Available online at www.sciencedirect.com
ScienceDirect
Transportation Research Procedia 12 (2016) 634 – 643
Transportation Research Procedia
www.elsevier.com/locate/procedia

The 9th International Conference on City Logistics, Tenerife, Canary Islands (Spain), 17-19 June 2015

Towards a collaborative Geographical Information System to support collective decision making for urban logistics initiative

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Abstract

This paper describes how a Geographical Information System (GIS) applied to urban logistics can be used for modelling complex urban freight situations, such as those related to the 'last mile deliveries'. It also highlights the fact that combining a GIS with tangible technologies enables creating a collaborative tool that can be used by a wide range of logistics stakeholders, even the non-specialists. It is explained how this collaborative GIS has been subject to experimenting in workshops related to urban logistics in European cities (London, Brussels and Luxembourg). The specific case study of Luxembourg is detailed. Finally, the paper stresses the key benefits of such a collaborative GIS, namely to foster discussions around specific topics and to make collective decisions.

Peer-review under responsibility of the organising committee of the 9th International Conference on City Logistics

Keywords: urban logistics; geographical information system; collective decision; tangible interface; last mile; urban freight; intelligent transport system

1. Introduction

While numerous studies have explored the usage of Geographical Information Systems (GIS) as Intelligent Transport Systems (ITS) for city logistics, this paper explores how such system could be opened to a wide range of stakeholders to support collective decisions. With a review of the R&D initiatives in the field of ITS applied to city logistics that rely on the use of GIS, the authors demonstrate the interest of GIS for analysing local city logistics

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Peer-review under responsibility of the organising committee of the 9th International Conference on City Logistics
doi:10.1016/j.trpro.2016.02.017

contexts and for making decisions related to the development of improvement initiatives. Then, the authors describe how, during a European project, a GIS for urban logistics stakeholders (municipalities, transport providers, retailers…) has been set up. The authors describe how relevant data were selected, collected, implemented, and represented with the aim of being used by non-specialists. They then describe how a GIS can be combined with tangible technologies to be used within a collaborative approach. Next, the authors expose a case study, presenting three situations where a GIS has been used for the City of Luxembourg. Finally they conclude on the benefits of such a collaborative GIS and they present foreseen future works.

2. Research background

Urban distribution plays a major role in cities' economy by supplying retailers, individuals, food businesses, offices, administrations or construction sites. It contributes significantly to environmental nuisances and has become a major challenge for public policies. The transport of urban goods in cities contributes to traffic jams with around a fifth of the road occupancy. Freight transport generates local harmful pollutants like carbon monoxide (CO), nitrogen oxides (NOx) and particles (PM10 and PM2.5) up to 20% - 60% depending on the pollutant. In cities, road transport is the major generator of noise which starts to be considered as a public health problem. However for many years, urban transport strategies have mostly focused on passengers. Now taking into account the development of e-business and the new dynamic of local shops in cities centres, difficulties generated by the transportation of goods in urban areas have considerably raised.

Lindholm (2010) stresses the fact that freight transport is rarely considered in urban planning, denotes the lack of knowledge sharing among stakeholders involved in urban freight transport, and argue for more collaboration on the issue driven by public bodies (in particular municipalities). Both van Rooijen and Quak (2014) and Witkowski and Kiba-Janiak (2014) confirm this situation and relate the low level of cooperation between local authorities and other urban logistics stakeholders while stressing the need for such clear communication and cooperation between stakeholders on urban freight issues. One can note that the lack of collaboration and knowledge sharing is neither new and nor inherent to city logistics but is rather generic by nature. Hall, Moore, Knight, and Hankey (2009) expose such case in an environmental context (oyster fisheries in New-Zealand) and show that the collaboration around a GIS is fruitful in filling this gap. GIS seems then to be a possible solution for collaboration and collective problem resolution. Any improvement approach starts by a clear representation of the current situation so as to identify problems that occur as well as improvement opportunities. Applied to urban logistics, a GIS allows to structure domain knowledge so as to make an assessment of the city logistics activities, and to develop and test scenarios of urban planning, regulations, and logistics operations. A GIS system allows to model complex situations both through large data sets and the data interactions. In addition, offering a visual representation of such data helps the collective understanding of situation. Thus, a GIS offers a communication channel that can be used to share knowledge with any kind of stakeholders, whatever their level of expertise in the domain.

