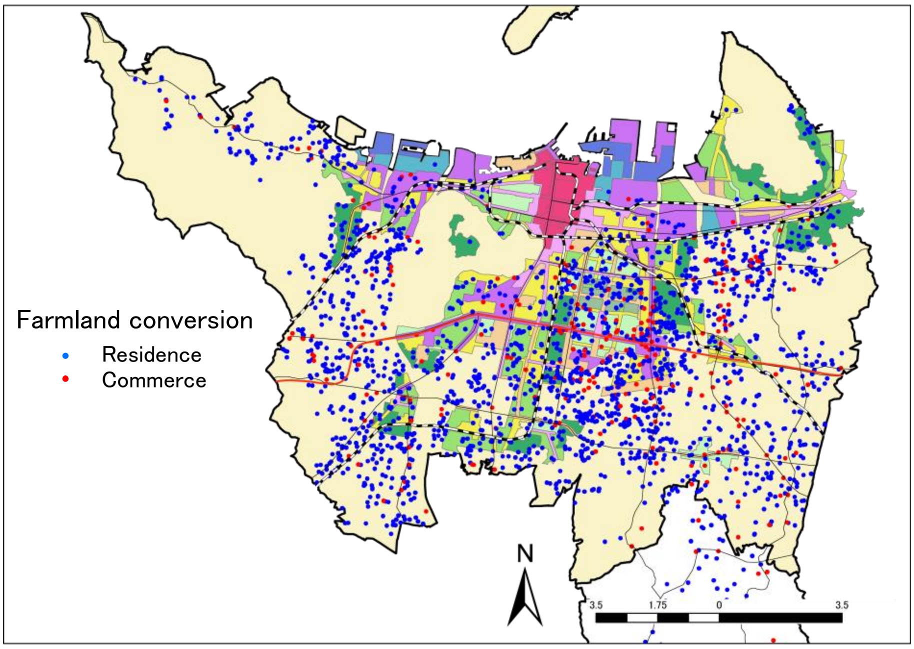

Figure 5. Farmland conversion after abolishing the Area Division System

3. CHANGES OF THE URBAN STRUCTURE BY ABOLISHING THE AREA DIVISION SYSTEM

3.1 Factors influenced by farmland conversion before and after abolishing the Area Division System

We made a 250 sq m mesh of the number of farmland conversions, regulations about land use (use district, agricultural promotion district[2)]), population, elevation, slope and distance to urban facilities (elementary schools, stations, public facilities, large scale stores, highway, interchanges, government offices and general hospitals). We analyse the factors that influence farmland conversion by quantification theory 1 (Table 5). Before abolishing the ADS, the multiple correlation coefficient is 0.5445, and, after abolishing the system, the multiple correlation coefficient is 0.5617

Before abolishing the ADS, “Use district”, “Distance to government office”, and “Population” have an influence on farmland conversions. Especially, “Residential district” (Category 2 Low-rise Exclusive Residential

District, Category 2 Medium-to-high-rise Exclusive Residential District, and Quasi-residential District) have an influence on farmland conversions.

After abolishing the system, “Use district”, “Distance to government offices”, and “Slope” have an influence on farmland conversion. Especially, Category 2 Low-rise Exclusive Residential District and gradual slope area have an influence on farmland conversions.

Table 5. Results of quantification theory 1 (Top 3 of each category)

Category		Mesh	Before abolition: Category score	Before abolition: Range (ranking)	After abolition: Category score	After abolition: Range (ranking)
Use district	Category 1 Low-rise Exclusive Residential District	87	0.7358	5.5799 (1)	0.0885	4.0620 (1)
	Category 2 Low-rise Exclusive Residential District	12	4.5505		2.6802	
	Category 1 Medium-to-high-rise Exclusive Residential District	112	-0.469		-0.5303	
	Category 1 Medium-to-high-rise Exclusive Residential District	54	2.1248		0.6863	
	Category 1 Residential District	161	-0.5775		-0.6294	
	Category 2 Residential District	54	-0.2513		-0.5117	
	Quasi-residential District	7	1.3752		-1.3818	
	Neighborhood Commercial District	55	-0.9845		-0.9487	
	Commercial District	38	0.0106		-0.5511	
	Quasi-industrial District	142	-0.2105		-0.833	
	Industrial District	17	-1.0294		-1.2617	
	Exclusive Industrial District	19	-0.6295		-0.3348	
	Outside use district	1,633	0.0179		0.2084	
Distance from government office	0–1,000	40	-3.1974	4.1828 (2)	-2.6437	2.9797 (2)
	1,000–2,000	84	-1.8477		-1.392	
	2,000–3,000	132	0.4424		0.085	
	3,000–4,000	167	0.9854		-0.2165	
	4,000–5,000	192	0.6746		0.336	
	5,000–7,500	781	-0.3949		0.1124	
	7,500–10,000	719	0.113		0.1296	
	10,000–	276	0.5717		0.0078	
Population	0	479	-0.8634	2.2907 (3)	-0.7146	1.3996 (9)
	1–50	539	-0.7374		-0.3787	
	50–100	400	-0.3379		0.1319	
	100–200	404	0.4756		0.4806	
	200–300	210	1.1508		0.685	
	300–	359	1.4273		0.4336	
Slope	0.0–0.3	596	0.5856	1.5225 (5)	0.7929	2.2931 (3)
	0.3–0.6	468	0.6852		0.9102	
	0.7–1.0	200	0.2486		0.4582	
	1.0–3.0	286	-0.1328		0.0251	
	3.0–15.0	447	-0.7865		-1.0122	
	15.0–	394	-0.8373		-1.3829	

3.2 Making development potential maps

Using category-score of quantification theory class 1, we calculate the predictive value of farmland conversion before and after abolishing the ADS (Formula 1).

Table 6 shows precision using presence or absence of farmland conversion within mesh and the predictive value.

Inside use district, meshes of predictive value over 3.0 have a precision value over 80%, and outside use district, meshes of predictive value of over 2.0 have precision of over 70%.

Before abolishing the ADS, the number of mesh of predictive value over 4.5 are concentrated inside the use district (Fig 6).

On the other hand, after abolishing the system, the number of mesh of predictive value over 4.5 decreased, and those over 3.0 are widely dispersed inside and outside the use district (Fig 7).

$$y_i = m + \sum_{j=1}^{R} \sum_{k=1}^{c_j} a_{jk}\, \delta_i(jk) \qquad \text{Formula 1}$$

I : sample i=1,2,…,n j : item j=1,2,…,n k : category k=1,2,…,n

m : average of score a_{jk} : score of item i $\delta_i(jk)$: dummy variable $\delta_i(jk)$ = 0,1

Table 6. Precision of predictive value of farmland conversion

	Predictive value	Number of mesh			Precision
		Presence	Absence	Total	(%)
Inside use district	–1.0	25	130	155	83.9
	1.0–2.0	75	73	148	50.7
	2.0–3.0	133	64	197	67.5
	3.0–4.0	140	22	162	86.4
	4.0–4.5	35	4	39	89.7
	4.5–	55	2	57	96.5
Outside use district	–1.0	84	570	654	87.2
	1.0–2.0	150	130	280	53.6
	2.0–3.0	243	81	324	75.0
	3.0–4.0	226	35	261	86.6
	4.0–4.5	64	8	72	88.9
	4.5–	39	3	42	92.9

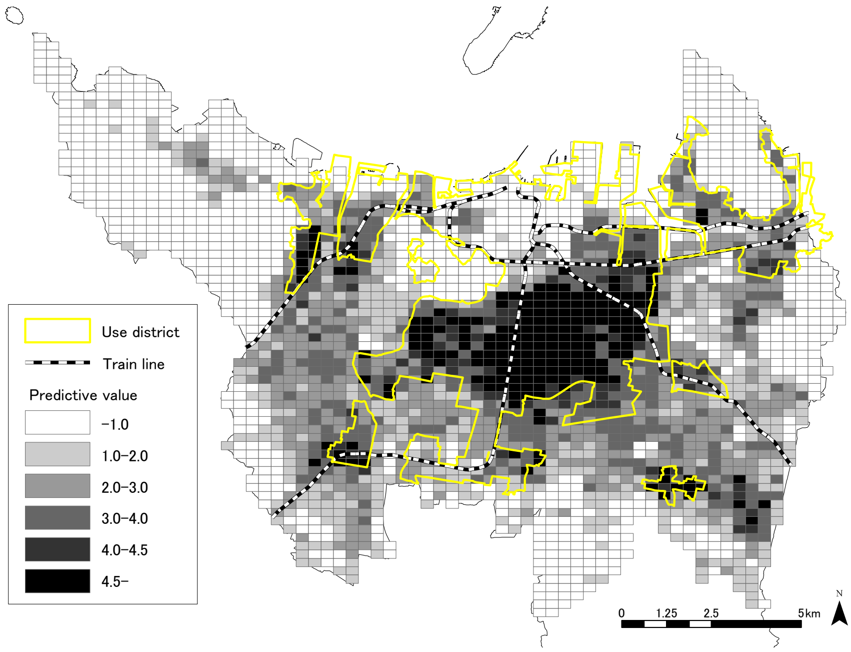

Figure 6. Potential map of development before abolishing the Area Division System

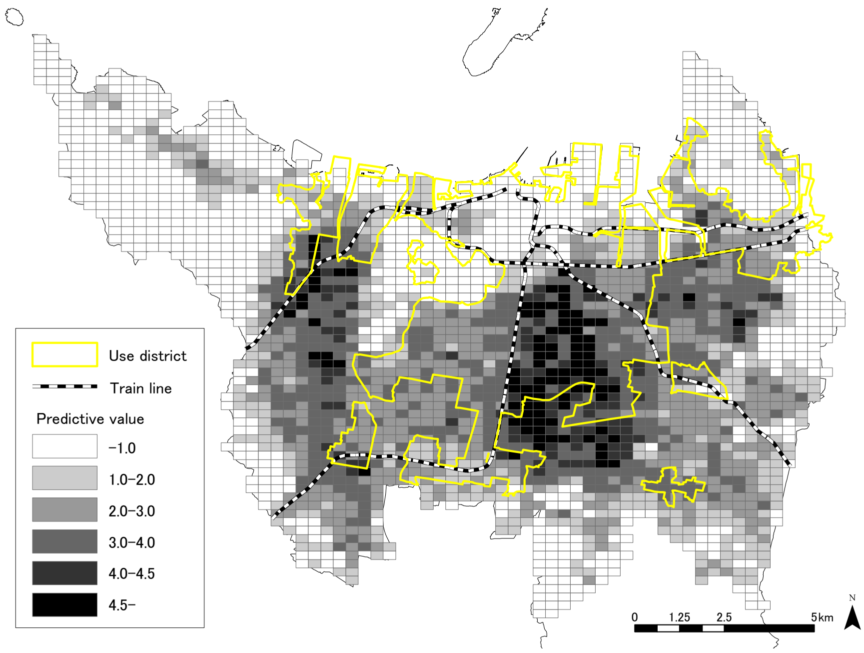

Figure 7. Potential map of development after abolishing the Area Division System

4. THE BUILDING OF CONCENTRATION URBAN STRUCTURE MODELS BASED ON THE MASTER PLAN

4.1 Calculation of future population

We calculate the future population by using the primary factors cohort for building a concentration urban structure. Table 7 shows the future population. Estimated population under 64-years shows a decreasing trend, and over 65-years show an increasing trend by 2050. The target area is estimated to proceed according to a declining and aging population.

Table 7. Future population

Age structure	2010	2020	2030	2040	2050	2060
0–14	45,630	37,229	31,330	30,667	24,441	22,183
15–64	200,586	179,640	165,512	138,651	121,260	110,023
65–	71,760	89,194	91,374	97,126	95,378	84,916
Total	317,976	306,062	288,216	266,443	241,079	217,122

4.2 Making the population migration tool

We develop the population migration tool based on multiple master plans (Kagawa prefecture, 2011a, 2011b, 2007, 2012, Takamatsu city, 2008a, 2008b and 2011). Figure 8 shows a flow population migration tool. Population migration tool can set a non-inhabitable, concentration base and target population density. By considering the concentration urban structure model using this tool, we can arbitrarily set the concentration base and target population density, and can consider and visualize many urban structures.

4.3 Building an concentration urban structure model

We build a concentration urban structure model for 2040 using the population migration tool. Figure 9 shows concentration urban structure model of 2040. Low density population decrease in suburban areas, and number of mesh over 40 person increases in the central city.

4.4 Evaluation of concentration urban structure model

We evaluate the concentration urban structure model using a number of mesh (Table 8). The number of mesh of “1-20 people” is decreasing, and the mesh of “over 100 people” is increasing. Next, we evaluate the concentration urban structure model using distance from urban facilities (Table 9). Population within 2,000m from hospitals increases, and population far from hospitals decreases. The concentration urban structure model becomes highly convenient.

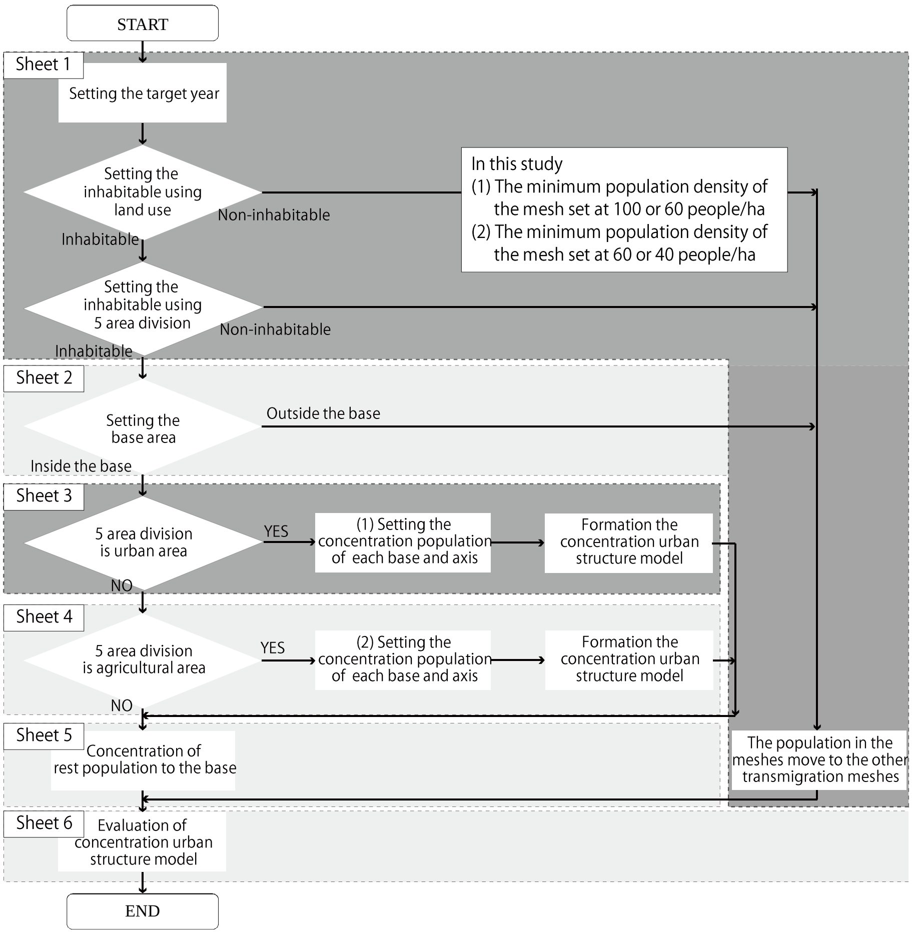

Figure 8. Flow chat of the population migration tool

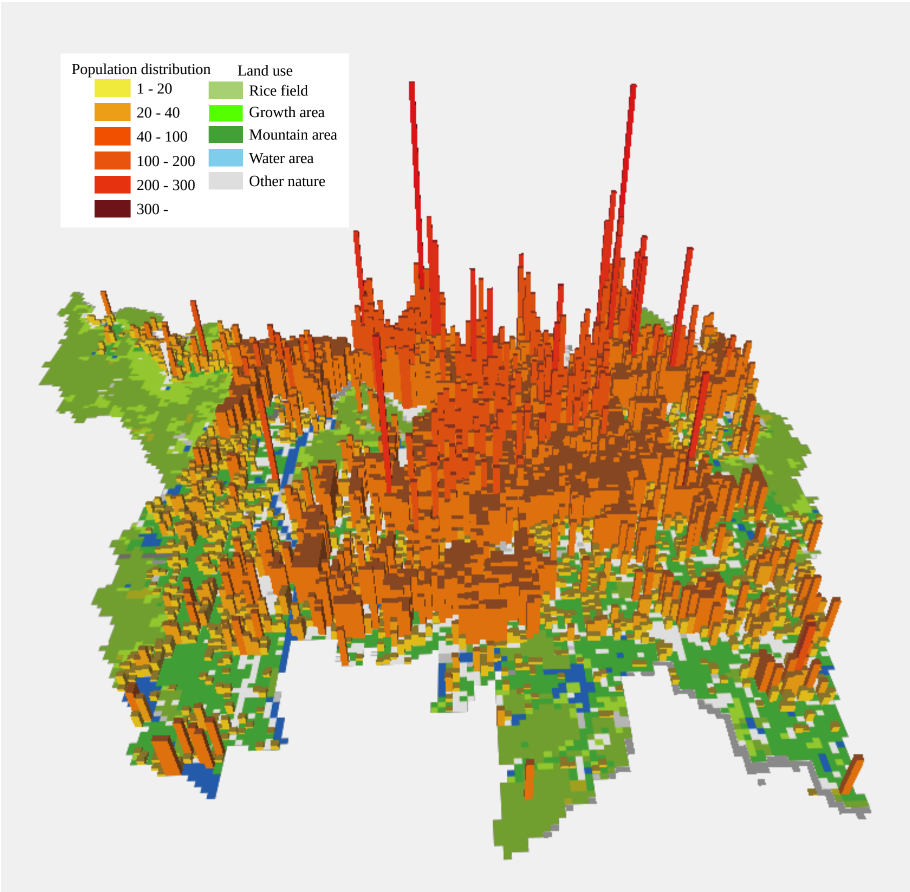

Figure 9. Concentration urban structure model of 2040

Table 8. Population category by number of mesh

	2040 population		2040 concentration urban structure	
	Number of mesh	Rate (%)	Number of mesh	Rate (%)
0	5,639	37.4	9,522	63.2
1-20	5,451	36.2	1,020	6.8
20-40	1,812	12.0	1,060	7.0
40-100	1,803	12.0	3,143	20.9
100-200	346	2.3	304	2.0
200-300	19	0.1	21	0.1
300-400	0	0.0	0	0.0
400-	2	0.0	2	0.0
Total	15,072	100.0	15,072	100.0

Table 9. Population by distance from urban facilities

	Train station		Hospital	
	2040 population	2040 concentration urban structure	2040 population	2040 concentration urban structure
0-1000	178,815	167,912	16,259	47,797
1000-2000	54,699	69,381	46,736	101,720
2000-3000	18,839	17,047	75,477	74,850
3000-4000	3,674	1,863	67,137	18,316
4000-5000	1,030	1,047	39,153	8,890
5000-	1,019	825	13,315	6,504
Total	258,075	258,075	258,075	258,075

5. COMPARISION OF POTENTIAL MAP TO CONCENTRATION URBAN STRUCTURE MODEL

Finally, we compare the development potential map after abolishing the ADS with the concentration urban structure model. Figure 10 shows the high predictive value area. We estimate that farmland conversion the outside use district increases, and takes into account the future urban structure sprawls to the suburbs. On the other hand, people in the concentration urban structure model in high potential areas of the suburbs decrease. If we realize to the form of the compact city according to the municipal plan, urban structure becomes more convenient and becomes the compact city.

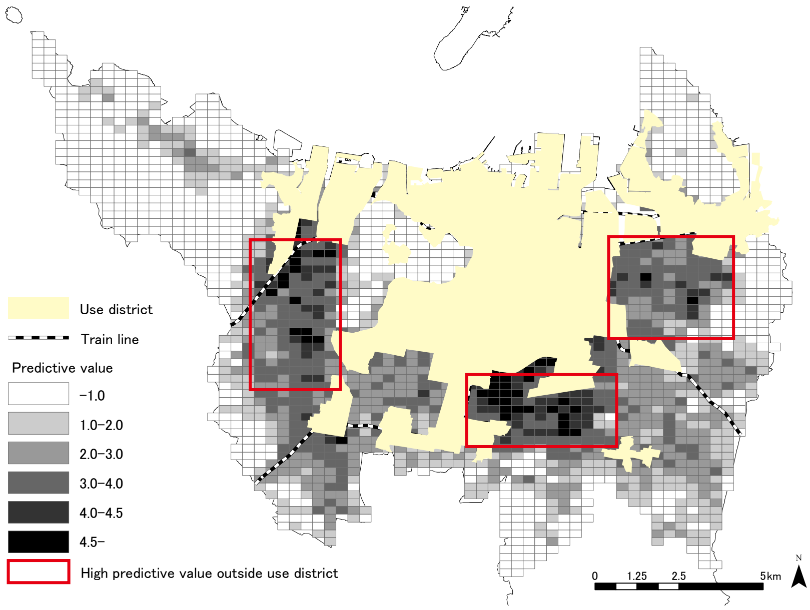

Figure 10. High predictive value area

6. CONCLUSION

The results are as follows.

(1) The result of comparing the number of farmland conversions before and after abolishing the ADS, farmland conversion increase outside of use district.

(2) Before abolishing the ADS, "use district", "distance to government offices", and "population" have an influence on farmland conversion. After abolishing the ADS, the number of mesh with predictive value over 4.5 decreases, and the over 3.0 widely disperse inside or outside the use district.

(3) We developed a "population concentration tool" using Expert System theory based on municipal administrative master plans, and built the concentration urban structure model. The model shows high density population and convenient.

(4) We compared the development potential map after abolishing the ADS in the concentration urban structure model. According to the development potential map, farmland conversion outside the use district increases, and takes into account that the future urban structure sprawls to the suburbs. On the other hand, people in the concentration urban structure model in high potential areas of suburbs decrease. If we realize the form of the compact city according to the municipal plan, urban structures become more convenient and resemble the compact city.

NOTES

1) The use district is described in City Planning Low, which aims to prevent mixing the type of uses. It is divided into seven residential areas, two commercial areas and three industrial areas.

2) The agricultural promotion district is area that is determined to be necessary to promote agriculture.

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Understanding Car Drivers' Preferences regarding Parking Attributes to support Smart Parking Developments for Enclosed Business Areas

Key words: Parking attributes, enclosed business area, Smart Parking

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Abstract

This paper presents a parking choice model for enclosed business areas to support the development of a Smart Parking system. The following attributes were included in the experiment: walking distance between parking and final destination; parking tariff; occupancy rate; driving distance between entrance and parking facility; size of parking facility; number of conflicting traffic flows on route between parking and final destinations. The model estimation is based on data gathered with a stated choice experiment. In total, 169 participants of the University's Parking Panel completed the questionnaire that included the experiment. The model estimation shows that walking distance from parking to final destination and parking tariff are the most influential attributes. The model is used to evaluate a parking measure at the parking situation at the campus of Eindhoven University of Technology.

Introduction

The increased attention for the climate and the influence of traffic on climate change forces organizations to look more carefully to the functioning of the traffic system(s) they are responsible for. This is also true for the organizations that are responsible for the management of enclosed business areas like university campuses and office parks (e.g., Shang et al., 2007; Van der Waerden et al., 2008; Barata et al., 2011; Guo et al., 2013; Riggs, 2014; Filipovitch & Boamah, 2016). One of the challenges of the management is to take care of an optimal traffic system keeping all involved stakeholders satisfied. In most enclosed business areas, different types of stakeholders can be identified. The first stakeholder type is the parking company that maintains and operates the available parking facilities. This group mainly focuses on occupancy rates with corresponding revenues and costs. The second stakeholder type concerns the area management organization that is responsible for both the motorized and non-motorized traffic flows in enclosed business areas. They are responsible for the accessibility, safety, and emissions (including noise). The final stakeholder type consists of the car drivers who want to find and use the most optimal parking facility to park their car. They are mainly interested in parking tariffs, walking distance, and space availability.

To keep the traffic system of an enclosed business area working properly, management organizations could consider the introduction of Smart Parking (e.g., Rodier & Shaheen, 2010; Wood & Gartner, 2013). Smart Parking can be described as an ‘umbrella’ term for ways to make parking easier and more efficient in ways such as payment (e.g., Chatman & Manville, 2014), information (e.g., Karunamoorthy et al., 2015), or innovating techniques (e.g., Lan & Shih, 2014). With Smart Parking, car drivers can be directed to a free parking space considering shortest route from entrance to parking and time to find a free space (e.g., Geng & Cassandras, 2012; Shin & Jun, 2014), but also based on lowest price level and/or smallest number of conflicts on the walking route between parking and final destination (e.g., Mackowski et al., 2015). When introducing a system to optimize an areas’ parking system, it is essential to understand car drivers’ parking choice behavior (e.g., Chaniotakis & Pel, 2015).

The main question in this context is what car drivers prefer when they enter an enclosed business (or campus) area. The preferences could be included into the advice that a Smart Parking system produces at the entrance of an enclosed business area (physically or virtually). The remainder of the paper is organized as follows. First, some basic issues of car drivers’ preferences regarding parking within enclosed business areas are presented. Two approaches and findings of two studies are highlighted in this section. The following section presents the adopted research approach. After that section, the data collection and the sample are described. The analyses section shows the results of the modeling estimation process. The results of the model estimation are used to set up an application. The paper ends with the conclusion and suggestions for future research.

Parking within enclosed business areas

When looking at parking in relation to enclosed business areas, it seems that most studies focus on parking supply (e.g., Shang et al., 2007) and/or pricing strategies (e.g., Van der Waerden et al., 2006; Riggs, 2014; Filipovitch et al., 2016) to regulate parking demand for the whole area. Limited attention is paid to parking demand within an enclosed business area. Most enclosed business areas have a limited number of entrances/exits and host a variety of buildings and parking facilities, both lots and garages. In studies regarding car driver’s parking choice, it is assumed that car drivers who enter the campus area base their parking choice on the location of the parking vis-à-vis the building they work in and some specific attributes of the available parking facilities. The existing studies present a divers view of the importance of different attributes.

Van der Waerden et al. (2008) focused on several physical attributes of parking facilities located in an enclosed business area. They found that a car driver’s parking choice strongly depends on the size of the parking facility, the presence of maneuver space at the facility, the presence of right-of-way when leaving the parking facility, and the location of the parking facility vis-à-vis the workplace. The results were extracted from a revealed choice study at the campus of Eindhoven University of technology. In the study the parking choices of car drivers are related to nine physical attributes of the chosen parking facilities. At the moment of the study, the campus was (and still is) not equipped with separate parking tariff levels for individual parking facility. Nowadays, the occupancy of each individual parking facility is measured and presented at information panels located at the entrance(s) of the facility.

Guo et al. (2013) included in their agent-based transportation model a component that determines all the parking lots that commuters chose to search for an available parking space. The set of considered parking facilities is based on the destination building. The probability that a parking facility is chosen by a car driver is based on the *distance* between parking lot and a given building and the *capacity* of a parking lot. The importance of the attributes was determined using a revealed choice study. Car drivers who visited the campus of University at Buffalo were asked to indicate three parking facilities they had considered for parking and the parking facility they actually used.

Both studies show the possibilities when having detailed insights in parking choice behavior at enclosed business areas. The tools that are developed in the studies can help area management to optimize the use of both the areas' network and parking facilities. This requires more detailed attention to attributes of individual parking facilities and, in addition, better insights in the effects of measures that focus on the introduction of differences between individual parking facilities.

Research approach

To find out what car drivers prefer when entering an enclosed business area a stated choice experiment is set up. The following attributes and attribute levels are included in the experiment: walking distance between parking and final destination; parking tariff; occupancy rate; driving distance between entrance and parking facility; size of parking facility; number of conflicting traffic flows on route between parking and final destinations (Table 1). The selection of the attributes is based on experiences in previous studies and the local situation of the Eindhoven University of Technology campus.

Table 1: Attributes and attribute levels

Attributes	Levels
Walking distance between parking and final destination Parking tariff per day Occupancy Distance between entrance of campus and parking Size of parking facility Number of conflicts on walking route	50; 150; 450 meters 2.00; 4.00; 6.00 euros per day 50; 70; 90 percent occupation 200; 400 600 meters 100; 200; 300 parking spaces None; some; many conflicts

Most attributes are commonly used in this kind of studies and are easy to interpret. The levels of the attribute occupancy are explained in the questionnaire as follows.

- 50% means that the parking facility has a low occupancy: it is easy to find a free space;

- 70% means that the parking facility has a medium occupancy: it will take some time to find a free space;
- 90% means that the parking facility has a high occupancy: it will be difficult to find a free space.

The attribute ‘conflicts on the walking route’ refers to the number of conflicts a car driver faces on the walking route between parking facility and final destination. Conflicts could be crossings, traffic lights, absence of footpaths along a road.

Based on the selected attributes and their accompanying levels 18 hypothetical parking alternatives are generated using a fractional factorial design. The parking alternatives are randomly combined into choice sets of three alternatives. Car drivers were asked to choose one of the three offered parking alternatives. To become familiar with the choice task, the included attributes were explained in more detail and the car driver was asked to indicate her/his experience with the attribute (Figure 1). After evaluating all attributes, a practice question was presented (Figure 2). This question was followed by three choice tasks that were prepared for the analyses.

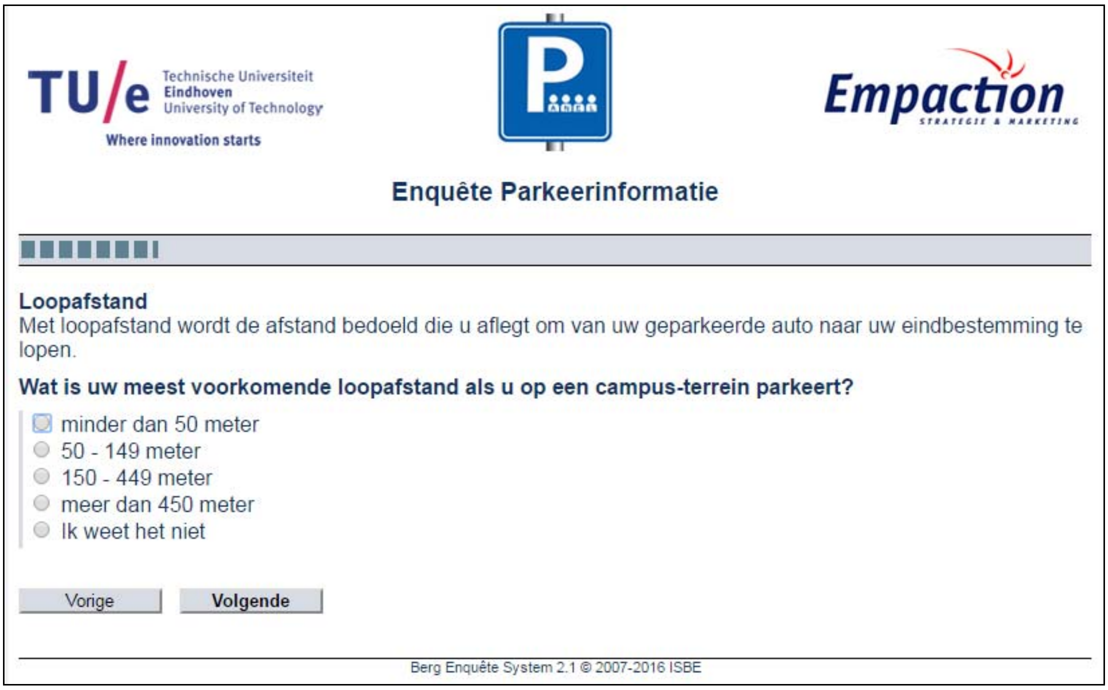
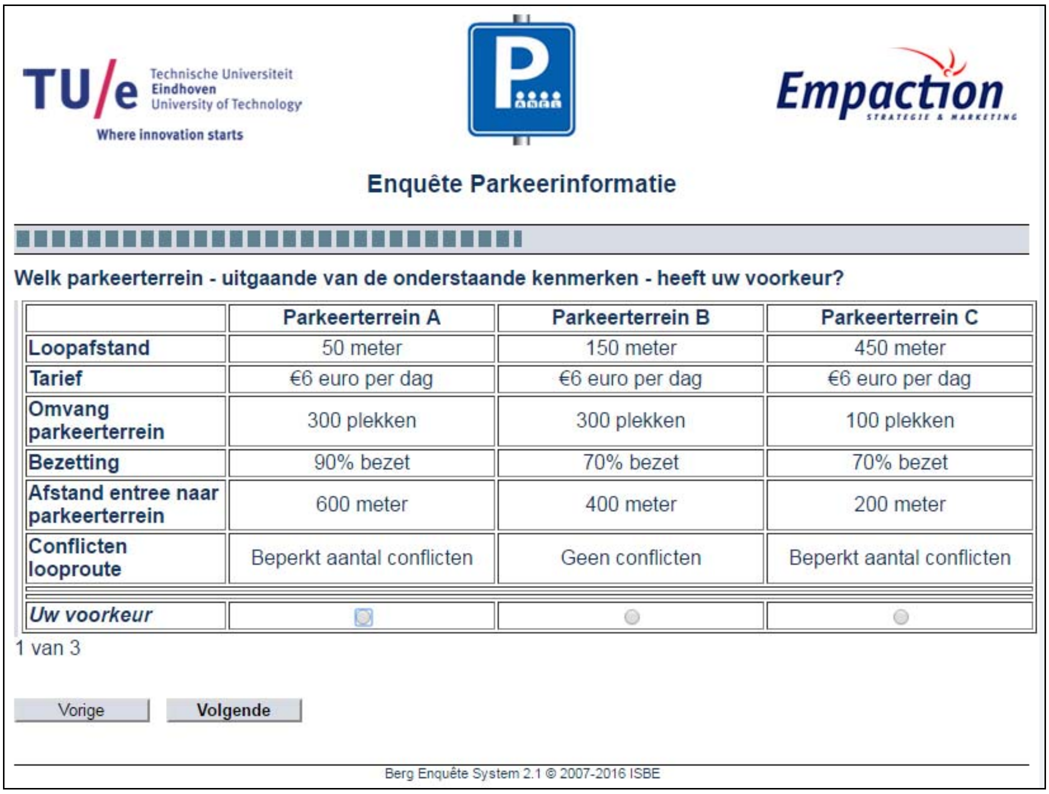


Figure 1: Example of attribute evaluation, Walking distance


Technische Universiteit Eindhoven University of Technology
Where innovation starts

Empaction
STRATEGIE & MARKETING

Enquête Parkeerinformatie

Welk parkeerterrein - uitgaande van de onderstaande kenmerken - heeft uw voorkeur?

	Parkeerterrein A	Parkeerterrein B	Parkeerterrein C
Loopafstand	50 meter	150 meter	450 meter
Tarief	€6 euro per dag	€6 euro per dag	€6 euro per dag
Omvang parkeerterrein	300 plekken	300 plekken	100 plekken
Bezetting	90% bezet	70% bezet	70% bezet
Afstand entree naar parkeerterrein	600 meter	400 meter	200 meter
Conflicten looproute	Beperkt aantal conflicten	Geen conflicten	Beperkt aantal conflicten
Uw voorkeur			

1 van 3

Vorige Volgende

Berg Enquête System 2.1 © 2007-2016 ISBE

Figure 2: Example of stated choice task

The stated choice experiment was included in an online questionnaire. The questionnaire also contained questions regarding respondents' experiences with parking at campus areas and personal characteristics (gender, age, educational level).

Data

Respondents were recruited from the University's Parking Panel. The panel consists of individuals who participated in different previous parking studies conducted by researchers of the university. Most of the participants are not related to the university but do have experiences with parking at enclosed business areas.

Table 2: Personal characteristics of sample

Characteristics	Levels	Frequency	Percentage
Gender	Male	112	66.3
	Female	57	33.7
Age	45 years and younger	48	28.4
	Between 45 and 60 years	68	40.2
	60 years and older	53	31.4
Education	Medium level	60	35.5
	Higher level	64	37.9
	University level	45	26.6
Total		169	100.0

The invitations to participate in the questionnaire were sent in April 2015. Because of the focus on parking at campus areas, only a limited number of panel members reacted on the invitation. In total, 169 panel members completed the questionnaire. Some details of the sample are presented in Table 2. It is not possible to indicate if the sample represents visitors of enclosed business areas well. In general, the frequencies show an acceptable distribution for further analyses.

Analyses

The respondents evaluated 507 choice sets each consisting of three parking alternatives. The choices are analyzed using a standard multinomial logit model. The Log likelihood ratio statistic in combination with the chi-square test value shows that the estimated model outperforms the model with all parameters equal to zero (Table 3). In addition, McFadden's R^2 shows that model is well able to represent the observed choice behavior.

Table 3: Estimation results MNL-model

Attributes	Levels*	Parameters**	Range
Walking distance parking to destination	50 meters	**1.6720**	3.3712
	150 meters	-0.0272	
	450 meters	*-1.6992*	
Parking tariff per day	2.00 euro per day	**1.0239**	2.0478
	4.00 euro per day	0.0000	
	6.00 euro per day	*-1.0239*	
Occupancy	50 percent	**0.5377**	1.0030
	70 percent	-0.0724	
	90 percent	*-0.4653*	
Distance entrance of campus to parking	200 meters	**1.0369**	1.5929
	400 meters	**-0.4809**	
	600 meters	-0.5560	
Size of parking facility	100 parking spaces	0.1872	0.5836
	200 parking spaces	0.2092	
	300 parking spaces	*-0.3964*	
Number of conflicts on walking route	No conflicts	**0.6981**	1.5212
	Some conflicts	**-0.8231**	
	Many conflicts	*0.1250*	
Goodness-of-fit			
Log-likelihood - zero		-556.9964	
Log-likelihood - optimal		-344.3242	
Log-likelihood ratio statistic		425.3444	
Chi-square test value (degrees-of-freedom: 11)		19.68	
McFadden's R^2		0.382	

* Value of third level is based on values of first and second level
** **Bold**: significant at 90 percent confidence level

Most influential parking attributes on the car drivers preferences are walking distance and parking tariff. Car drivers prefer parking facilities that are close to their final destination and have the lowest parking tariff. In line with expectations, car drivers prefer parking facilities with a low occupancy rate and parking facilities that are connected to their final destination by a walking route with no conflicts. The effect of many conflicts is not in line with general expectations. Maybe it was too difficult for car drivers to distinguish between some and many conflicts. Surprisingly, car drivers prefer a short driving distance (200 meters) across the campus more than a longer driving distance (400 or 600 meters).