2.1. Public Participation GIS

The collective usage of GIS have been studied in the environmental field and in urban planning (Balram, Dragicevic, and Feick (2009)). When the GIS usage includes the broad participation of the public, this usage is qualified as Public Participation GIS (PPGIS in short). Salter, Campbell, Journeay, and Sheppard (2009) describe the combined use of a PPGIS and immersive technology during specific workshops and the successful stakeholders' collaboration on urban planning issues. Bugs, Granell, Fonts, Huerta, and Painho (2010) explain the building of a PPGIS prototype for urban planning and assess the participation level after the deployment of the prototype. Davies, Selin, Gano, and Pereira (2012) show that participatory GIS have been used in many different areas and have demonstrated that they foster the participants' engagement in collective decision making in urban planning contexts.

Various technological approaches to PPGIS exist. In Table 1, we compare the type of interactions between participants (synchronous or asynchronous), the qualitative number of participants in the collaboration, and the capacity of the participants to interact with the GIS models (directly or indirectly) with regard to the type of PPGIS technological approach.

Table 1. Comparison of PPGIS technological approaches

	GIS used in collective sessions on-site	Web-GIS used on-line	Immersive technology	Tangible technology
Participants' mutual interactions	synchronous	mostly asynchronous	synchronous	synchronous
Number of participants	moderate	potentially unlimited	limited	moderate
Participants' interactions with the model	indirect	direct	indirect	direct

The less technological approach for PPGIS is to use a GIS, whatever its underlying technology, in a dedicated and collective session with participants. In this situation, the participants however do not interact directly with the model, but often through a moderator or a presenter. The most frequent option for PPGIS is to use web technologies for accessing or interacting with the core of the GIS. Indeed web-based systems have demonstrated since years that they do enable a wide public participation when used on-line, with potentially no limit to the number of participants. The drawback is that such configuration applied to GIS rarely allows synchronous interactions between participants. However initiatives of PPGIS that use other technological artefacts in addition or in substitution to web-based systems have been explored. As already mentioned, Salter, Campbell, Journeay, and Sheppard (2009) combines PPGIS with immersive technology: a wide screening system displays the GIS models to a limited set of users who can interact among themselves but not directly with the GIS model. Also for urban planning, Maquil, Zephir, and Ras (2012) propose a tangible table: a system in which users can handle tangible items to interact with the GIS models and immediately see the results of their actions and decisions on the table screen.

2.2. Research method

The authors' proposal is to set up a City Logistics PPGIS, to raise awareness among stakeholders and to assess its interest for stakeholders' collaboration. The research questions driving these works are double: (a) which methods are effective to deploy a GIS for city logistics? (b) how to make the city logistics stakeholders share a common understanding of an issue specific to urban logistics and jointly formulate improvement proposals?

To answer these questions we applied a method inspired by design-science research methods (DSRM). DSRM have been used in information systems research (Hevner, March, Park, and Ram (2004)) and more recently in organizational management research (Jelinek, Georges, Romme, and Boland (2008)). Focusing on "human-constructed" concepts (the "design" part of "design-science"), DSRM follow so-called design-research cycles where research findings lead to practice improvement (deliberate design) through the building of design principles, prototypes and experiments, or the reverse way from practice to research (emergent design) where practice study or even performance lead to research questions. In our case, we followed the emergent design principle by building a research artefact (the Smart City Logistics GIS prototype) for which we studied the usage in various collaboration contexts (online asynchronous, tangible synchronous) and for different purposes (cases analysis, improvement recommendations). As part of the DSRM, building such artefact still requires a scientific anchoring.