Application

To show the contribution of the study results to the working of a Smart Parking system, an example is elaborated for the campus of Eindhoven University of Technology. Assume that a car driver arrives at entrance ‘Den Dolech’ and works in Building ‘Vertigo’ (see Figure 3). In general, the most relevant parking facilities are P1, P2, and P12. Table 4 presents the attribute levels of the facilities and the calculated total utility using the model parameters. The utilities are used to calculate the probability that a parking facility will be chosen by a car drivers.

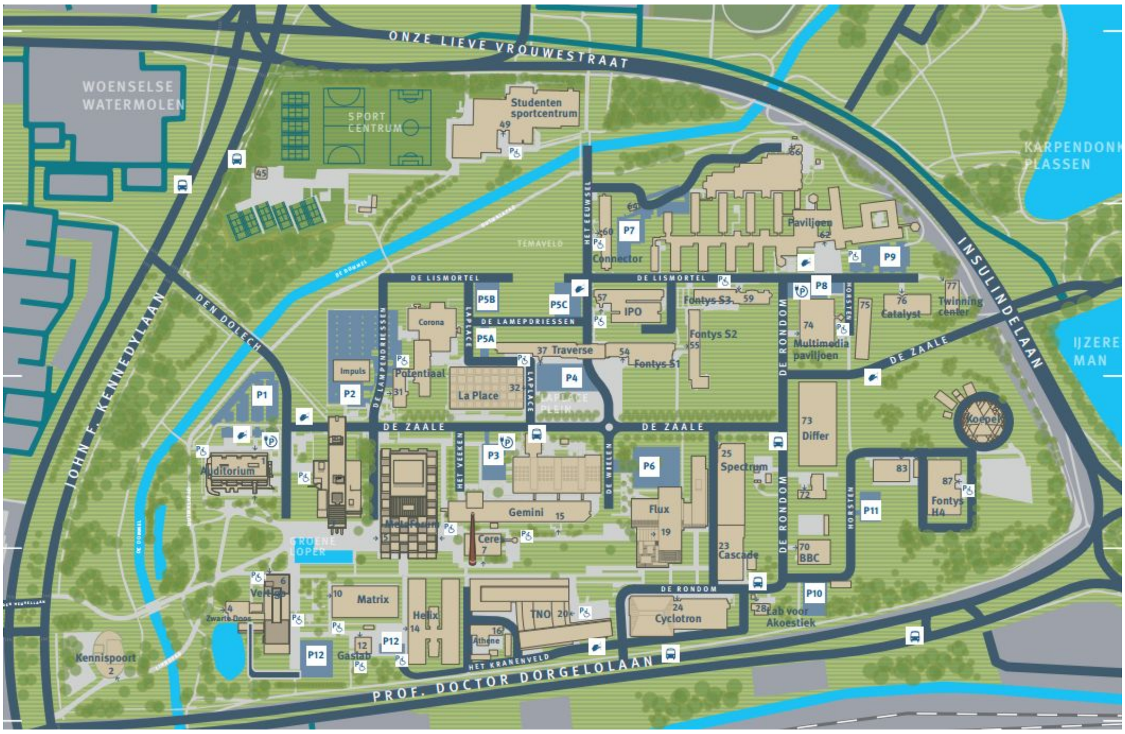


Figure 3: Map of the campus of Eindhoven University of Technology

Table 4: description of alternative parking facilities

Attributes	Parking P1	Parking P2	Parking P12
Walking distance parking to destination	450 meters	450 meters	50 meters
Parking tariff per day	2.00 euro / day	2.00 euro / day	2.00 euro / day
Occupancy	70 percent	50 percent	90 percent
Distance entrance of campus to parking	200 meters	200 meters	600 meters
Size of parking facility	300 spaces*	300 spaces*	100 spaces*
Number of conflicts on walking route	Some conflicts	Some conflicts	No conflicts
Total utility	-0.5339	0.0762	2.3727

* No contribution because parameters is not significant

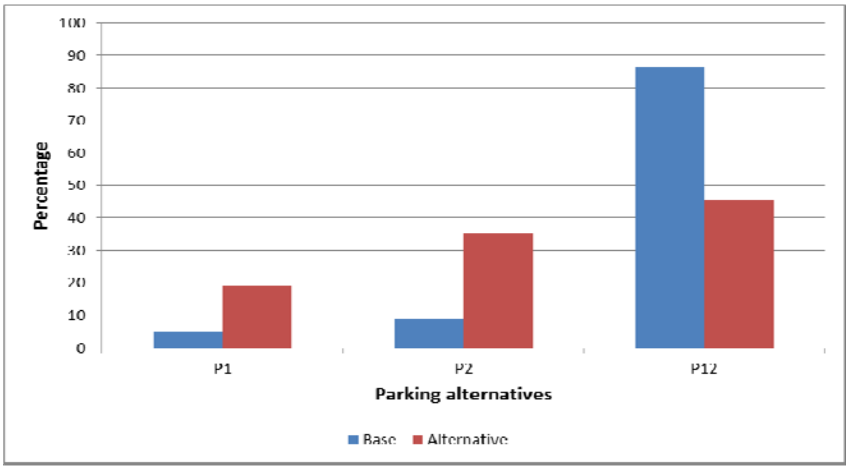


Figure 4: Choice probabilities for two different price levels

The utilities are used to calculate the probabilities that a driver who arrives at entrance ‘Den Dolech’ and works in Building ‘Vertigo’ will choose the three alternative parking facilities (Figure 4, blue bars). Assume that the campus management wants to stimulate car drivers to choose for parking P1 or P2. Using Smart Parking, the management could raise the parking tariff of P12 with 4.00 euro to 6.00 euro per day for car drivers who enter the campus area when the occupancy of parking P12 becomes too high. Calculations with the model show new choice probabilities for the alternative parking facilities (Figure 4, red bars).

Conclusions

The introduction of Smart Parking requires not only detailed data of the actual situation but also detailed knowledge of car drivers’ parking search and choice behavior. This study was set up to feed the knowledge of car drivers’ parking choice behavior in enclosed business areas. A parking choice model is developed based on stated choice data of almost 170 respondents. The model fit indicates that the developed model is well able to reproduce the car drivers’ parking choices. The signs and values of the estimated model parameters are in accordance with general expectations.

As the application shows, the area management can use the generated parking choice model to optimize the use of parking facilities by changing certain parking attributes. In this case the parking tariff of one specific parking facility is increased to direct more car drivers to alternative parking facilities. The model could be implemented in an agent-based transportation model as suggested by Guo et al. (2013).

The study included some limitations that can be subject of future research. The small sample used in this study was not directly related to a specific enclosed business area. It would be interesting to see if more respondents reveal the same parking choice behavior in enclosed business areas. An enlargement of the sample also gives the opportunity to subdivide the sample into different groups of interest. In addition, more attention could be paid to less obvious attributes of parking facilities and the route between parking and final destination like the number of conflicts at the route.

Acknowledgements

The authors want to thank Ivo Bastiaansen and Martin Wink of Movares Adviseurs & Ingenieurs for their contribution to the study.

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Domain knowledge extraction for industrial area redevelopment planning

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Keywords: Planning Support, Natural Language Processing, Zoning Plans

Abstract: Domain knowledge in regional planning is essential for depicting the local specific context. Past experience which is summarized in the language of domain knowledge can guide future redevelopment planning tasks. Recently industrial area redevelopment has been emphasized by many Dutch regions. To overcome the difficulty in domain knowledge extraction (DKE) in industrial area redevelopment planning process, a method is proposed in this paper which provides an easy and general starting point for decision support. Only land use maps and zoning plan maps are needed for retrieving more information. North Brabant region in the Netherlands is used as a case study for the proof-of-concept. The problem in industrial redevelopment planning in the Netherlands is first illustrated, followed by the methodology we have proposed. Several tools are applied to perform the tasks. A domain knowledge extraction visualization webpage is developed for collaboration and discussion among stakeholders. Further directions are also discussed.

1. INTRODUCTION

1.1 Problems

A large amount of abandoned industrial areas causes severe problems for regions. In the Netherlands, more than 28% industrial areas are obsolete (Nijssen & Kremers, 2013). Revitalizing these areas is essential for regional sustainability. To lead better redevelopment practice and accelerate the process, learning from past experience from redeveloped cases can be of much help. However, it is problematic in urban planning field because of the complexity involved, including but not limited to, expectations from various stakeholders, a large amount of investment and complex impacts on the environment, society and economy (Yeh & Shi, 1999). Moreover, only cases that have similar demographic and spatial characteristics could be considered as possible references for a new planning case (Du, Wen, Cao, & Ji, 2010; Li & Liu, 2006). Domain knowledge retrieved from redeveloped cases from a specific region is suitable references for new redevelopment planning tasks in this region.

To extract domain knowledge from past experiences, cases need to be collected and analysed. To construct such a case library, a large amount of data is needed. Particularly in industrial area redevelopment field, redevelopment process always involves several phases and many concerns which are difficult for a computer to reason from one summarized short descriptive paragraph of text. In this sense, the development of machine learning and data mining tools provide us with solutions, such as using text mining techniques to analyse descriptive and detailed zoning plan documents.

Zoning plan documents are good sources for domain knowledge extraction. Each region has its own structure of concerns in zoning plans. Some regions might emphasize more on economic while others might have more concerns on environmental issues. As a result, cases collected should reflect the local main concerns. In other words, a case library which represents the past experience and domain knowledge needs to be constructed in the similar regional context, preferably the same region. Meanwhile, the cases should be described by prior agreed-upon terms. However, it is troublesome to find the associated redeveloped zoning plan documents and common concerns for redeveloped industrial sites from one region.

To overcome the difficulty in domain knowledge extraction in industrial redevelopment planning process, a method is proposed in this paper. This method provides an easy and general starting point for decision support in industrial site redevelopment. Only land use maps and zoning plan maps are needed for retrieving more information since many detailed descriptions are illustrated in zoning plan documents which are listed in the zoning plan maps in the Netherlands. Section two illustrates the methodology we have applied in this study. Afterwards, North Brabant region in the Netherlands is used as a case study for the proof-of-concept. Further steps and discussion are provided at the end of the paper.

1.2 Objectives

As explained in the problems, the main purpose of this paper is to present a method for constructing case library which represents the past experience and knowledge for a specific region to guide future industrial area redevelopment planning exercises.

In the meanwhile, we have succeeded in reducing the data collection time by using computation power of modern techniques to analyse zoning planning documents, which provides us with plenty of information not only quantitative but also qualitative. In this way, the data sources are limited to an acceptable amount. Moreover, the method we have proposed enables the analysis to be a semi-automatic process, which is less time-consuming and less expert dependent.

It is necessary to show the applicability of our approach using a case study. A web application is presented to illustrate the functionality. Stakeholders can use this application for further collaboration and discussion.

2. METHODOLOGY

In this section, a flowchart of the research is firstly presented, followed by the tools we have applied in each of the steps.

2.1 Flowchart

Figure 1 presents the flowchart of this research. Industrial land use and other land uses are categorized based on land use maps in the first step. In our study, we are only interested in industrial areas redevelopment, so other land uses are grouped into rough categories like nature areas, agricultural areas and transportation networks.

In the second step, one map is created which contains land use information of two consecutive years. From this land use map, we have compared which parcel has been changed from industrial use to other uses. All the parcels larger than a threshold size and have been detected changed from industrial use to other land use are overlaid with zoning plan maps. In this way, the specific zoning plans associated with the redevelopment process can be identified. Therefore, we have conquered the problem of only a simplified descriptive document exists for a redevelopment case which is normally presented on a website collecting industrial area redevelopment projects. More information from detailed zoning plan documents can be retrieved for each redevelopment case.

Thereafter, natural language processing tool is applied to analyse these zoning plan documents to perform text mining task for finding the most frequently mentioned concerns of each redevelopment case. According to the study of all these zoning plans, several popular concerns such as sustainable development, student housing and so on in a specific context (region) can be identified. This could be used as the basic reasoning rules for designing future similar redevelopment planning tasks. Our method of using the same region redevelopment cases ensures the demographic and political homogeneity. As a result, each case has been described by several frequently used keywords or concerns from the zoning documents. These case and keywords relationships can be presented using computer tools in the next step.

A forced-graph is presented to visualize the most similar cases based on their commonly mentioned concerns in the zoning plan documents. The mostly used concerns are more to be in the middle of the image. And the more similar two cases are, the closer they are to each other. Policy makers can use this tool for better communication, visualization and collaboration for designing future industrial area redevelopment areas, such as finding similar cases with the same concerns. Similarities and differences among various cases can be easily identified and visualized.

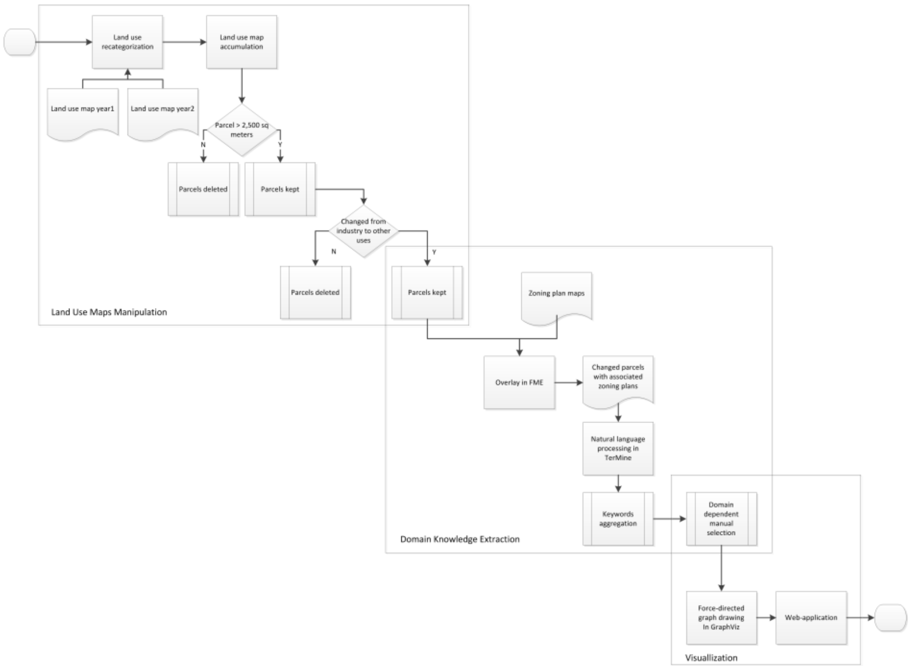

Figure 1. Flowchart of the research with used tools

2.2 Tools

This section introduces the used tools in our research. Other tools can be utilised as well. For this research, the tools are selected for the purpose of simplicity. The main purpose is to illustrate the method we have proposed. Therefore, the use of these tools is mainly for the purpose of proof-of-concept.

2.2.1 FME

FME desktop version 2015.1 ("FME Workbench Transformers FME Desktop 2015.1," 2015) is applied for land use map accumulation and zoning plan maps overlay tasks. FME is a powerful tool for manipulating geospatial data. It provides many functions and users can easily modify the settings for further changes.

2.2.2 TerMine

We have applied TerMine (Frantzi, Ananiadou, & Mima, 2000)as our tool for text mining tasks since it is a domain independent open source web service. This gives us the possibility to test different documents without spending a lot of configuration time. However, it is a tool designed for English texts. Dutch language orientated text mining tools can be applied in the further research for better results.

2.2.3 GraphViz

To generate the graphs which represents cases with their used concerns in the planning documents, we have used open source software GraphViz (Ellson, Gansner, Koutsofios, North, & Woodhull, 2004) for better visualization. This tool provides several ways to present the results. We have chosen the most general way to visualize the results. For other purposes, this image can be easily changed in the software.

3. CASE STUDY

3.1 North Brabant

North Brabant has been chosen for the case study for its sustainable ambition and the industry and research oriented regional characteristics. Many industrial areas have been redeveloped since the 21st century because of the limited land resources. Therefore, we consider North Brabant region in the Netherlands as a good case study for the purpose of industrial land use redevelopment domain knowledge extraction.

3.2 Data

3.2.1 Data sources

In our research, land use data comes from the Dutch cadastral organization Kadaster (Centraal Bureau voor de Statistiek & Kadaster, 2010, 2011). Cadastral data ensures the parcel shapes are well preserved which are normally the basis for the urban planning process.

The zoning plan maps are downloaded from Nieuwekaart van Nederland ("Documentatie bij het GIS bestand van de Nieuwe Kaart van Nederland," 2010) which is not in service anymore. Optional choice for further research is Plan-viewer service which is not free ("PLANVIEWER," 2016).

3.2.2 Land use map accumulation

Figure 2 shows the manipulation process of accumulating two-year land use map information. This script starts with snapping two land use maps from the year 2006 and year 2008 together and overlays all the parcels from these two maps. Only attributes about the land use types are left from the original datasets after renaming. Only the parcels that have changed from industrial land use to other uses are left in the following step, which is shown in the tester of C0608=1. Dissolve function is applied to minimize the small errors created during the overlay process of these two land use maps. In the next step, only parcels that are bigger than 2,500 square meters are left. This is based on the calculation of 50 meters resolution setting in

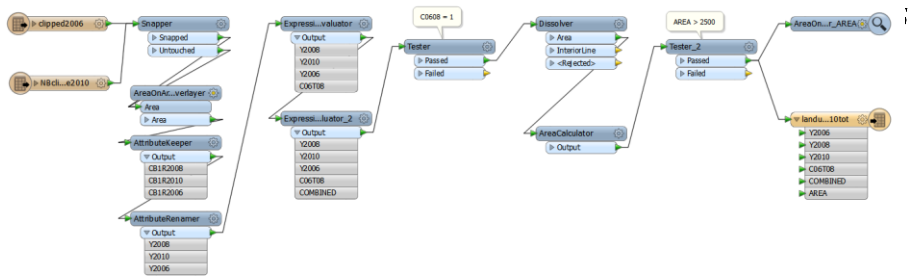

Figure 2. FME script for manipulating land use maps

further research for cellular automata land use simulation process. In the end, an accumulated land use map which contains two years land use information is created.

3.2.3 Zoning plan maps overlay

Zoning plan maps which contain zoning document information for each parcel is then utilised to overlay with the accumulated land use maps. The parcels that have transformed from industrial land to other land uses are overlaid with the zoning plan maps. Since the zoning plan maps are separated based on polygons and lines, we have manipulated the maps in two ways. For the polygons, the Spatialrelator from FME is used to check whether the zoning plan maps overlap with the changed parcels. While for the lines, a buffer of 50 meters is set first to check the overlaps. This ensures the relevant zoning plans can all be found, eliminating possible small errors. The specific script is shown in Figure 3.

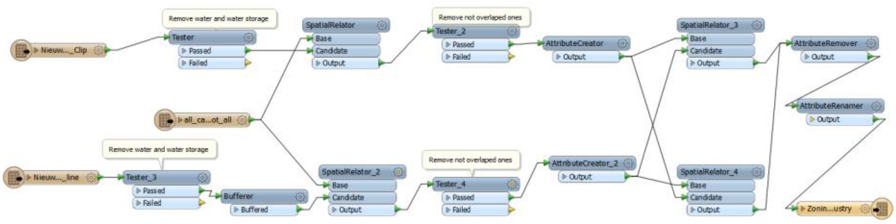

Figure 3. FME script for overlaying zoning plan maps

Zoning plans related to water and water storage areas are deleted since they are mostly plans about areas under research for further decisions. In the Netherlands, these plans are considered as research plans, not as decided and irreversible plans. In our research, only the zoning plans that are determined and irreversible are identified.

In the end, polygon and line zoning maps are combined to make a complete zoning plan map dataset which only include information for changed industrial sites. This dataset is used to perform further natural language processing task for domain knowledge extraction.

3.3 Dutch zoning plan documents

3.3.1 Structure and main concerns

The Dutch zoning plan documents have several main chapters including an introduction, description of the planning area, principles, environmental concerns, water section, legal issues, enforcement, financial arrangements, procedures and attachments. Based on the documents we have examined, we have proposed a simple version of the main concern structure in English. All the zoning plan documents which have overlaid with the changed industrial sites are translated into English first and presented based on the structure we have created.

3.4 Domain knowledge extraction

In order to extract the domain knowledge or main concerns for each zoning document, we have applied natural language processing tool TerMine. Based on the frequency of concerns, we have made a list of all the concerns that have appeared more than five times in the documents. A manual selection procedure is also performed by the experts in this field to eliminate the most commonly used words such as zoning plans. These are the words that appear in every zoning document but would not give us further information.

3.4.1 Natural language processing

We have applied the web-service from TerMine to process the texts from our documents. Each translated Dutch zoning document is uploaded and after the natural language processing procedure which includes part-of-speech tagging, linguistic filter, terms in stop-list exclusion and terms under set threshold processes (Frantzi et al., 2000).

After processing all the documents, all the concerns left are listed based on their appeared frequency. In total, 533 concerns are listed.

However, as we have indicated, TerMine is an independent tool in the sense of natural language processing. In our research, domain knowledge is necessary to give a frame which words should be included and which not.

Therefore, in the following session, we have manually selected the terms that we consider as important in industrial site redevelopment planning process.

3.4.2 Manual selection

The manual selection procedure ensures that the knowledge extracted is domain specific. We have applied three types of performances.

The first type is to merge synonyms and one example is “city center” is equal to “city centre”. This is a typical sort of synonyms that needs to be merged.

Another type of merge is executed on hypernyms. Take this as an example. A policy maker wants to develop an office building on an abandoned industrial site. Talking about office functions, other words might also come into the document such as offices, office building, and office space. These words are merged into the hypernym which can represent all of them on a top level such as office functions.

The last manipulation is to delete the commonly used words in every zoning plan document such as zoning plans, plan areas, water sector and so forth. In the end, 179 concerns are left.

3.5 Visualization

To make it more easily understandable for policy makers, we have created a force-directed graph and an interactive HTML document for users to play with. In the visualization part, proof-of-concept for this framework is presented.

3.5.1 Force-directed graph

For each case, we have identified its associated concerns. This case-concerns relationship is presented using a force-directed graph. Examples of these relationships are as the following, which shows that case 0 is represented as proj0 with four concerns, namely concern 27, 14, 12 and 21.

```
proj0 -> node27;
proj0 -> node14;
proj0 -> node12;
proj0 -> node21.
```

GraphViz tool is applied for generating such graphs. The closer two cases are on the canvas, the more commonly used concerns they have. The more to the centre of a keyword, the more it is used by more cases we have studied. This tool simulates the system until it comes to an equilibrium state based on different algorithms; the positions then are used to generate the graph. In our presented graph, NEATO(North, 2004), a component of GraphViz is applied to generate the graph. It applies "spring model" layouts. This is the default tool to use if the graph is not too large and you don't know anything else about it. NEATO attempts to minimize a global energy function, which is equivalent to statistical multi-dimensional scaling.

3.5.2 Interactive HTML document

Since all these relationships between cases and their concerns are generated from the previous step, they are presented in an interactive HTML document which can be shown on a web browser. This provides easy access for users for further discussion. Figure 4 shows the screenshot of this HTML document. This is a simplified version for the purpose of illustrating how this HTML looks like. The reason to make it simplified is to make the image more visible. In the original file, there are more concerns for each ease. You can see that case “Drie Hoefijzers” has mentioned five concerns: industrial, historical image, attractive living environment, brewery and close to centre.

The more to the centre one keyword is, the more it is used by all the examined cases. The closer two cases are, the more commonly used concerns they have. This image presents clearly which cases are similar to each other and what are their common concerns. It also illustrates the regional main concerns for industrial site redevelopment. In North Brabant region, the main concerns include sustainability, student housing, and so forth. In this way, domain knowledge for a specific regional land use redevelopment planning process can be extracted from long text documents. Policy makers and decision makers can easily apply this approach for their regions and discuss the further strategies. For example, one of their new redevelopment cases which focus on green living can consult the past experiences such as these 39 cases and once you click on the green living concern on the webpage, similar cases are shown. Further information can be retrieved easily and further discussion can be initiated.

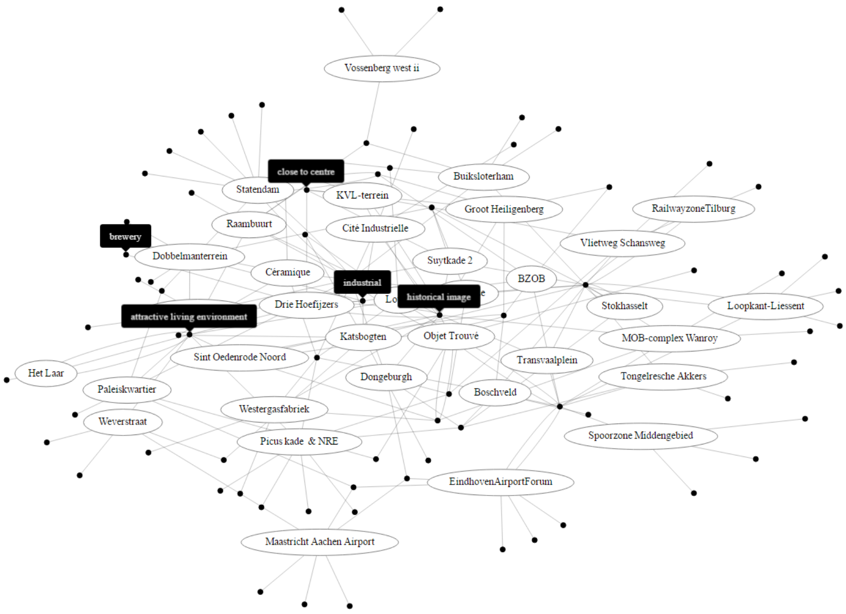

*Figure 4.*Redevelopment cases similarities based on commonly used concerns

4. CONCLUSIONS AND DISCUSSION

This section is divided into conclusions and discussion. Conclusions briefly describe the method we have proposed and the proof-of-concept results. General usage of this method is also illustrated for other regions and for other purposes. The scientific and societal contributions are emphasized. In the discussion part, points that can be improved or further discovered are listed.

To identify the redeveloped industrial sites in one region, we have applied FME and written two scripts to automatically detect the transformed industrial sites and their associated zoning plan documents. We have examined in total 39 Dutch industrial area redevelopment cases. For each of them, their most mentioned concerns in the zoning plan documents are identified using natural language processing tools. The manual selection procedure is included to ensure that only the domain specific concerns in the industrial site redevelopment planning process are included in the corpus.

A web page is presented to illustrate the relationships between each case and their used concerns. A force-directed graph is generated on the web page to minimize the global energy function for allocating these cases and concerns.

This paper illustrates a method or framework to identify transformed industrial sites and their associated planning documents. Scripts and tools are used to automatically extract domain knowledge in regional redevelopment planning. However, there are several further directions which can be emphasized here.

For the translation of Dutch language, we have used google translator which is not very precise. To conquer this problem, we have asked students to translate all the documents and summarize their concerns after reading the documents. The comparison study is necessary for further research. Besides, a better Dutch language processing tool is needed. Currently, we couldn't find suitable software for this purpose.

More cases are needed to enrich the domain knowledge extraction library. Case-based reasoning is a self-learning system which requires more information to be added in the future. This complies with the case based reasoning discipline.

Last but not least, we need to mention that the separation of concerns and actual actions to deal with the concerns need to be further studied. For example, the concern of sustainability might require more green areas in the neighbourhood, but for now, green area and sustainability are both listed as concerns but with no type difference.

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Smoke simulation for large buildings in CFAST

Using BIM to facilitate simulation process

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Key words: Building fire simulation, CFAST, BIM, validation

Abstract: The maximum number of rooms can be simulated in CFAST is limited to 30. In this study we propose a selection algorithm that enables CFAST to simulate the most critical 30 rooms of a building with more than 30 rooms. We then verified the validity of the proposed algorithm by testing the scalability of smoke propagation simulation through test cases. The validation tests showed that when selecting rooms with merging scheme, the simulation results are reasonably consistent compared to the baseline. In addition, the algorithm showed better consistency when the model has no direct connection to the exterior.

1. INTRODUCTION

Building fires cause many fatalities each year. From 2007 to 2009, there were more than 10,000 building fire deaths each year in 27 industrialized countries (WFSC, 2012). Protecting occupants from building fires is one of the major tasks when architects design buildings. To predict the behaviour of a building fire, researchers have developed various fire simulation models. Fire simulation models simulate the temperature and the air composition of the spaces in a building for each discrete time step. Major indicators of the air composition include soot, oxygen, and toxins such as CO, hydrogen cyanide, and heavy metal vaporized from burning paints and synthetic polymers. CFAST is one of the commonly used smoke simulation models. This research focuses on how to simulate large buildings in CFAST. Throughout this article, we will use the term "*large building*" to define buildings that have more than 30 rooms. This is merely a context-specific definition for easier communication in this paper.

1.1 Problem statement

The maximum number of rooms can be simulated in CFAST is limited to 30, i.e. CFAST currently cannot directly simulate large buildings. If there are more than 30 rooms in the input file, CFAST will fail to initiate simulation. In reality, a great portion of the buildings have more than 30 rooms. This poses challenges to simulate smoke propagation for large buildings in CFAST.

1.2 Research goals

In this research we propose an algorithm that enables CFAST to simulate large buildings. The validity of the proposed algorithm will be tested.

2. PREVIOUS STUDIES

Understanding the physical characteristics of fire and smoke is the essential key to model fire and smoke. Since the 1970s, researchers have extensively experimented with fire to unveil various characteristics of fire and smoke. Many researchers have tested the ignition behavior of various flammable materials such as different types of wood (Moghtaderi, Novozhilov, et al., 1997), polystyrene, epoxy (Ohlemiller and Summerfield, 1971), cardboard, newspaper, canvas, cotton cloth, polyurethane foam (Smith and King, 1970), different types of polymeric materials (Kishore and Mohan Das, 1980), etc. During these experiments many parameters were monitored, including ignition temperature, time to ignite, heat release ratio, yields of combustion, toxicity of each type of gas, oxygen depletion, etc.

Researchers also have performed extensive research on how building fire and smoke spread horizontally and vertically, from one object to another. In some of the earlier work, Quintiere (1977) reviewed full-scale and scaled model experiments to study fire growth and spread in building compartments. Later, Quintiere and Harkleroad (1985) tested ignition temperature, thermal inertia, and flame spread speed of 36 building materials caused by radiation. Hasemi (1986) conducted experiments on flame spread of vertical walls with combustible surface. Cheney et al. (1997) developed fire spread/time curve to show the fire growth and acceleration. Heskestad and Delichatsios (1979) studied heat transfer by convection in a fire. Larson and Viskanta (1976) studied flame radiation, wall heat conduction, and laminar convection. These experiments have laid the foundation for the simulation models developed in the later days.

During the pyrolysis process, smoke is released along with heat. Smoke contributes to death in two ways: first by incapacitating victims and causing death directly by toxic gases, and/or secondly by indirectly inhibiting people from escaping because of reduced visibility. Smoke can contain more than a dozen types of gases, but CO has proved to be the major toxicant that directly causes deaths. Currently there is not enough evidence that any other toxic gases such as HCN or HCl directly cause deaths, although they might contribute to early incapacitation (Terrill, Montgomery, et al., 1978; Birky, Halpin, et al., 1979).

2.1 Smoke simulation models

As physical characteristics of fire have been revealed with countless experiments, researchers have tried to model building fire and smoke using mathematical equations and computer simulation. Two-zone model is one of the most commonly used fire simulation model due to its fast simulation speed and acceptable accuracy. In two-zone models, a room is stratified by smoke line into an upper zone, which is filled with hot and toxic smoke, and a lower zone, which is filled with fresh air (figure 1). He and Beck (1997), based on their experiment of burning a multi-story building, confirmed the existence of the two-zone on the same floor, but two-zone model does not apply to vertical spaces such as stair cases at the time. While the smoke rises in vertical shafts, the temperature of the smoke cools down quickly, which is call the chimney effect, and the air become murky instead of forming two distinctive layers. He and Beck also found that stratification is not dominant at the rooms that are remote from the origin of fire.

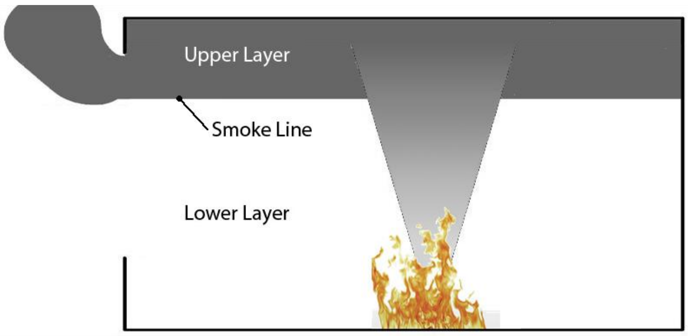

Figure 1. Two-zone model.

2.2 CFAST model

Consolidated Fire And Smoke Transport (CFAST) model is a two-zone model developed by National Institute of Standards and Technology. Considering the consequences of building fires, the validation of CFAST model is essential. Key validation research of the models used in CFAST was funded by US Nuclear Regulatory Commission Office of Research for fire safety of nuclear power plants where building fire can cause catastrophe (Growth and Model, 2007). They found that although there are some mismatches, CFAST simulation “predictions compared reasonably well with experimental results”.

There are three major limitations to integrate CFAST into Building Information Modeling (Wu, Zarrinmehr, et al., 2015). 1). CFAST can only simulate rooms that have rectilinear box shape. 2). The maximum number of rooms can be simulated is limited to thirty. 3). The maximum length of a building can be simulated is limited to 100 meters. This research focuses on the resolution of the second limitation, the maximum number of the rooms.

3. RESEARCH METHODS

CFAST only can simulate buildings with maximum 30 rooms. To simulate smoke propagation for large buildings using CFAST, we propose an algorithm to select 30 rooms that have the shortest smoke travel distance from the fire origin. Then we will test the validity of this selection algorithm. If the proposed algorithm is valid, we can simulate at least 30 most critical rooms of the building. The underlying assumption is that the occupants closer (by smoke travel distance) to the fire origin are more vulnerable because they have less time to safely evacuate.

3.1 Selecting rooms by shortest smoke travel distance

We used BIM to facilitate smoke propagation simulation because BIM stores the properties of each building components as well as the relationship between the components. For example, an interior door knows which two rooms it connects. If a door connects a room and the exterior, we define it as an exterior door. By reading the information of the doors iteratively we can easily generate the room-door connection graph of the building as shown in Figure 2. However, the room-door connection graph does not contain distance information of each connection, e.g. although we know that door 5 and door 2 are connected through room I, we don’t know the shortest travel distance between the two doors. The linear distance between door 5 and door 2, does not equal to the shortest travel distance because room K is blocking the linear path.

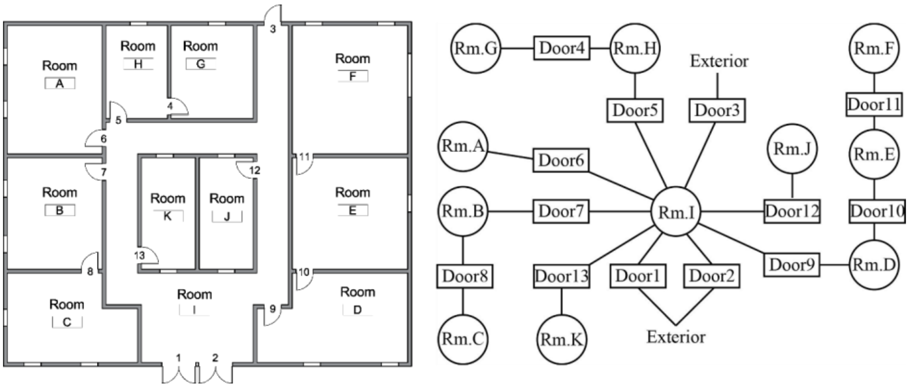

Figure 2. A sample building in BIM (left) and its room-door connection graph (right).

To calculate the shortest travel distance, a network graph is generated for each room respectively, using the doors and vertices (corners) of the room as nodes, and the linear distance as the weight between any two nodes (figure 3 left, the length of each green line is the weight between the two end points). If the linear line between two nodes intersects the boundary of the room, the weight is set to infinity. For example, the linear link between door 5 and door 2 passes room K, so the weight between the two doors is set to infinity. Use this information, we can generate the adjacency matrix of the network graph for each room (table 1). By running Dijkstra algorithm, a shortest path algorithm, we can easily calculate the shortest path between any two nodes. In figure 3 (right), we can see that the shortest path from door 6 to door 3 passes V2, and the shortest travel distance is 13.6 meters (8.2m + 5.4m). Similarly, the shortest path between door 6 and door 9 passes V1, and the distance is 15 meters. By combining the room-door connection graph and the network graphs of the room, we can easily sort the rooms based on the shortest smoke travel distance from the fire origin, and extract the first 30 rooms for smoke propagation simulation (when the building has more than 30 rooms). For example, assuming that the fire origin is room A, the next room that smoke propagates to is room I because room A and room I share door 6, i.e. the distance is 0. Then the next is room H because door 5 is the next closest door to door 6, and so on. The whole selection process is automated by the algorithm and can be done within one mouse click.

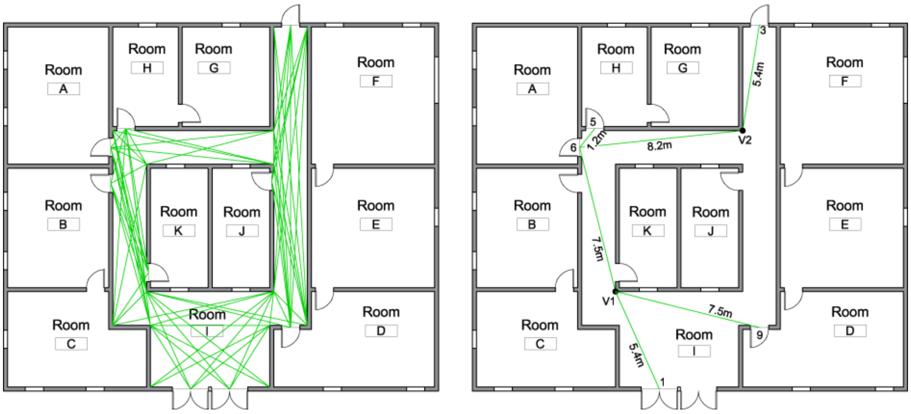

Figure 3. Network graph of room I, using the doors and the vertices of the room as nodes (left). The shortest travel distance between door 6 and other four doors of room I (right).