To answer the question (a), we took into account challenges like the dissemination and difficulty to aggregate data relevant for urban freight. Allen, Ambrosini, Browne, Patier, Routhier, and Woodburn (2014) argue for the need to standardize the data collection methods. The knowledge structuration requires an important work of data quality improvement. As for awareness raising and dissemination, Sidlar and Rinner (2009) observe that "Crucial characteristics for a successful PPGIS implementation include issue clarity, development of local knowledge, strategic actor relationships, and incremental problem resolution".

As for answering question (b) and partially answering question (a), we already identified from the literature review that PPGIS have proven their positive impact on public participation in environmental research but do not seem to have been widely explored in City Logistics or Urban Freight contexts.

3. Smart City Logistics: a PPGIS for city logistics

As our aim was to build a PPGIS as a research artefact a) that allows participants to interact with the model in a direct way as well as b) that allows synchronous interactions between participants c) that can be used by a large number of stakeholders, we relied on both Web and Tangible technologies to build our PPGIS. As a GIS dedicated to urban logistics, we named this artefact “Smart City Logistics”. The system was built using open-source GIS technologies (PostgreSQL, PostGIS) combined with Web publishing and interaction applications. For the tangible interface, the Web application was ported to a tangible table (Maquil, De Sousa, Leopold, and Tobias (to be published)): a device that provides a horizontal display and tangible interaction capabilities. Thus instead of using an input device like a mouse or a keyboard to interact with buttons and switches of an application, participants manipulate tangible objects to display information and to activate functions of the software application as represented in Fig. 1.

Fig. 1. The Smart City Logistics artefact running on a tangible table

3.1. Data collection

The scope of the data was determined by the scope of our research project (see Acknowledgement). We focused on three European capitals of various sizes: London (UK), Brussels (BE) and Luxembourg (LU). For each of these cities we looked at collecting statistical information relating to the population (e.g. density) and to the economy (real estate prices), freight transport networks (road, rail and waterways), access restriction to specific areas (based on weight, type of vehicle or time slot), transport facilities (gas and charging stations, parking), and urban logistics spaces (consolidation centres, pick-up shops and pack-stations).

The artefact was built taking into account the INSPIRE directive: a European directive which aims at facilitating the sharing of spatial data between public authorities and improving public access to spatial data. However during the identification of possible data sources, we noted that systems fully implementing the directive and providing open-data are scarce. Indeed, very few administrations or public organisations are ready to release the (geographical) data they generate, even for public research purposes. That is why we had to put in place a parallel strategy for collecting background data. On the one hand, for each city we intended to gather the available data directly from the organisations that are the most suited to manage and provide such data. For example, the city’s urban planning department or the traffic management department was contacted for road network data, and commercial websites were consulted in the case of services offered by logistics or energy operators (e.g. locations of delivery points or gas stations). On the other hand, when these data were not available (for technical, legal or organisational reasons), an alternative was to use crowd-generated spatial data, like the one provided by the Open-Street-Map community. Provided by a community, even with some quality control mechanisms, these data are often of lower quality than data provided by a specific organisation. As an example, for describing the same concept (e.g. a road with a cycle lane) the Open-Street-Map community allows two or three different valid data representations. If we want to retrieve all the data corresponding to the same concept, we need to query the data following each of these representations, and to consistently regroup all retrieved data in a next step. Thus the usage of such community data required more work on our side, in order to correct the data or improve their quality.

3.2. Data representation

For each of the three cities in the scope of our research project, the datasets in Smart City Logistics are partitioned into a set of layers. The tool also proposes different background base maps (Google streets, Google satellite, Open Street Map…) to which the user adds as many information layers as desired. To display a layer on the tangible table, the user puts the corresponding physical object (a token) on the table (Fig. 1). Thus, by putting several tokens on the table, it is possible to combine several layers and consequently, to display a full picture representing all the data needed to take a decision.

For example, by displaying the 'railway network', the 'subway network', and the 'pack stations' layers, it is possible to identify how the parcel lockers in the city of Brussels are distributed along the railway network, as shown in Fig. 2.