Table 1. Adjacency matrix of room I. D stands for door, V stands for vertex. Room I contains 9 doors and 14 vertices.

	D1	D2	D3	D5	D6	D7	D9	D12	D13	V1	V2	…
D1	0	1.9	∞	∞	∞	∞	∞	∞	∞	5.4	∞	
D2	1.9	0	∞	∞	∞	∞	∞	∞	∞	6.5	∞	
D3	∞	∞	0	∞	∞	∞	15	7.9	∞	∞	5.4	
D5	∞	∞	∞	0	1.2	2.9	∞	∞	7.3	8.3	7.7	
D6	∞	∞	∞	1.2	0	1.8	∞	∞	6.5	7.5	8.2	
D7	∞	∞	∞	2.9	1.8	0	∞	∞	4.9	5.8	∞	
D9	∞	∞	15	∞	∞	∞	0	7.4	∞	7.5	9.9	
D12	∞	∞	7.9	∞	∞	∞	7.4	0	∞	∞	2.5	
D13	∞	∞	∞	7.3	6.5	4.9	∞	∞	0	0.9	∞	
V1	5.4	6.5	∞	8.3	7.5	5.8	7.5	∞	0.9	0	∞	
V2	∞	∞	5.4	7.7	8.2	∞	9.9	2.5	∞	∞	0	
…												

3.2 Testing the validity of the room selecting algorithm

With the proposed room selecting algorithm, we can simulate 30 most critical rooms of a large building using CFAST. The suspicion is that ignoring the rest of the rooms may affect the accuracy of the simulation results for the selected 30 rooms. The question now is that **"how consistent are the simulation results of the selected 30 rooms compared to the same 30 rooms assuming that CFAST could simulate the entire building of more than 30 rooms?"** To answer this question, we ran dozens of test cases to find out the scalability of smoke propagation simulation.

To test the scalability, we modeled a single story building in BIM with exactly 30 rooms (elevator shafts are not counted into the 30 rooms), so that

CFAST can run the entire building without any modification (figure 4). We first simulated the entire floor of 30 rooms (figure 5A). The simulation results are set as baseline that all following simulations were compared to.

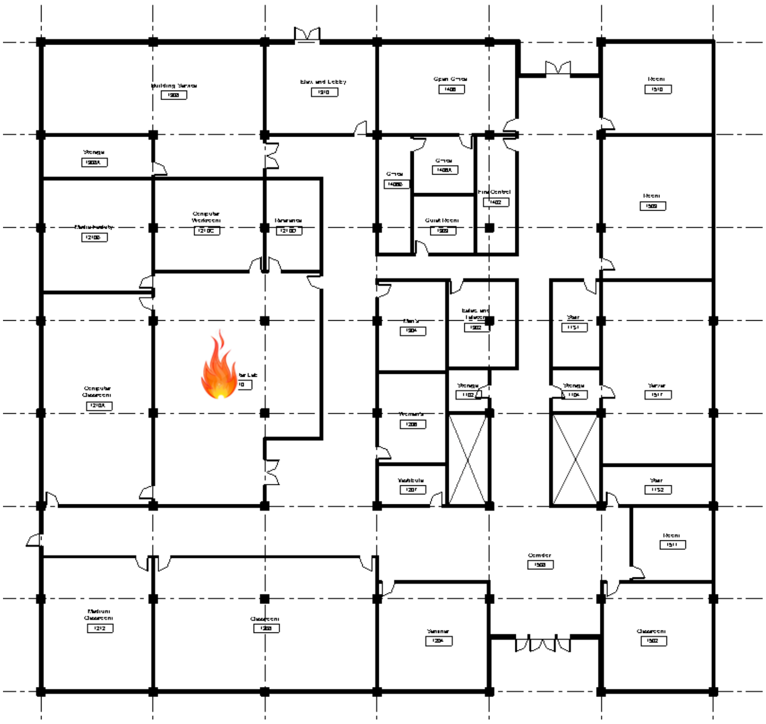

Figure 4. A floor plan with 30 rooms used in the test cases. Two elevator shafts are excluded from the 30 rooms assuming that elevators are not used during building fire evacuation. The flame icon denotes where fire first started.

We then simulated 25 of the rooms that are selected using the proposed room selecting algorithm (figure 5B). By comparing the simulation results of the same 25 rooms with the baseline, we could demonstrate how consistent the simulation results of the 25 rooms are. *Scalability in this study refers to a concept such that "if the simulation results of the selected 25 rooms are close to the simulation results of the same 25 rooms in the 30-room-simulation, selecting 30 rooms out of 35-room building would produce reasonably accurate simulation results, i.e. smoke propagation simulation in CFAST is scalable."* It turned out that the smoke height in the selected 25 rooms is usually slightly lower than the same 25 rooms of the baseline. We then simulated four more cases which are first 20 rooms (figure 5C), 15 rooms (figure 5D), 10 rooms, and five rooms that are selected by the proposed algorithm. The simulation results are compared to the baseline respectively to test the extent of scalability. It turned out that the fewer number of rooms selected, the more discrepancy occurred between the simulation results of the selected rooms and the baseline.

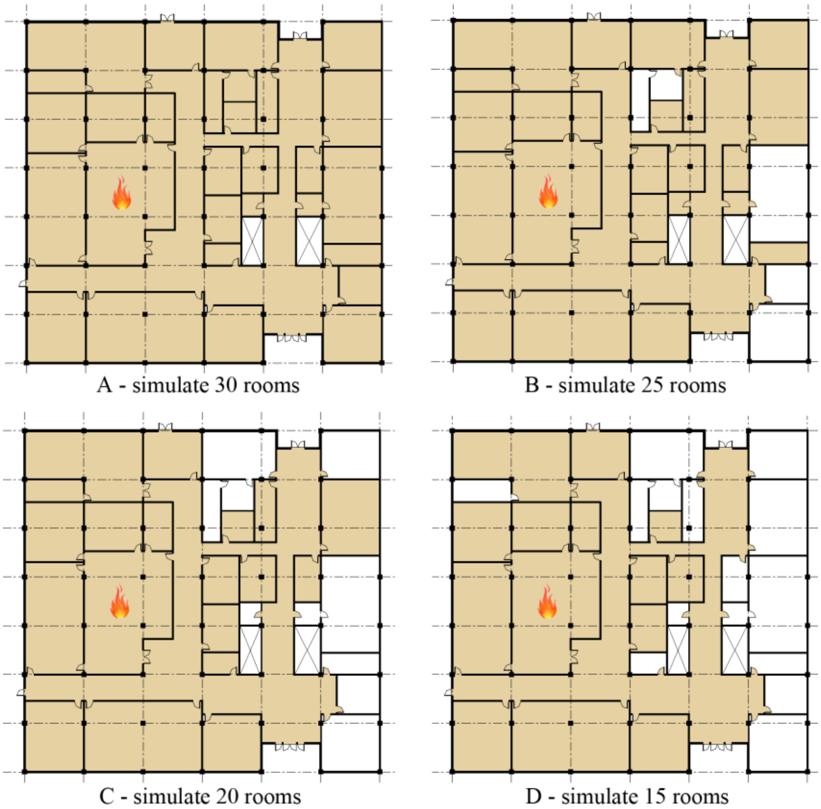

Figure 5. Selecting different numbers of rooms using the proposed algorithm.

We hypothesized that selecting N number of rooms and merging the rest to the Nth room (figure 6, right) to keep the overall volume unchanged would get more consistent simulation results of the first N-1 rooms, compared to ignoring the rest of the rooms (figure 6, left). In the rest of the paper, we will address this issue in short as merging scheme and ignoring scheme. This is possibly because when the overall volume become smaller when using ignoring scheme, the smoke line which separates the upper zone and the lower zone moves downward faster given the same smoke producing rate of the fire source. This hypothesis is later proved to be true.

We also hypothesized that the accuracy of the room selecting algorithm is affected by whether the simulated floor is directly connected to the exterior or not. It turned out that the simulation results are more consistent when the floor is not directly connected to the exterior.

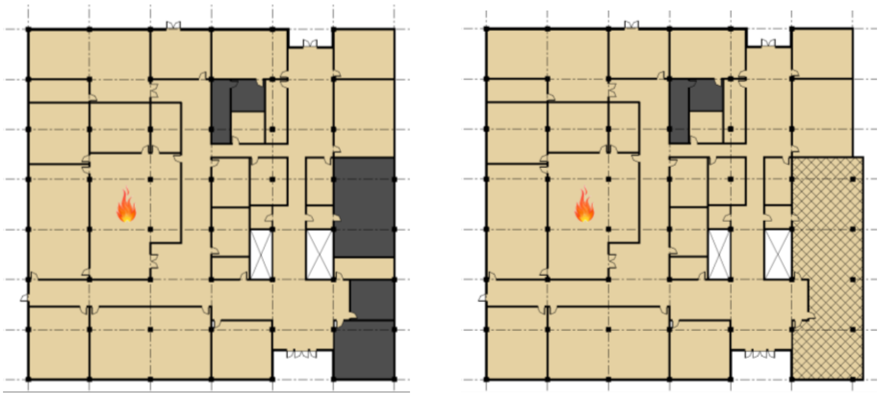

Figure 6. In the left figure, the five rooms (in grey) that are furthest from the fire origin by smoke travel distance are ignored in the simulation. In the right figure, the volume of the last five rooms are merged into the next last room which shown as the room in checker pattern. The volume of the two rooms in grey is also merged into the big room which resulted the wall protruded from the column grid. The two rooms in white colour are elevator shafts.

4. SIMULATION RESULTS

We simulated all 30 rooms of the model shown in figure 4. From the visualized simulation results (figure 7), we can see how smoke propagates from the room of fire origin to all the other rooms, and how smoke height changes as simulation progresses.

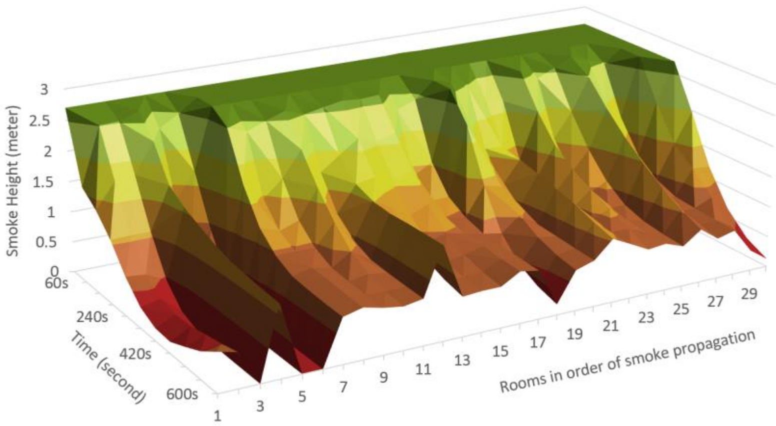

Figure 7. Visualized simulation results showing smoke propagation through time. Room 1 is the fire origin. The rest of the rooms are sorted by the smoke travel distance from Room 1. Ceiling height of the rooms are all set to 2.7 meters.

We then selected 25, 20, 15, 10, and five rooms respectively and ran simulations using both ignoring scheme and merging scheme. The model used in this set of simulations is directly connected to the exterior through several exterior doors. In the simulation results, we selected the two most critical indicators: smoke height and carbon monoxide (CO) concentration. The simulation results are shown as in figure 8-11. The duration of each run is set to 600 seconds. The time step of the simulation is set to every 30 seconds which ended with overall 168 charts. Due to the limited space, we only present the charts at the end of 600 second simulation.

For the interpretation of the simulation results, the green is the baseline that all the others are compared to. X axis denotes the rooms in order of smoke propagation. Room 1 is the fire origin. Y axis denotes smoke height of each room in meters. Line graphs with different colour denotes the simulations with different number of rooms. The smaller the gap from the green line, the more consistent the simulation results are.

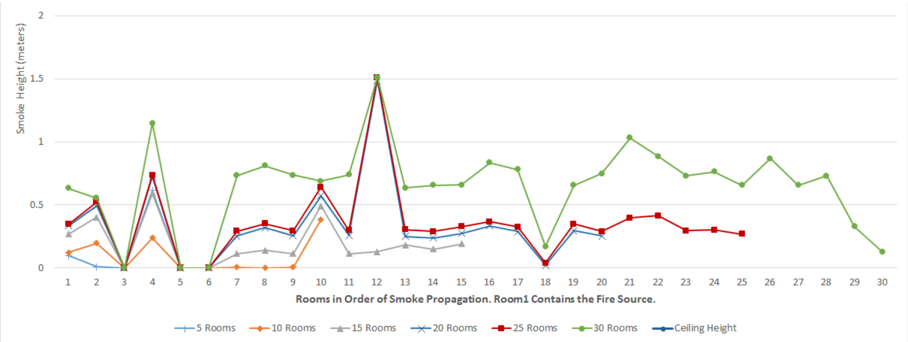

Figure 8. Smoke height with ignoring scheme.

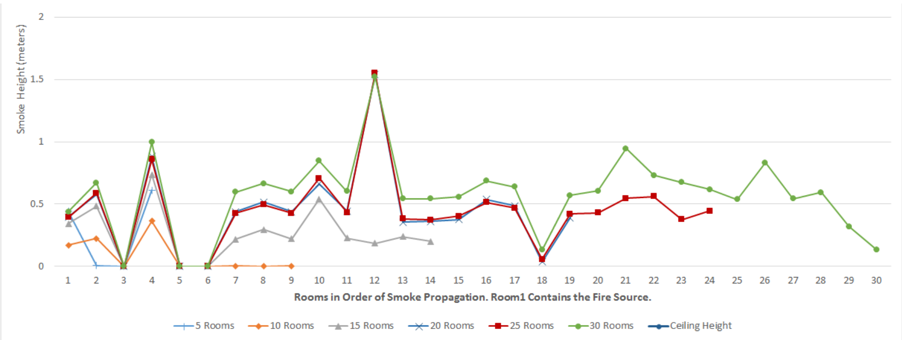

Figure 9. Smoke height with merging scheme.

As for the interpretation of CO concentration, the dash lines are for upper layer, and the continuous lines are for lower layer. The green line (the longest) is the baseline that other simulations are compared to. X axis remains the same, and Y axis denotes CO concentration in ppm.

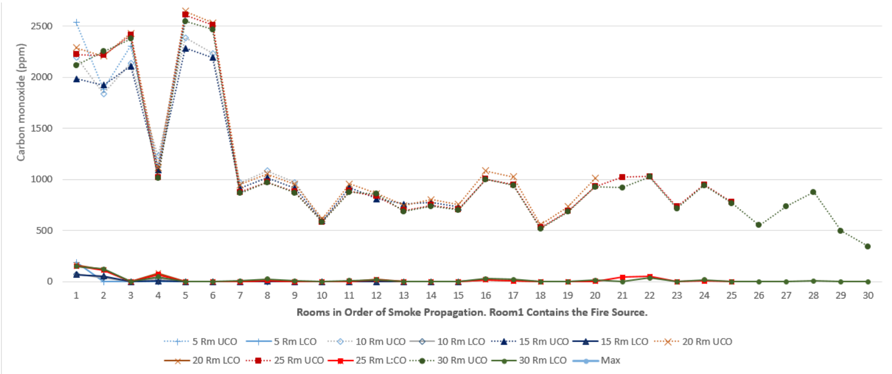

Figure 10. CO concentration with ignoring scheme.

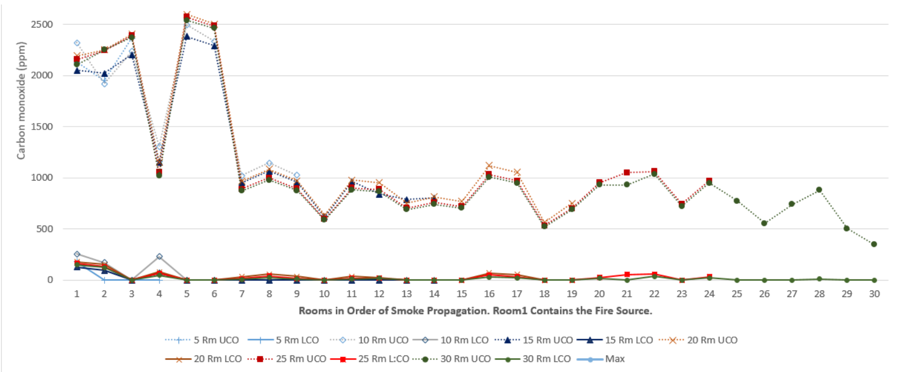

Figure 11. CO concentration with merging scheme.

To test how direct connection to the exterior affects simulation results, we modified the model such that the exterior doors are removed and walls are placed instead, i.e. none of the rooms are directly connected to the exterior. The occupants in the building are assumed to evacuate through staircases. We then selected 25, 20, 15, 10, and five rooms respectively and ran simulations using both ignoring scheme and merging scheme for the modified model. The simulation results are shown as in figure 12-15.

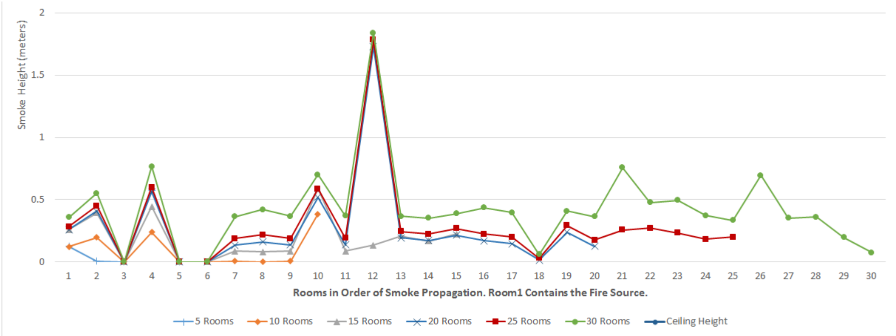

Figure 12. Smoke height with ignoring scheme.

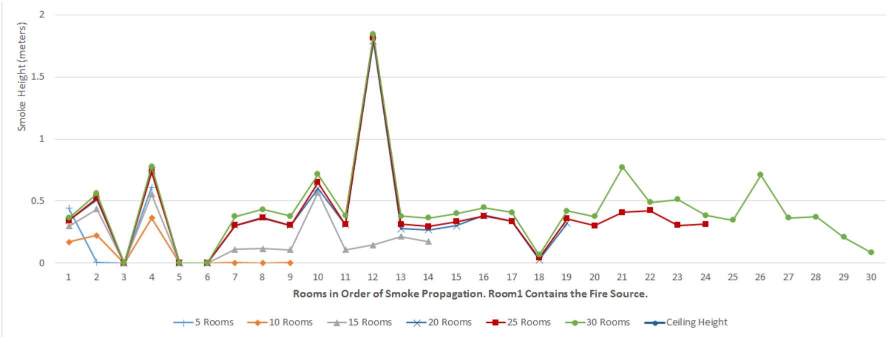

Figure 13. Smoke height with merging scheme.