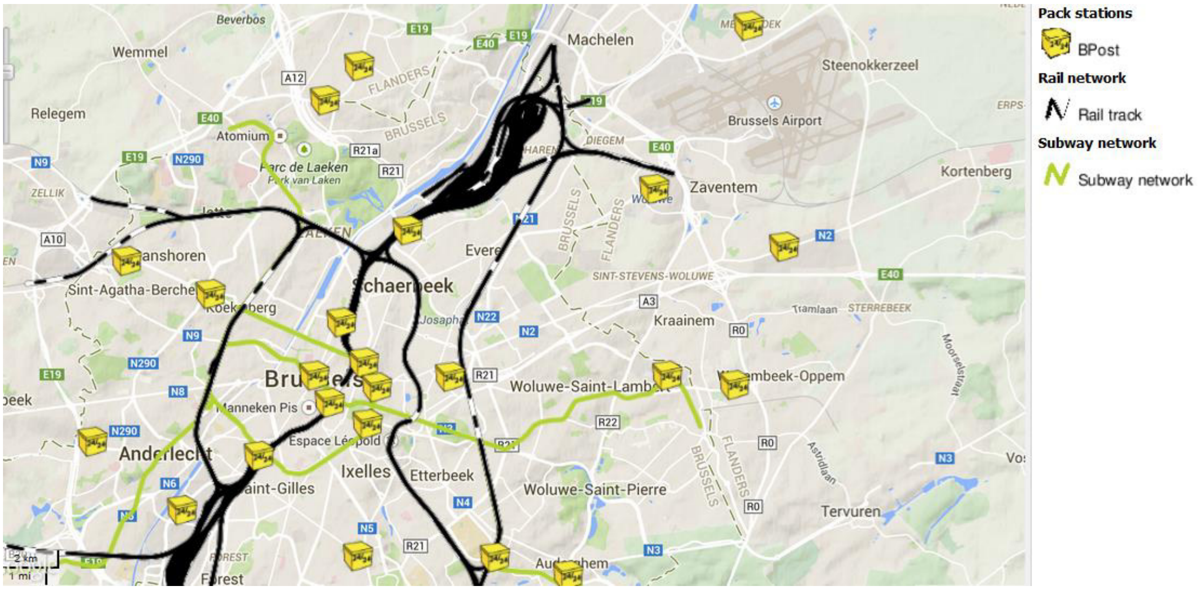

Fig. 2. Parcel lockers distribution along the railway network in Brussels

4. Collaborative approach strategy

To facilitate the collaboration between stakeholders and support the decision making process, three workshop sessions have been set up with Smart City Logistics. Each session was dedicated to one city in the scope of our study; the cities concerned were Luxembourg, London and Brussels. However all the three workshops were physically organised in Luxembourg for logistics reasons.

Around ten individuals participated in each workshop. The participants represented private and public actors familiar with the urban logistics issues, and most of them were directly concerned with one of the cities under study for the workshop. The workshops were proposed in a semi-structured way to provide participants with the opportunity to discuss in a relaxed environment. The workshops involved two facilitators: one person who has a strong knowledge of the local territory and another one (one of the author) with more knowledge on the artefact to help participants consistently manage the tangible table and identify errors of data.

Thanks to the large dimension of the tangible table, all the participants were able to stand around it. The two facilitators stood next to the table in the opposite direction to the map reading. According to the recommendations stated by van Rooijen and Quak (2014), an initial introduction to the objective of the workshop and the tangible table was provided prior to the beginning of the workshop. Depending on the participants and their interest, a set of topics was proposed: e-commerce delivery, alternative to conventional fuels for deliveries, green initiatives, transferability of initiatives from one city to another one, and location of an urban consolidation centre. For each topic, a set of trigger questions were prepared to help the stakeholders familiarize with the data and to progressively start the discussions. With a minimal support on the artefact, the participants were able to use the features of the tangible table very quickly. The stakeholders easily identified the questions and answered some of them themselves, with the previously collected data. The discussions between the stakeholders enabled to draft, for each topic, a set of potential solutions that have to be further explored. The tokens were all available on the table and reachable by every participant to promote the interactivity. Each participant was able to place, manipulate or remove tokens on the table.