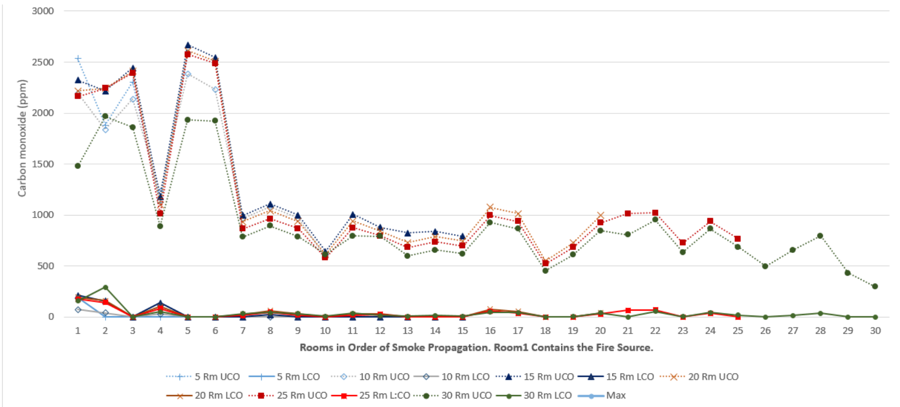

Figure 14. CO concentration with ignoring scheme.

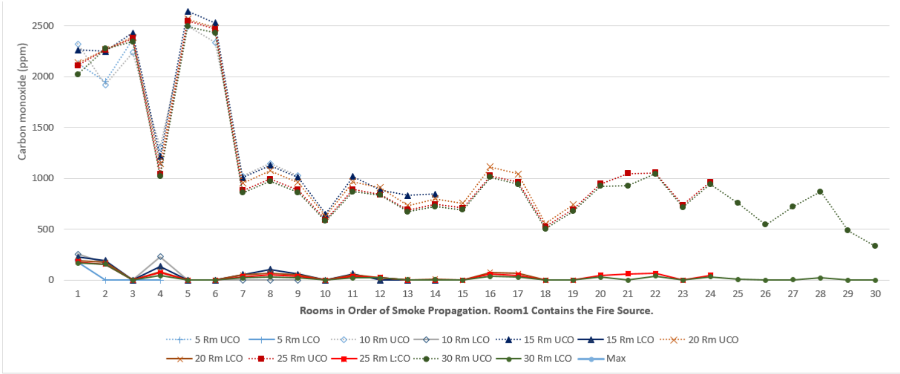

Figure 15. CO concentration with merging scheme.

5. DISCUSSION

All simulation tests showed negligible difference in CO concentration compared to the baseline, i.e. different selection schemes or connection to the exterior does not have much influence on CO concentration. In addition, the CO concentration of lower layer is very low compared to the upper layer even for the room of fire origin.

Merging scheme showed better consistency in terms of smoke height. With the model directly connected to the exterior, ignoring scheme showed approximately 40cm difference in smoke height while merging scheme showed roughly 20cm. With the model that is not directly connected to the exterior, ignoring scheme showed roughly 20cm difference in smoke height while merging showed only around 5cm. This also can be interpreted in another perspective, namely when the model is not directly connected to the exterior, the simulations showed better consistency.

When using merging scheme, simulation of selected 20 or 25 rooms showed 5 - 20 cm difference in smoke height compared to the baseline. This is about 2% - 7% error considering the ceiling height is 2.7meters.

6. CONCLUSION

In study we proposed an algorithm to simulate smoke propagation of large buildings using CFAST. We then verified the validity of the algorithm through test cases. Validation tests showed that merging scheme provides reasonably consistent simulation results. In addition, the algorithm showed better consistency when the model has no direct connection to the exterior.

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A GIS BASED BICYCLE LEVEL OF SERVICE ROUTE MODEL

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Key words: Infrastructure assessment, Bicycle Level of Service (BLOS), GIS modelling, Route level

Abstract: The Bicycle Level of Service (BLOS) concept, as first developed by Landis et al. in 1997 is intended to evaluate the quality of bicycle infrastructure and facilities. Although BLOS appraisal of infrastructure is a spatial problem by definition, GIS has found limited application as yet, mostly due to the complexities of developing an appropriate data model that is able to deal with varying attribute information along segments, at crossings and for entire routes. In this research a new GIS based approach to the modelling of BLOS is developed. Contrary to existing modelling applications, this approach does not address the level of individual segments and intersections only, but develops the BLOS concept at route level. A BLOS model was developed for and in cooperation with the city of Enschede, a city that has high ambitions to make cycling the preferred mode for urban trips and that is interested to find out which role infrastructure plays in the decision of people to choose a particular route. In analysing the model results, the factors shortest distance and shortest travel time dominate cyclists' routes choice in the morning peak.

1. INTRODUCTION

Cycling is becoming a preferred mode of sustainable transportation for many people, because of its characteristics of being healthy, eco-friendly and congestion-reducing. To promote bicycle usage, one of the key interventions is to improve the bicycle network. To do this effectively, it is crucial to evaluate the existing infrastructure and improve the level of service on locations where this is required, in order for the entire network to perform better. The "Bicycle Level of Service” (BLOS) index is a much applied concept to measure the comfort level of infrastructure. It considers physical factors such as traffic volume, through lanes, speed limits, pavement condition, width, and heavy vehicles but also combines these with participant’s perceptions of roadways (Landis, Vattikuti and Brannick, 1997).

Most previous BLOS researches were focused on the scale of segment and intersection, and as such were insufficiently considering the route scale. (Landis, Vattikuti and Brannick, 1997; ; Jensen, 2007; Providelo and da Penha Sanches, 2011; Lowry et. al, 2012; Calister and Lowry, 2013). This is an omission, as it is the level of the entire route that plays a role in people’s route choice, not just individual segments and junctions. Current methods therefore present discontinuity in BLOS assessment at the level of routes and at the level of the entire bikeway network. Consequently, measurement of BLOS at route level is needed to evaluate the bicycle infrastructure, to see how well it is functioning. In addition, whether Geographic Information Systems (GIS) can be used as an analytical tool to support BLOS assessment by performing a series of spatial analytical operations using different indicators to measure BLOS for entire networks. In order to carry out these operations, a new GIS based BLOS model was developed for the city of Enschede, in the Netherlands.

Enschede is the largest city in the province of Overijssel, in the Netherlands. Cycling has traditionally been a very important mode of transport in Enschede with pre- and post-war levels of 80 % and 35 % respectively (Ministerie van Verkeer en Waterstaat, 1999) and current levels at around 34 % of modal split (Gemeente Enschede, 2012). Fostering and trying to further improve this high share of cycling trips, the municipality has proposed an agenda for Enschede to become a cycling city by 2020. The cycling policy of the municipality of Enschede -the bike vision- wants everyone to pick up the bike in 2020. The municipality is building a cycle network with preferred routes in the coming years, so called bicycle streets, where cyclists as prominent road users can make use of connections. The new network is aimed at the densification of the non-stop connections of cycling to the residential areas. This research is investigating bicycle levels of service in the South of Enschede, where a lot of new infrastructure is planned.

The remaining of the paper follows the following structure: Section 2 describes the data collection efforts, where a cyclist intercept survey was held to obtain route data of actual commuting trips and route preference data (section 2.1). Based on the set of selected BLOS indicators, an infrastructure inventory was made by field surveys along the traversed routes indicated by respondents. This process was supported using aerial photos and existing GIS data at the municipality of Enschede (section 2.2).

On Section 3 there is the description about the development and operationalization of a GIS model that allows the registration and analysis of BLOS data at the level of intersections, segments, parts of segments and entire routes (section 3.1). This model was implemented in a network GIS to allow for network analytical calculations (section 3.2), and the operationalisation and calculation of BLOS scores.

Section 4 discusses the results of a GIS based network analysis that was carried out to calculate the BLOS scores of actual routes travelled. On the basis of key infrastructure characteristics, BLOS scores were calculated for the entire road network, allowing the comparison of alternative competitive routes with actual routes chosen. The paper is concluded and recommendations for future research are addressed.

2. DATA COLLECTION

2.1 Cyclist intercept survey

A cycling intercept survey was held to capture travel behaviour of commuters. The targeted respondents were employees of the Municipality and the hospital. The survey sites selected were the office locations of the municipality and the hospital, both in the city center. A questionnaire survey was conducted to collect the home-to-work route choices of these cyclists' in the morning peak. The survey consisted of questions asking the cyclists to draw their preferred route on a map and to state the reasons of their choices. 200 questionnaire forms were handed out, from those 122 were found to contain valid route sketches and preference ranking of route choice reasons.

2.2 Indicator development

In order to be able to calculate BLOS scores at the various scale levels (intersection, segment, route) the service level of both segments and intersections needed to be evaluated first. To this end, a set of indicators was identified to form the BLOS score. The choice of indicators was based on discussions with the municipality and earlier work in the province of Noord Brabant (Provincie Noord Brabant, 2014).

Six indicators pertaining to road sections and signalized intersections were identified to determine the BLOS score, as shown in Table 1. For each indicator, the scoring adopted a 6-point ranking system. The scoring standard was derived from the bicycle facility design principles of Enschede. The sections and intersections were scored based on their service level on a scale from 1 – 6, where 6 indicates the highest service level and 1 the lowest.

The physical data collected from the field and through aerial photo interpretation at the municipality were processed in the GIS, by populating and managing attributes describing the service situation along the roadways.

Table 1. Indicators of Bicycle level of service index

Indicators	**Specification**
Width	Sharing road
	Bicycle lane
	Bicycle path
Vehicle traffic volume and speed limit	AADT
Pavement	Condition
	Colour distinguishing and marking
Waiting times at signalized intersection	Weekdays
On-street parking	Type
Number of intersections	Signalized

For each indicator, the scoring - which was derived from the bicycle facility design principles of Enschede - adopted a 6-points ranking system to make it comparable to the traditional 6-point scoring method introduced by Landis et al. (1997). The worst situations are assigned “6”, the best ones are “1”. The moderate cases are interpolated to be scored.

The principle by which we divide the route into portions (named section) is based on the positions where at least one of the attributes along the roadway suddenly changes. Sections are here defined as parts of routes where any one of the indicators changes its value. As the waiting time at signalized intersections/traffic lights is considered, these intersections would also be a type of the division points. A route has m linear portions and n signalised intersections. In the next section the development of the GIS model that is needed to be able to carry out the BLOS analysis is discussed.

3. GIS MODEL DEVELOPMENT AND OPERATIONALISATION

The BLOS indices at both intersections, (parts of) segments and complete routes were developed within a GIS environment and applied using the cycling routes taken by the respondents as base. The objective of this approach is twofold. First, it enables the capturing of the respective indicator values at the lowest scale; followed by the determination of BLOS scores at route scale. Second the generation of BLOS scores on the basis of route characteristics, such as shortest travel time, within a city-wide network is facilitated.

Starting point of the model for both objectives is a representation of the roads within the study area using road centrelines. Only roads suitable for cycling will be represented.

While traversing a route (combination of road segments) the individual BLOS indicators will potentially change at respectively distinct locations. This happens within road segments as well as across segments. The Linear Referencing System (LRS) is particularly suited to represent this phenomenon. A network dataset will be constructed to allow level of service analysis of routes. Data from the LRS will be processed to among other information populate the Network dataset.

The next sections will discuss the operationalisation of the LRS and Network dataset.

3.1 The LRS model

The LRS stores data utilizing relative positions along existing line features. The logical model of this approach is shown in Figure 1.

In this GIS model, the routes are derived from the original bicycle network, combining each portion to the whole route with directions based on the linear referencing system. The centrelines store the geometry providing the backbone of all the possible routes that can be created. A set of consecutive centreline segments is selected to form a route. A linear measuring system needs to be established to allow projection of the diverse road physical attributes in the form of BLOS indicator values as linear events along the route. This is realised by setting the start of the route at a measure value of 0 and using the units of measure of the map (meters) to create a relative measure system along the route.

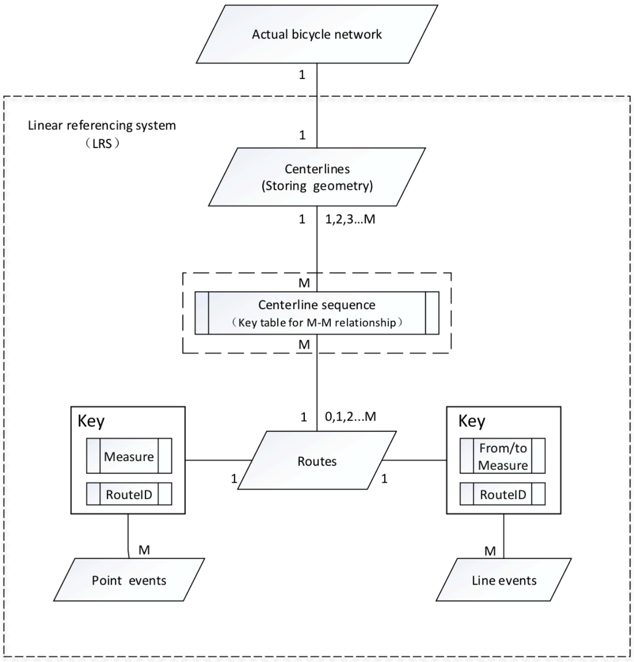

Figure 1 GIS logit LRS-model of routes information storing and management

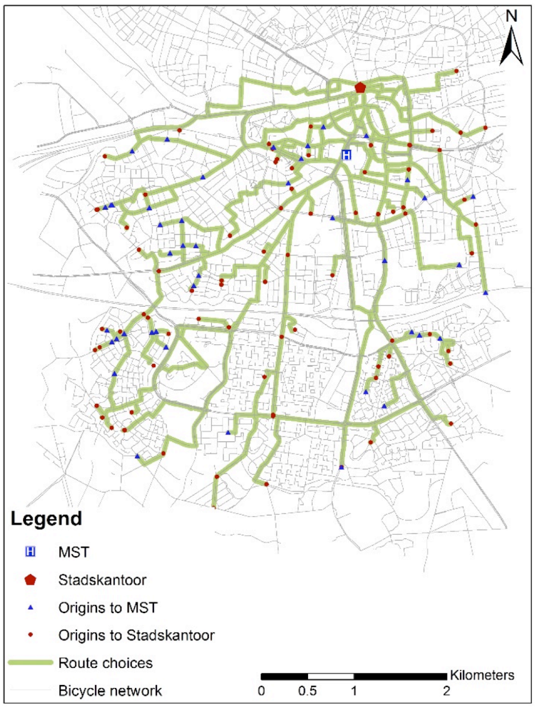

Figure 2 Route choice of respondents

All the preferred routes of cyclists are composed and provided with the linear referencing system where the starting points were located at the MST (local hospital) and the Stadskantoor (municipal main administration building) depending on the respondents' route. Figure 2 illustrates the route set from the questionnaire feedback after digitization. It shows all the routes the cyclists take from where they live to their work place in the morning peak.

The road related BLOS attributes are expressed in terms of event tables in the form of line – and point events. An event is linked to a route using the combination of RouteID and measures under the linear referencing system. Thus, the events of any route are independent to those of the other route, even if they share a common portion. The measures vary by the event type - line events contain a *from* and a *to* measure, whereas point events contain just *one locational* measure.

3.2 Network dataset

To perform level of service analysis on the basis of alternative derived routes, a Network dataset construct is developed. Within the GIS environment this is a topologically sound set of line-features, connected at line intersections only.

The basis for the model is the set of centrelines representing the bicycle network. Two base elements in this model are used: a) segments; lines between intersection and b) signalised intersections. To perform network analysis such as shortest routes based on *travel time* or *minimal distance* both elements need to be attributed. The segment length is the actual length of the segment (meters). The travel time to traverse the segments is computed using the average cycling speed of 15 km/h (Gemeente Enschede, 2011). The time involved at the traffic light is based on the average waiting time (Gemeente Enschede, 2011) at particular crossings (left, right and straight forward) and for some cases 0 (right turn).

Basically all the traffic light crossings in the network are modelled using 'complex' segment compositions called turn relationship. The stored segment composition (for example a left turn) are provided with the respective waiting time as attribute value. Figure 3 gives examples of the turn relationships implemented.

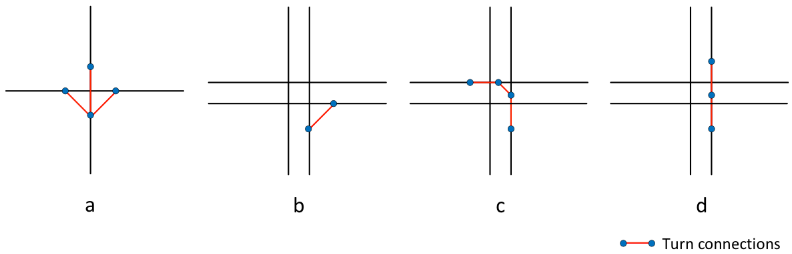

Figure 3 Modelling of intersections

3.3 Definition and operationalisation of BLOS at all scale levels

The cycling routes identified by respondents have been surveyed to record the BLOS indicator values along the routes. Several compositions and combinations of BLOS indicators were used to reveal BLOS scores at all levels. A set of equations was developed to enable processing of the BLOS scores. First the Local BLOS score will be expressed followed by the Route BLOS score.

The Local BLOS score is used to specify the overall BLOS score of a section, part of a route where all respective indicator values remain constant within one section. The LocalBLOS is represented by either a *Line*BLOS, representing a linear part of the route with constant indicator values or a *Point*BLOS representing a signalised intersection.

The *Line*BLOS is calculated by a weighted summation of the different scores of the various BLOS attributes. The *Point*BLOS is based on the average waiting time at a signalised intersection.

$$Local\mathrm{BLOS} = Line\mathrm{BLOS} = \sum_{1}^{n} s_k w_k \quad (localblos = line\ feature) \text{(Equation 1)}$$
$$Local\mathrm{BLOS} = Point\mathrm{BLOS} = \mathrm{WT} \qquad (localblos = intersection)$$

Where,
s_k is the score of the kth indicator (Roadway attribute) of BLOS index;
w_k is the weight of each indicator ($0< w_k <1$);
WT is waiting time

The weighting method is equal-weight in this study. But it can be adjusted in the future. In this case, the LineBLOS and PointBLOS are operationalised by,

$$Line\text{BLOS}=\frac{1}{5}(\text{FT+WD+PT+PV+VS}) \qquad \text{(Equation 2)}$$

$$Point\text{BLOS} = \text{WT}$$

Where,
FT=Facility type
WD=Width
PT=Parking type
PV=Pavement condition
VS=Volume and speed limit indicator
WT=Waiting time

In this case, LineBLOS is the average BLOS score of the 5 line-event attributes (Facility type, width, etc.), and PointBLOS indicates the Waiting Time at the traffic light.

The Route BLOS (RBLOS) is the combination of all BLOS indicators along the route. It is calculated based on the LocalBLOS along the route by means of travel time-normalization. The RBLOS score ranges from 1 to 6, as it is based on the other indicators that fall in this range. The used RBLOS equation is,

$$\begin{aligned}\text{RBLOS}&=\frac{1}{6}\sum(\text{FT+WD+PT+PV+VS})*w_i+\frac{1}{6}\sum\text{WT}*w_j\\&=\frac{5}{6}\sum(\frac{\text{FT+WD+PT+PV+VS}}{5})*w_i+\frac{1}{6}\sum\text{WT}*w_j \qquad \text{(Equation 3)}\\&=\frac{5}{6}\sum Line\text{BLOS}*w_i+\frac{1}{6}\sum Point\text{BLOS}*w_j\end{aligned}$$

Where,

$$w_i = \text{Weight of the ith segment}=\frac{\text{Cycling time}}{\text{Total travel time}}=\frac{\text{CT}}{\text{TT}}$$

$$w_j = \text{Weight of the jth traffic light}=\frac{\text{Waiting time}}{\text{Total travel time}}=\frac{\text{WT}}{\text{TT}}$$

All attributes are equally important and contribute $1/6^{th}$ to the RBLOS.

To reveal the Route BLOS scores of the cyclists' routes the following process was performed after the administration of the indicator values within the LRS system:

- The individual indicator values (Facility type, Width, etc.) will be overlaid with each other per route. This results in so called Sections, (Figure 4). A section is a linear portion of the route where all BLOS indicator values remain constant. Sections will be assigned with a LocalBLOS score being a LineBLOS score; a weighted summation of the different scores of indicator values or *point*BLOS scores; the waiting time at intersection, Equations 1 & 2.

- To reveal the Route Bicycle level of service scores the series of LocalBLOS scores along the route are combined in combination with travel time-normalization using Equation 3. This results in Route BLOS scores (RBLOS) for all respondents cycling routes.

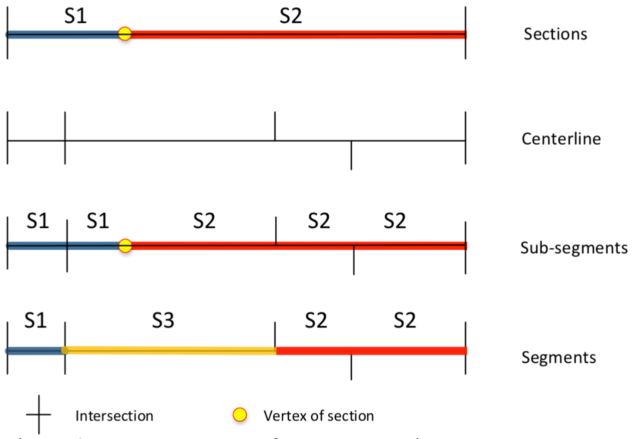

Figure 4 Intersect process of segment acquirement

To be able to use network analysis routines to define alternative routes and in return retrieve corresponding BLOS scores, it is necessary to populate the Network dataset with BLOS values (specifically, the network segments: centreline between two intersections). The following process is performed enabling the BLOS distribution, where the starting point is the Section BLOS score dataset.

- The section score set is intersected with the bicycle network centrelines to retrieve the so-called sub-segment scores, (Figure 4). The actual road intersections present in the centrelines are used here as cutting points of the sections.
- The segment score is then composed by the combination of sub-segment scores through the weighted mean method, as illustrated in (Figure 4, where S1, S2 and S3 represent the different scores. This results in BLOS scores at segments being part of respondents cycling routes.
- The segment scores are used to extrapolate scores to the other segments within the bicycle network. This is done by identifying segments with similar conditions or in similar performance, by means of field surveys and /or aerial photo interpretation, and assigning them with the same scores. This results in a Network dataset, where all its segments have BLOS values assigned.

The combination of BLOS scores at segment scale and signalled intersection BLOS scores within the bicycle network makes a flexible evaluation of bicycle level of service in any combination possible. Using network analysis routines it is now possible to generate 'new' cycling routes on the base of for example highest level of service or shortest travel time.

4. RESULTS AND DISCUSSION

The BLOS GIS model illustrated on the previous section allows the calculation and projection of the indicator values that contribute to the BLOS scores of the commuter routes. The first results of this operation are displayed in Figure 5, in separate maps for each of the indicators.

It is worthwhile to analyse the BLOS results at this disaggregate level of a single indicator for a proper inventory of which indicators are responsible for a low score of a particular street or segment, allowing for a more targeted policy response. At the aggregate level the score generally averages out, which leads to a loss of valuable detail.

Figure 5 shows that there is considerable variety in service level quality at the disaggregate level of a single indicator. In the facility type map we see that the two largest groups of segments are of the type that scores lowest in BLOS score (6, shared road with no marking for cyclists whatsoever), or highest (1, a separate facility for cyclists). The width map shows that generally towards the city centre the width of facilities reduces, leading to a low service level (score of 6), whereas in the more peripheral parts the score is 3.

The picture with parking is also diverse, where a lot of areas have the best score of 1 (no parking on roadside), particularly in the periphery, and the rest scores worse, with on road parking. In addition, the pavement map shows more variety, we see most classes appear in the map, with generally the best quality pavement in the peripheral areas and the worst quality pavement in the city centre, where actually the density of trips is highest and where good quality pavement is most needed. Furthermore, the volume and speed limit map indicates interesting results in which the major traffic axes appear as high speed and low level of service, particularly also in the south of the city, reason for the municipality to develop new route options on traffic calm streets. Lastly, traffic waiting time is generally equal across the city, but routes with less or no traffic lights will obviously have lower scores. As a result this visualization of the individual BLOS scores enables the municipality to prioritize local road improvements and recalculate criteria scores and overall scores.

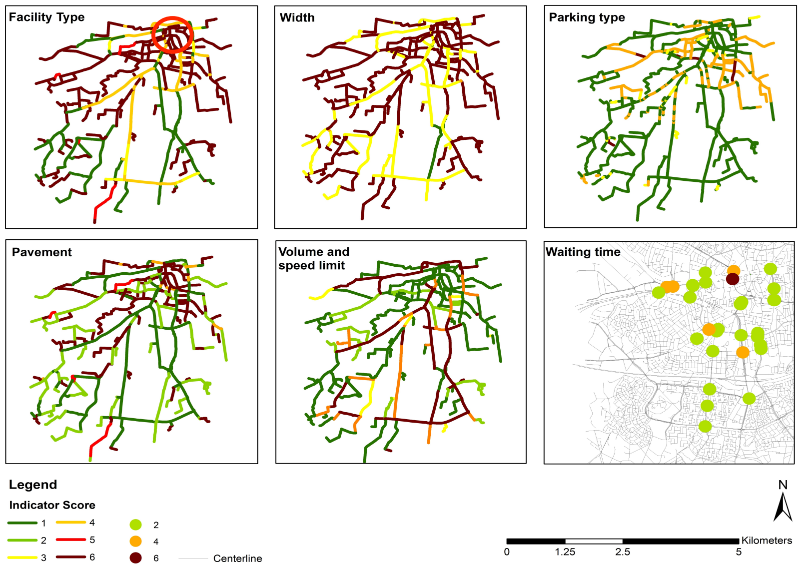

Figure 5 Rated values of the different indicators projected on the real routes

In the next step, the scores of entire routes are calculated, following the methods discussed before. The route BLOS (RBLOS) values of the 122 real routes were calculated by applying Equation 3, and are based on the overlaying of the individual indicator values (segment LineBLOS) and the PointBLOS scores at signalised intersections. The results are shown on Figure 6. Looking at the overall scores, the city centre and a 1 km belt south of it have relatively high BLOS values of 4-5, indicating a low level of service, whereas the more peripheral residential areas in the south have higher levels of service with BLOS scores mostly in the 2-3 range. Although the municipality is focused on improved of the infrastructure in the southern part, these results suggest that equal if not more attention should be paid to the city centre and the residential areas directly surrounding it.

The GIS model also allows us to calculate the scores of each entire route that was ridden by each of the respondents. After evaluation of all 122 routes we find an average and median of the RBLOS for the selected routes of 3 (2.6) and 2 (2.4) respectively. The standard deviation for all routes is 0.48, the best route had a score of 1.4 and the worst route a score of 3.9. As routes are overlapping to a large degree, these results are not shown in map form.

To allow an analysis of how the BLOS of actual travelled routes compares to competing shortest distance and shortest time routes, an extrapolation of BLOS criteria scores to the entire network was done based on characteristics derived from the GIS data base and aerial photos of the municipality. The results of this operation are the BLOS populated segment scores shown in Figure 7.

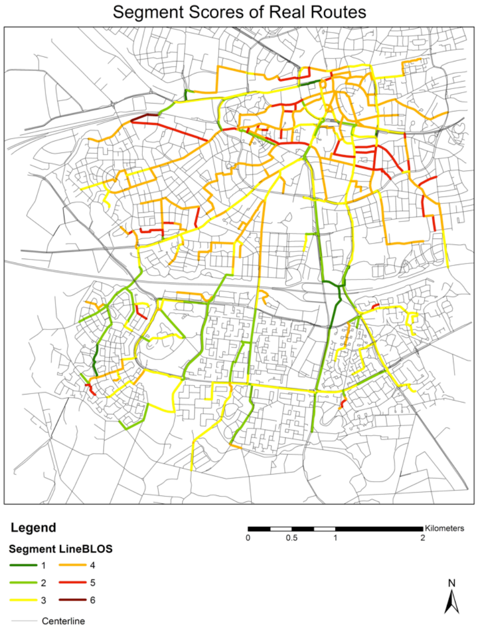

Figure 6 Segment BLOS scores of real routes

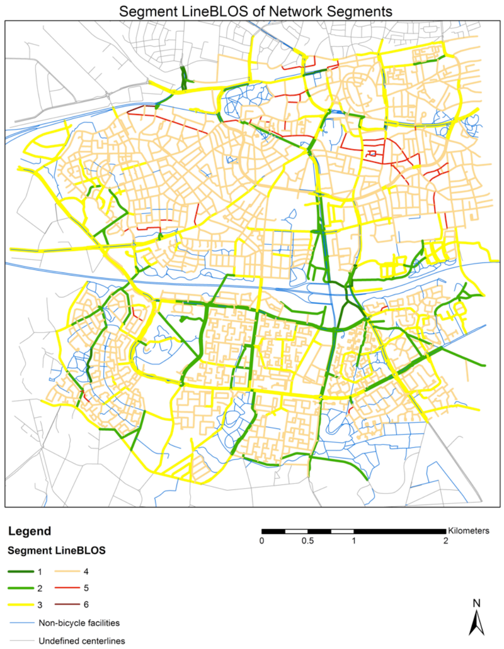

Figure 7 Segment BLOS scores of real routes

Comparing the differences between the real routes, shortest distance routes and shortest time routes, we find that at the aggregate level, the RBLOS scores are quite similar for the real routes and the shortest distance routes, whereas the shortest time routes indicate a slightly lower level of service (Figure 8).

Looking at a disaggregate level, we find that the RBLOS scores do vary considerably between routes, as shown in Figure 9 for the routes to MST. These results imply that there are only a few routes chosen by the commuters that are exactly identical to the shortest distance and shortest time route, although these have been reported as being the most important route choice reasons (table 2).

Table 2 Frequency of the first reason preference

Route choice reason	**Frequency**
Shortest distance	64
Shortest travel time	42
Most safe	12
Most comfortable	17
Other	8
Total	143

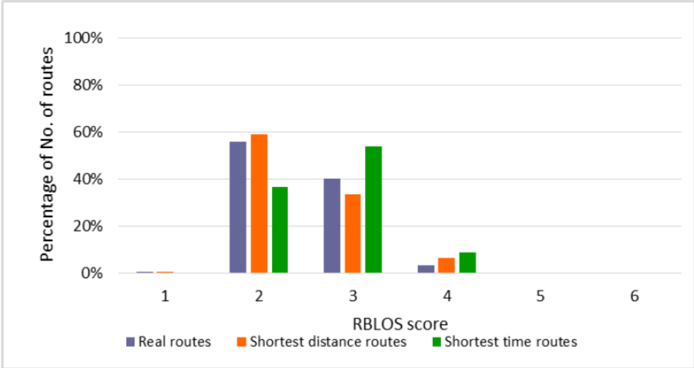

Figure 8 Comparison of RBLOS scores of real routes, shortest distance routes and shortest time routes at the aggregated level

Figure 9 Variation of RBLOS scores for individual routes

5. CONCLUSIONS AND RECOMMENDATIONS

In this research, a BLOS model has been developed for the southern part of the city of Enschede. The BLOS model operates at the level of individual sections, segments, intersections and routes. This allows for an evaluation of bicycle infrastructure quality at route level. For this end, a GIS-based dynamic segmentation model and network analysis model was developed. This model is flexible in evaluating the bicycle system. This model allows to:

- Visualise attributes of a single roadway, to facilitate local improvement of bicycle facilities.
- Visualise the comprehensive service level of the existing and the updated network based on the various attributes, which can be flexibly adjusted.

- Adapt the BLOS calculation to any route or of any O-D pair within the whole bicycle network.

This study has some limitations. The most noteworthy is that theoretically with the segments BLOS dataset acquired, the optimal BLOS routes of certain O-D pairs can be obtained by setting the segment BLOS as the impedance. Nonetheless, the BLOS score is a categorical assessment, which means there is no numerical or multiple relation among these various level values. But the relative magnitude relation exists. For example, the segment that scored 1 point doesn't perform twice as good as the segment that scored 2 points. This implies that the segment BLOS score cannot simply be used as a form of travel impedance.

Future research aims to investigate whether the developed GIS modelling approach may be linked to a discrete choice modelling approach, to better capture which level of service attributes are most appreciated by different user profiles and preferences, and then evaluate whether this translates into actual route choice behaviour.

Acknowledgement

The authors would like to thank Mr. Gerran Spaan from Enschede municipality for his support in organizing data collection and providing access to the GIS system of the municipality.

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Modeling taxi driver dynamic passenger-finding behavior under uncertainty

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Key words: Taxi flows, Passenger search strategies, Uncertainty

Abstract: In many cities, taxis continuously circulate in search of customers. Such dynamic search behavior consumes much road space, contributing to local traffic congestion and air pollution. To better understand movements of vacant taxis, several studies have examined taxi drivers' movement patterns. However, topics such as dynamic passenger finding strategies, endogenous taxi travel demand and drivers learning processes have still been scarcely addressed. This article proposes a model to simulate taxi drivers' dynamic passenger search behavior under uncertainty. The model emphasizes: (i) taxi drivers' subjective utility of passenger finding strategies under uncertainty, (ii) information learning and updating processes, and (iii) the sensitivity to dynamic passengers demand.

1. INTRODUCTION

In many cities in the world, taxis represent a substantial share of the volume of traffic. Modeling taxi demand and taxi driver behavior is thus a key component of traffic forecasting models applied to such cities. Different from other transport modes, taxi transport involves the interaction between taxi supply and passenger demand. Understanding taxi drivers decisions underlying taxi movement patterns may provide guidance for improved taxi supply services and taxi regulation policy. Yang and Wong (1998) proposed an equilibrium based taxi service model, in which the equilibrium state was reached when all customers travel demand was satisfied by vacant taxis. In their model, taxi drivers were assumed to follow a logit model to maximize searching time. Taxi travel demand was treated as fixed and given. Later, Wong, Wong, et al. (2001) considered elastic demand, assumed to depend on customer waiting time, monetary cost and travel time cost. At the same time, the waiting time of customers depended on taxi service supply. Wong, Wong, et al. (2005) formulated a micro-simulation model in which search time costs are not the only consideration, but taxi drivers also make a trade-off between perceived profit and search costs. A perceived probability is added to the drivers search behavior model (Wong, Wong, et al., 2003). In the same framework, additional components are added to the model such as congestion externality (Yang, Ye, et al., 2005a), dynamic customer demand (Yang, Ye, et al., 2005b), uncertainty in expected profit (Wong, Wong, et al., 2005), and multiple user classes and vehicle modes (Wong, Wong, et al., 2008). These models were validated using empirical data (Sirisoma, Wong, et al., 2010; Szeto, Wong, et al., 2013; Ryan, Szeto, et al., 2013). A bi-level model is proposed together with a stated preference survey (Wong, Szeto, et al., 2014). A driver first decides whether to travel to a taxi stand or search on streets, and then decides whether to wait at the stand or to leave to search locally. Zonal choice and circulation time/distance choice in the zone are introduced into the behavioral model in cell-based space (Wong, Szeto, et al., 2014; Wong, Szeto, et al., 2015). Li, Zhang, et al. (2011) used taxi GPS traces to differentiate searching and waiting strategies. Liu, Andris, et al. (2010) analyzed taxis spatial-temporal behavior, route choice and operation tactics.

Generally, these taxi drivers models are built on two basic assumptions: individual maximum profit and system equilibrium. However, three problems remain unsolved in modeling passenger search strategies. First, a taxi is generally assumed to search along the road to have a better chance of finding passengers. The strategy of waiting at a taxi stand was not well discussed, though it has been identified as an important strategy. Waiting is quite common at important transportation facilities such as airports and railway stations because taxi drivers have a good chance of earning more profit in one ride. Second, uncertainty and learning processes were not explicitly modeled. Third, utility models under certainty assume perfect knowledge of individual drivers, but this assumption not realistic in dynamic urban transport systems. Rather, taxi drivers have their subjective beliefs that are imperfect and based on learned past experiences on the basis of which they make decisions. With these considerations in mind, this article proposes a comprehensive model to simulate taxi driver's passenger finding strategies.

In the following sections, we will first present the decision making model under uncertainty and introduce information updating process. Then, to test the basic performance of the model, we illustrate a numerical simulation. Finally we draw conclusions and discuss avenues.

2. MODEL

The proposed model contributes to uncovering mechanisms of drivers' decision making in passenger-finding strategies. To better represent taxi mobility, the following assumptions were made in light of the numerical simulations described in the next section.

(a) The study area is divided into a set of zones i $(i = 1,2,3, \ldots, l)$.
(b) Time is divided into identical intervals denoted by $t = 1,2,3,\ldots, T$.
(c) A taxi can cross one location zone in one time interval.
(d) A taxi makes one decision in a time interval, that a taxi chooses a target location to find next passengers.
(e) A taxi driver experiences the outcome of this time interval t and updates information, and chooses a strategy of next time (t+1).

2.1 The uncertainty model

After having delivered a passenger, a taxi driver has two choice options: search for a new passenger or wait for a new passenger. A searching strategy is revealed when a vacant taxi cruises the road in search of passengers. A waiting strategy is manifested in a vacant taxi is waiting at a taxi stand for the next passengers. Within a certain period of time, a driver can search along the road across several locations, or wait at a specific location until picking up passengers. A driver can combine those two strategies, to head for a specific location to wait and choose a route with higher on road picking-up probability.

At each small finite time interval, a taxi driver decides to go to an adjacent location, reachable within that time interval, or to wait at the current location. A driver makes a decision and updates information in each time interval. After several time intervals, a behavioral pattern can be observed. If a taxi keeps going to different locations, it is in a search mode; if a taxi always stays at the same location, it is in a waiting mode. The purpose of the model is to simulate how taxi drivers make decisions on target locations to find passengers at each time interval. Decision utility of a location consists of the immediate reward and the future rewards. Both immediate and future rewards are derived from attributes of a location. Taxi drivers are assumed to be uncertain about attributes, and learn probability distributions of attributes from their experience. The details of the model are to be presented as follows.