The combination of the Smart City Logistics application and the tangible table allowed the participants to discover and discuss the logistics operations in the city.

4.1. Evaluation protocol

To analyse the tangible PPGIS impact and improve the collaborative decision making process, the evaluation of workshops was scheduled. Three complementary methods were combined to assess the effectiveness of the workshop sessions: (1) a post-session questionnaire, (2) a video analysis and (3) a researcher observation (details of the evaluation can be found in Schwartz and Maquil (to be published)).

(1) The post-questionnaire was designed for collecting anonymous feedback of participants at the end of each workshop session. In the first part of the questionnaire, following the System Usability Scale, ten questions were designed to evaluate the level of satisfaction about the PPGIS artefact using five point Likert scales (1: Strongly disagree to 5: Strongly agree). These questions covered aspects such as frequency of use, system complexity, system integration, support needed, or learnability. In the second part of the questionnaire, following the Critical Incident Technique proposed by Chell (2004), open questions were designed to collect participants' feedback on carrying out the required actions, on using the artefact, and to describe their global experience while using the artefact.

(2) The video-recording of workshop sessions was designed to capture the rich but complex interactions between a) the participants and the factual data displayed on the tangible interface and b) between the participants themselves. The analysis of the video record was planned to be made after each workshop to analyze the workshop proceeding and the facilitators' behavior. The aim of such analysis was to improve the workshop timing and the facilitators' actions from one workshop to the following one.

(3) The presence of a non-participating observer was planned to record additional notes on the organization of the workshops.

5. Case study

For conciseness, we report in this section the proceeding of only one of the three workshops, the one dedicated to the analysis of Luxembourg city. In order to demonstrate how the tangible PPGIS can support collective decision-making related to urban logistic problems, the Smart City Logistics artefact has been used to analyse three different situations in the City of Luxembourg:

- The distribution of delivery areas and their compliance with regards to the number of retailers and companies,
- The availability of alternatives to conventional fuels for urban logistics operations, and
- The availability of initiatives for Business to Customer (B2C) deliveries.

5.1. Delivery areas

Loading bays are the favourite logistical tool used by cities in order to support their urban freight transport policies. Prior to the workshop, based on CERTU (2010), the authors conducted a study in the rail station area of Luxembourg City in order to determine if the loading bays offer is sufficient with regard to the number of deliveries in this quarter of dense business and commercial activities. On the basis of a survey of the commercial, industrial and business typologies, the number of movements generated in this area has been calculated (1200 movements per week). Then, following the method described in CERTU (2010) the theoretical number of loading bays needed has been determined (14 loading bays in our case). The location and number of existing loading bays was input in Smart City Logistic. The PPGIS was used during the workshop to represent, as visible in Fig. 3, the existing loading bays, and to visualize the delivery area of each bay (based on the implicit “50-metre rule”). Thus, participants noticed that, although the actual number of loading bays available in the area was compliant with the common recommendations, their location does not follow a clear logic (related to the categories of business and commercial activities in this sector).