When making a decision, a driver is assumed to choose the location from all possible alternatives that maximizes his expected utility. Let the set of candidate locations be denoted as C=$\{\boldsymbol{i}, 1 \leq i \leq l\}$. Ignoring a subscript for taxi drivers, the decision utility U_{it} of location i at time t consists of the immediate reward R_{it} and future rewards F_{it}. R_{it} is the reward of location i which is adjacent to the current location or the current location itself. If i is adjacent to the taxi's current location, it moves from the current location to i; or a taxi stays at its current location. The immediate reward reflects the probability of immediately picking-up a passenger. At the same time, a driver has to consider the probability of failure in immediately picking-up a passenger, and consider likely future rewards F_{it}. We assume this decision utility U_{it} is given by:

$$U_{it} = \alpha_R R_{it} + \alpha_F F_{it} \tag{1}$$

where α_R is a parameter for the weight of the immediate reward, while α_F is a parameter for future rewards.

Both the immediate reward and the future rewards depend on the probability of finding a passenger after a certain time (waiting time), multiplied by the fare generated by the next trip, and the costs of finding the passenger and delivering the passenger at his/her destination. Income I_i^t is the profit of the next ride after picking up passengers at i, consisting of the base fare and the fare per distance unit. Fuel cost C_i^t is the cost of fuel consumption. A trade-off exists between increasing travel costs to search other locations and reducing travel costs by waiting at the current location. Waiting time W_i is defined as the time the taxi needs to wait to get new passengers. The waiting time W_i depends on the demand for taxis at a particular location and the competition, i.e. the supply of taxis at that location. If passenger demand is larger than taxi supply ($D_i^t \geq S_i^t$) a taxi picks up passengers without waiting, otherwise ($D_i^t < S_i^t$) it has to wait for at least one interval or leave. The waiting time W_i is then determined by the time it takes to observe $D_i^{t+k} \geq S_i^t - D_i^t$, where D_i^{t+k} is the demand at i after k time intervals. In case $D_i^t < S_i^t$, the new taxi arrives to see that $S_i^t - D_i^t$ taxis are already waiting. The newly arriving taxi can pick up passengers when the newly generated demand D_i^{t+k} is larger than the number waiting taxis $S_i^t - D_i^t$. Waiting time reflects the probability of successfully picking up passengers after some designated amount of time. The less the waiting time, the higher the utility for that location.

Both the immediate reward and the future rewards are inherently uncertain, because taxi drivers do not have perfect information and thus need to make decisions about uncertainty events and imperfect information. When choosing a taxi stand, a taxi driver does not know the waiting time at the stand and the income generated from his next trip. The decisions they make should be based on their limited subjective knowledge, which can only be learned from their past experiences. Therefore, the formulation and application of taxi driver behavior models should take uncertainty and imperfect information into consideration. A recent introduction to uncertainty theory in mobility studies can be found in Rasouli & Timmermans (2014).

To model the decision making process under uncertainty and imperfect information, a layer of subjective beliefs is to be introduced. Subjective beliefs on attributes of each alternative location of taxi drivers are formed based on their past experience. Waiting time and income are assumed uncertain in the paper. The imperfectly known uncertainty of the attributes is represented in terms of probability distributions p_{iW} and p_{iI}, respectively. Based on their decisions, taxi drivers learn and update their beliefs in each time interval.

Behaviorally, in this study, we assume that taxi drivers maximize their expected utility. We admit this is a primitive assumption that does not capture risk-taking or risk-avoiding behavior. It serves as a benchmark as we plan to develop more sophisticated decision models later. The expected value model, which states that the overall expected utility V_i can be derived by taking the expectation of the outcome evaluations x_i over the probability distribution p_i. That is,

$$V_i = \sum_{k=1}^{K} p_k v_k\,; \;\; v_k = h(x_k) \tag{2}$$

where V_i is the utility of alternative i on an attribute, v_k is the possible outcome value, p_k is the probability of outcome v_k, and x_k is the possible attribute value. Outcome value v_i depends on the form of $h()$. Using linear value function form we have $v_i(x_i) = x_i$. In our model drivers learn probability distributions (p_{iW} and p_{iI}) of attributes of waiting time W_i and income I_i. With learning they adjust their subjective beliefs, which results in a changing expected utility and improve their strategies.

The probability of immediate picking-up equals the probability of zero waiting time $p_{iW=0}$, and the rest part of waiting time distribution $p_{iW>0}$ reflects the future reward. Therefore, the expected utility of location i consists of expected immediate reward and expected future reward:

$$U_{it} = p_{iW=0}R_{it} + \beta p_{iW>0}F_{it} \tag{3}$$

$$F_{it} = \sum_j R_{jt+} \tag{4}$$

where β is a parameter of future reward, location i is an alternative location of this movement, j is a location can be reached from i, R_{jt+} is the reward a taxi can get from location j in the future. When immediately picking-up a passenger, a driver gets an immediately a reward, thus its utility is found by multiplying zero waiting probability $P_{iW=0}$ and expected profit V_{it}; otherwise a driver evaluates the future reward F_{it} of i, and multiplies its probability $P_{iW>0}$. A better reward R_{jt+} from location j contributes to a better future reward in location i. A summation of reward of all reachable locations from i is its future reward F_{it}.

The immediate reward is:

$$R_{it} = \sum_{I_i} p_{iI}I_i - C_i \tag{5}$$

where I_i is perceived possible income of location i, and p_{iI} is its probability distribution. As space is divided into cells, travel distance is discrete, so expected income is in summation form. C_i is the fuel cost to travel to location i, and it is certain without considering traffic congestion.

The reward of candidate zone j in the future involves waiting time uncertainty and income uncertainty. Similar with equation (5), the expected income of one ride is $\sum_{I_j} p_{jI}I_j - C_j$. In all possible waiting time, the expectation of R_{jt+} is:

$$R_{jt+} = (\sum_{I_j} p_{jI}I_j - C_j)(p_{jW=0} + p_{jW=1} + p_{jW=2} + \cdots + p_{jW=T}) = \sum_W p_{jW}(\sum_{I_j} p_{jI}I_j - C_j) \tag{6}$$

In dynamic choice theory, uncertainty of future reward becomes increasingly large, so that future reward is usually discounted by a parameter γ. Then equation (6) becomes:

$$\begin{aligned} R_{jt+} &= (\sum_{I_j} p_{jI}I_j - C_j)(p_{jW=0} + \gamma p_{jW=1} + \gamma^2 p_{jW=2} + \cdots + \gamma^T p_{jW=T}) \\ &= \sum_W \gamma^W p_{jW}(\sum_{I_j} p_{jI}I_j - C_j) \end{aligned} \tag{7}$$

When evaluating potential reward of j, a driver also considers how long time it needs D_{ij} to reach j from i, and the time lag effect is also reflected by the discount parameter $\gamma^{D_{ij}}$. Then the future reward of j becomes:

$$R_{jt+} = \gamma^{D_{ij}} \sum_W \gamma^W p_{jW}(\sum_{I_j} p_{jI}I_j - C_j) \tag{8}$$

Substituting equations (4)(5) and (8) into (3) we have the final form of utility:

$$U_{it} = p_{iW=0}(\sum_{I_i} P_{iI} I_i - C_i) + \beta p_{iW>0} \sum_j \sum_W \gamma^{W+D_{ij}} p_{jW}(\sum_{I_j} p_{jI} I_j - C_j) \tag{9}$$

2.2 Learning and updating strategies

Bayesian updating theory provides a framework for updating subjective beliefs. In Bayesian updating theory an individual is assumed to hold initial knowledge of p_W and p_I, represented by a prior probability density function, of all possible outcomes in an uncertain event. An individual begins to update this initial information once he/she participates in the event. With new information obtained from the experience, an individual updates subjective belief into a posterior probability density function. After observing several outcomes from an event, an individual tend to estimate subjective probability density function closer to the reality. Bayesian procedure of conditional probability is adopted to this updating process.

Taxi drivers update their beliefs on waiting time p_W and following income p_I at taxi stand i, after they experience a number of outcomes on that location. As indicated above waiting time is determined by dynamic latent taxi demand and supply, the probability distribution of waiting time is in a dynamic competitive system that drivers decision jointly affect the distribution inside. It is problematic to assume waiting time to follow a probability distribution. Instead a set of parameters $\boldsymbol{\theta} = \{\theta_k, k = 0, 1, 2, \dots\}$ define the probability of every possible discrete waiting that:

$$p_{iW=k} = \theta_k \ \ (k = 0,1,2, \dots) \tag{10}$$

where k is the number of intervals that a taxi needs to wait for. The posterior density distribution of $\boldsymbol{\theta}$ is given by (Train, 2009):

$$K(\boldsymbol{\theta}|W) = \frac{L(W|\boldsymbol{\theta})k(\boldsymbol{\theta})}{L(W)} \tag{11}$$

where $k(\boldsymbol{\theta})$ is the prior density of $\boldsymbol{\theta}$, $L(W|\boldsymbol{\theta})$ is the likelihood of waiting time condition to $\boldsymbol{\theta}$, $L(W)$ is the marginal probability of W satisfying $L(W) = \sum_{\boldsymbol{\theta}} L(W|\boldsymbol{\theta})k(\boldsymbol{\theta})$.

Since travel distance is generally believed to follow a power law distribution, the income is also power law distributed:

$$P_I = \alpha I^{-\beta} \tag{12}$$

where α and β are to be updated. The posterior density distribution of α and β are:

$$K(\alpha, \beta|W) = \frac{L(I|\alpha, \beta)k(\alpha, \beta)}{L(I)} \tag{13}$$

3. NUMERICAL SIMULATION

A numeric simulation was conducted to test one of the key mechanisms of the model. The essential question that is addressed in this paper is: can the model successfully react to dynamic demand and competition? Examining passenger demand and taxi supply at the airport is a good illustration of this question. An airport is a special location in a city. It has a highly time-dependent passenger demand. Accordingly, there is a strong competition. Passenger demand at an airport is dynamically changing, reflecting the typical patterns of arrivals and departures that characterize hubs in the airline network. Airports are usually located in an outer zone of a city, and its nearby locations are not good options for taxis. Taxi drivers expect high rewards and have to judge whether such relatively high rewards exceed the relatively high costs of going to the airport. More specifically, because of the high competition, a taxi may have to wait a long time in the queue. Once a passenger is pick up, taxi drivers face the uncertainty where the passenger has to go. If the downtown is the destination, the taxi driver will accrue a substantial fare that may justify the time driving to the airport and the idle waiting time at the airport. However, the passenger may also have to go to the closest hotel to the airport, implying that the taxi fare will be low and the taxi has to return to the end of the queue or decide to search for passengers elsewhere in the city.

The aim of the numerical simulation is to examine whether the proposed model is sensitive to dynamic demand and supply change. Some components, which are important but not our initial concern, are not stressed. First we give partial information of passenger demand of airport to taxi drivers. Drivers are informed about average waiting time when there is no competition. However, they still need to learn the probability of immediate picking-up a passenger from their experience. Second, the expected income of the next trip from a location is given to taxi drivers. Third, the subjective waiting time of a location is calculated as the average experienced waiting time, rather than as a probability distribution. The details of simulation are as follows.

A space of 400 km^2 was created and divided into 400 grid cells. These grids were divided into 42 as inner grid cells, 127 intermediate grid cells, 231 outer grid cells, and one location as the airport. Assuming the searching speed of taxis is 10 km/hr, crossing a grid cells takes 6 minutes. Thus, one time interval represents 6 minutes. A pool of 800 taxis was created. According to observations of taxi GPS records, these 800 taxis correspond to a real demand of 30000 passengers on a single day and 125 passengers per time interval. Passenger demand generation rates were set at 1.2 passengers/interval for inner grid cells, 0.5 passenger/interval for intermediate grid cells, 0.06 passenger/interval for outer grid cells, and 2 passengers/interval for the airport. Passenger arrival rates at a certain location are related to locational type, which is the same to its passenger generation rate. Arrival probability at the airport is higher than for other locations according to its demand generation rate.

We assume that taxi drivers build up subjective beliefs based on their experiences. At the beginning, taxis are distributed randomly across the 400 grid cells. Because at the start, taxi drivers are completely ignorant and therefore uncertain, their subjective beliefs about waiting times are assumed to reflect a uniform distribution and given a high initial value. They need to learn and update information of the location in the simulation process. The simulation is a discrete time simulation, in which one iteration represents one time step. Each time step represents 6 minutes in real time, which determines the demand generation rate in a time interval. The setting of real time length in a time interval, does not affect behavioral patterns of taxis in this numerical simulation. The simulation was run in 400 intervals, thus representing 40 hours in real time.

We assume that taxi drivers are generally aware of flight arrivals and departures. To reduce simulation time, the generation rate of the airport was initially informed to all taxis drivers. After simulating a period of time, we increased the demand generation rate at the airport to 5 passengers/interval between time intervals 311-340. Taxi drivers were assumed to know this new demand generation rate.

Any successful model should exhibit the property that an increasingly larger number of moves to the airport in view of the expected increased passenger demand. If taxis leave their grid cell too late, they will arrive at the airport too late and thus may have to wait for a longer time or arrive by the time all passengers arriving during that peak time have been served. If they arrive too early, drivers will need to wait unnecessarily long, which is inefficient and has a detrimental effect on their generated income and profit. Once the peak is close to over, taxis should avoid the airport for some time. Thus, the utility that drives the actions of the taxi drivers, which has a time discounting effects should be sensitive to these mechanisms.

Figure 1 and 2 show the passenger demand and taxi supply at the airport. The supply consists of new arriving taxis and the waiting taxis from previous intervals. Passengers to be served consist of the number of newly arrived taxi passengers at each interval. At the beginning, taxis are shown to move to the airport. Taxi drivers' expected utility of the airport is large when they have no knowledge of competition of each location. Later on, they have the experience that although the airport may have a high passenger demand, they also face strong competition. Willingness to go to the airport decreases at intervals 100-200 compared to the first 100 intervals. When many taxis learn the strong competition at the airport, their expected utility of the airport decreases accordingly. At the first 200 intervals supply is always larger than demand. Each time there are new passengers, they are all picked up in the interval.

Then, in the next time period, passenger demand is larger than supply. During intervals 200-250, the number of taxis at the airport is not enough to satisfy the newly generated passengers. Accumulative unserved passengers increase as a result. It can be seen from the peak of Figure 2. However, this situation does not last long; taxis react to the new opportunity later (time 250-300). From time 311-340, taxis meet peak hours of demand. As in the simulation taxis are informed about the forthcoming peak hours, they adjust their decisions immediately. From the graph, a taxi supply peak appears at time 311-340. More taxis come to the airport to react to the peak hours demand. After that taxi supply fluctuates and drops down again. The illustrated example proves the model can successfully capture the dynamic change in demand and competition.

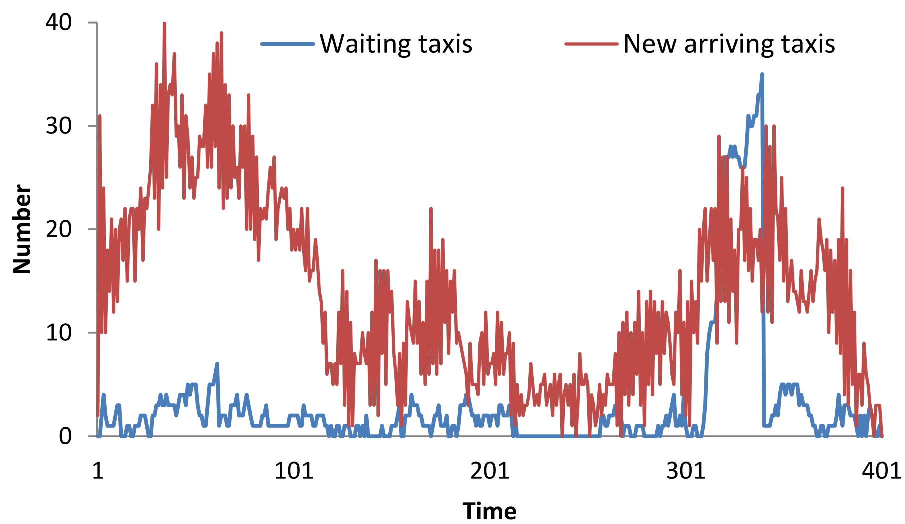

Figure 1. Taxis to provide service at the airport

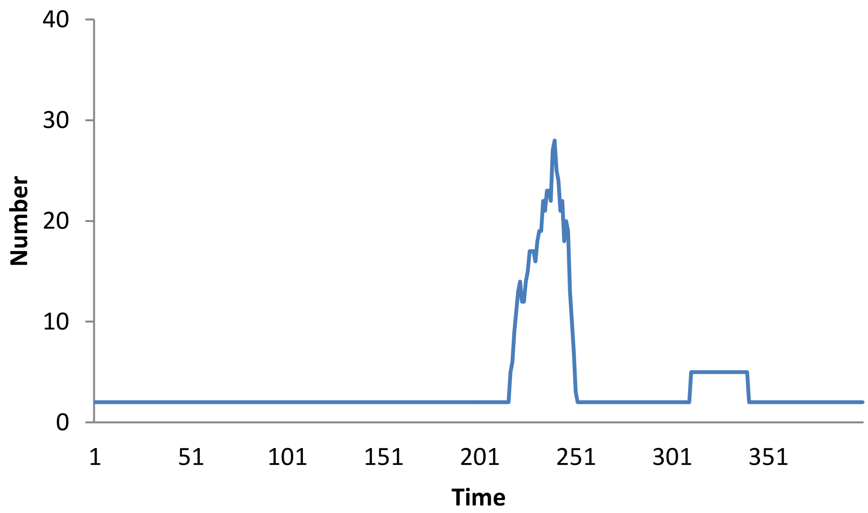

Figure 2. Passengers to be served at the airport

4. CONCLUSIONS AND DISCUSSION

This conference paper, with reports work in progress, has documented the results of a numerical simulation to examine the performance of a micro-simulation model of taxi driver behavior. The ultimate aim of a taxi driver is to make sufficient or maximum profit at the end of the day. These profits are the difference between the total collected fares minus the operating costs of the taxi, which are largely determined by fuel costs. Thus, basically, taxi drivers have to decide between making more frequent shorter trips and less frequent, but longer distance trips or any combination of these. They need to make such decisions in an inherently uncertain environment that results from uncertain time-varying passenger demand and uncertain (strategic) behavior of their competition. In case of the absence of real-time information and an ordering and taxi allocation system, taxi drivers need to make decisions under uncertainty and partial and imperfect information, which is based on their previous experiences, exchange of information, and which can only be reduced by their learning experience under stationary passenger demand.

Because demand is time-depending and may not be instantaneous, taxi drivers also need to decide to act reactively or proactively. In the latter case, they need to look into the future and weigh the increasing uncertainty propagation of their actions and how successful they turn out to be. Thus, the predictive success of the model largely depends on the sensitivity of the time-discounted utility function underlying the possible actions of the taxi drivers.

The ultimate aim of this project is to include taxi drivers personal beliefs, which represents their imperfect information about inherently uncertain events, learning and adaptions in the model. That version will also include advanced notions of decision making under uncertainty and imperfect information. The current version is simplified in that near-to-perfect information and expected utility drive the decisions of taxi drivers. We plan to report the full version in future papers.

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