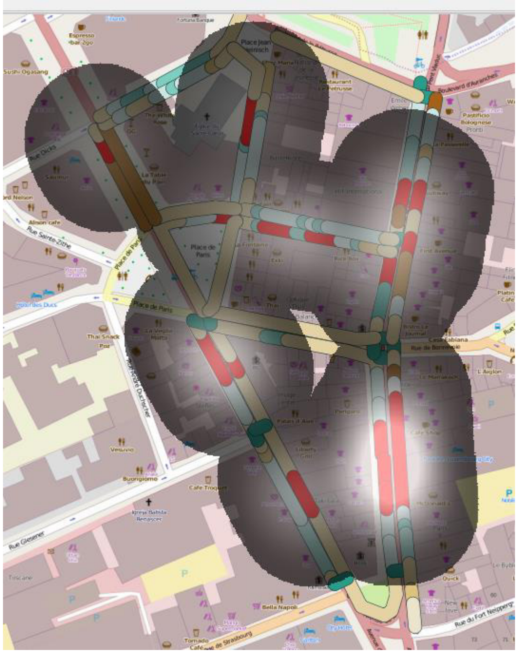

Fig. 3. Delivery areas covered by the loading bays

5.2. Alternative to conventional fuels

In order to reduce environmental nuisance (CO2 emissions, noise…), local authorities are more and more trying to foster the use of clean vehicles in urban areas. For instance, as described in OECD/IEA (2012) many cities employ a mix of financial (tax credits on vehicles, discounted tolls…) and non-financial (preferential parking spaces, access to restricted zone…) consumer incentives to boost demand for electric vehicles.

During the workshop dedicated to Luxembourg City, by using the Smart City Logistics artefact, the workshop participants were able to demonstrate that the offer in terms of stations proposing alternatives to conventional fuels was inappropriate in Luxembourg. Indeed, as shown in Fig. 4, by displaying simultaneously the information layers representing the Compressed Natural Gas (CNG) stations, the Liquefied Petroleum Gas (LPG) stations, and the electric charging points, it was easy for participants to see that the city centre, where most of the deliveries take place, is not sufficiently covered.

Fig. 4. Localisation of alternatives stations to conventional fuels (blue: CNG station, orange: LPG station, green: electric charging point)

5.3. B2C deliveries

There are few data available regarding e-commerce deliveries in Luxembourg. However, Eurostat (2014) states that, in 2013, more than 70% of the persons living in Luxembourg had ordered goods or services over the internet, for private use. In order to facilitate customer deliveries, and with the aim of decreasing the number of deliveries which fail at the first attempt, the number of urban logistics spaces tends to increase. After being reminded of that context by the workshop facilitators, the participants compared the offer (in terms of parcel lockers and of pick-up shops) with the demand (i.e. the population density), as visible in Fig. 5.

By superposing these three layers, participants could identify a lack of pick-up points in the quarters of Luxembourg-City that have the highest population density.

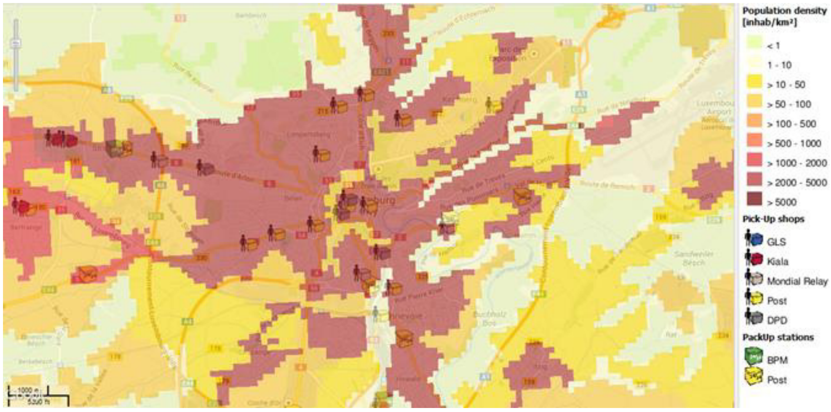

Fig. 5. Population density and urban spaces logistics

By displaying the population density layer with one or more layers representing the different types of commercial buildings, the participants were able to determine where to implant new urban spaces logistics. Indeed, the existing shops, which are localized in a high density but not sufficiently served area, could be considered as good potential candidates for the installation of a pick-up shop (as shown on Fig. 6).

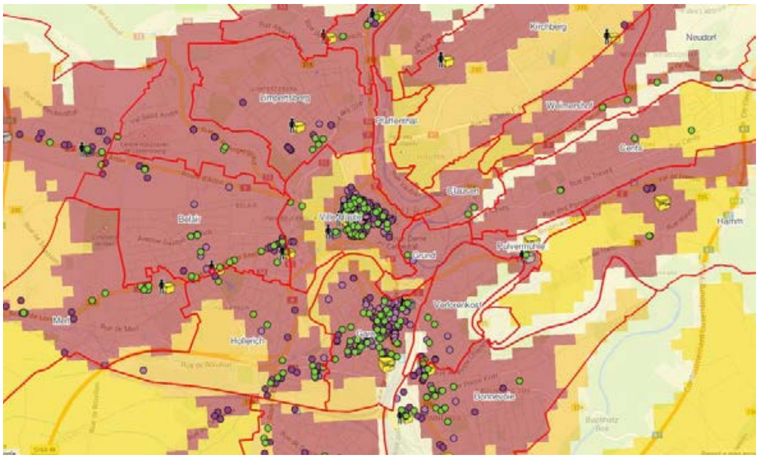

Fig. 6. Population density and shops distribution (population density: see Fig. 5 scale, green dots: food retail, purple dots: non-food retail)

5.4. Workshops evaluation

After each workshop, the feedback questionnaire, the video recording and the observations were cross-analysed with the facilitators to determine opportunities for improvement. This permitted, among others, to raise questions around the optimal number of layers available, or the colours, the form, and the size of the tokens to be used.

Globally, the participants' reactions were favourable (72.69% satisfaction rating) but their level of participations was different from one workshop to the other, suggesting some adaptions to add to the participatory process. It was clearly noticed that the data visualisations allowed people with less knowledge on a topic or on the territory to better understand the situation and to contribute actively to the discussions. Following the evaluations, changes were made to the structure of the following workshop in response to what was learned in the previous session; specifically increasing the time dedicated to discussions and interactive exchange, adding new information layers (thus increasing the number of tokens) and proposing icebreakers to create a good atmosphere for participation.

6. Conclusion

In each of the examples of the tangible PPGIS artefact utilization, several layers of information have been combined to finally display, a "full picture" representing a specific situation. As mentioned in the case study and confirming the collaborative approach strategy, the use of a PPGIS allowed participants to draw collective conclusions on each analysis and to suggest further development paths for each situation. By doing so, the authors verified, from the field, that the usage of a PPGIS based on tangible technologies enabled and fostered discussions and exchanges around a particular topic (such as B2C deliveries, or alternatives to conventional fuels) based on factual data related to the topic.

With feedback and observations collected during workshops, the authors conclude that a GIS system running on a tangible interface makes the understanding of spatial data and the spatial analysis easier for non-GIS-specialists. The cases studies on the three workshops have shown that by handling and manipulating the data through physical objects (tokens) altogether around a table, workshop participants with limited knowledge of GIS systems or of the local situation were able to propose relevant solutions that were also previously identified by specialists.

The limits of this study are first the somehow limited number of participants to each workshop and the quite controlled workshop environment. The opening to a wider panel of participants with either a very limited or with no support still has to be explored. This will be one of the next steps in the study, with the progressive opening of the Web version of the PPGIS artefact (http://iguess-sl.list.lu).

Another track of the future works is the development and deployment of more advanced spatial analysis functionalities in the PPGIS. These new functionalities will mainly target non-GIS-experts (such as most of the stakeholders impacted by urban logistics problematics), and consequently have to be easy-to-use. Currently the authors consider three main advanced analysis functions: the optimal location of a logistics space based on multiple criteria (delivery points location, population density, real estate prices, proximity to transport networks), a routing algorithm based on delivery vehicle characteristics (weight, size, engine technology) and access restrictions (time restriction, size restriction, environmental emissions), and a simulation of the environmental impact of urban logistics policies (limitation of vehicles size, vehicles number or fostering of low emission vehicles).

Acknowledgements

The authors would like to acknowledge the European Regional Development Fund, INTERREG NWE program, for funding the Last Mile Logistics project in which Smart City Logistics was developed (www.lamiloproject.eu).

The authors also acknowledge the teams of the Luxembourg Institute of Science and Technology who actively contributed to the development of Smart City Logistics and the tangible table, namely the Digital Knowledge Dynamics unit and the Visual Analytics and Geocomputation group.

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