Tourism, Transport, and Land use:

A Dynamic Impact Assessment for Kaohsiung's Asia New Bay Area

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ABSTRACT

This paper proposes a hybrid methodology for analysing the causal relations between public transportation development, tourism and land use by combining System Dynamics (SD) with Geographical Information Systems (GIS) and agent-based modelling (ABM). It is applied to illustrate the quantitative and spatial effect of the two phases Light Rail Transit (LRT) development in Asia New Bay Area, Kaohsiung, Taiwan. This paper also furthers the application of the ABM spatial information as interactive variables in the stocks-flow model. The simulation results support that development policies of LRT are significant to the future tourism in Asia New Bay Area, while the under debate second phase of LRT is estimated to raise the number of visitors in long term by alleviating the deteriorating road traffic congestion. This policy-oriented simulation can serve as a reference to the decision-makers towards the future management of LRT.

Keywords: transport & tourism; land use transition; system dynamics; cellular automata; agent-based model

1. Introduction

Over the past several decades, private vehicles have been the dominant method for travelling within towns, cities and rural areas. The resultant increase in traffic has led to many negative effects such as traffic congestion, urban sprawl and greenhouse gas emissions. In addressing these issues, the implementation of transit-oriented development (TOD) has become a critical measure for revitalising the urban environment in a sustainable manner by combining public transport and land use planning for boosting the economy (Dittmar & Ohland, 2012). Over the last decade, the coastal region of Kaohsiung, located in south Taiwan, has witnessed a rapid de-industrialisation and transforming the heavy industry into the leisure-oriented industry. The government has developed a LRT (light rail transit system) network along with a series of touristic flagship facilities, as a strategic tool in mobilising urban redevelopment. Within a spatial-temporal context, the public driven nature of transit system is intrinsically inter-twined with the discrete process of agents and land use activities, the effect of traffic improvement on tourism and its relations with land use are therefore remained to be investigated. This study applied system dynamics (SD) to develop the causal quantitative relationships between the recent transport policies and their effects on local tourism in Kaohsiung. This model is then linked to an agent-based modelling (ABM) simulation to estimate the detailed changes in tourism geographically, and to examine the differential effects of recent light rail policies across space and time.

This paper is divided into five sections. Following this introduction, in Section 2 the study area, LRT development and recent policies are described. In Section 3, the relationships between transportation, tourism and land use are discussed along with the presented methodology studying on geographical features of tourism as the application of SD, GIS and ABM. In Section 4, the dynamic effects of LRT development are discussed. The main conclusions and implications for the regional development are highlighted in Section 5.

1.1 Theoretical Background

Light rail transit (LRT) networks are increasingly implemented in both global and provincial cities around the world (Chen,2016). With its considerable superiority over heavy rail systems, such as underground metros and commuter rails on cost-effectiveness and road traffic improvement, LRT is widely perceived as a critical measure for shaping a sustainable and competitive city (Niedzielski and Malecki, 2012; Knowles, 1992; Knowles and Abrantes, 2008). To that end, previous studies have focused on investigating the relation between the LRT development, urban planning and governance, such as LRT effects on station-area land use development patterns, business siting incentives, and land use sensitivity to governmental intervention (Billings, 2011; Giuliano, 1995).

Nonetheless, apart from the effects on urban development, the light rail planning itself is attached to a systematic and holistic complex system which encompasses economy, population, environment, urban space and activities in proximity. As such, it is necessary to consider the related sectors with transport planning, to detect, diagnose and anticipate existing and future issues of the system for aiding the decision-making process (Shah et al., 2013).

In making an evaluation on transport planning policies, System Dynamics (SD) has been well adapted as a supportive tool for decision-making (Shepherd, 2014). SD is an interdisciplinary method to improve the understanding of a complex system by modelling the quantitative interactions and feedback processes of the observed variables across time. Over the past decade, a significant number of researchers have applied SD in studying public transport mobility policies, and their relations with urban environment, such as traffic congestion, energy consumption, land use and transportation interaction (Sabounchi et al., 2014, Guzman et al., 2014; Haghshenas et al., 2015; Wen and Bai, 2017).

During the decision-making process of public transport planning schemes, a more crucial challenge is to identify the involvement from different stakeholders and their concerns so that they can be taken into account (Bourne and Walker, 2005; Lindenau and Böhler-Baedeker, 2014;). The term 'stakeholders' refers to individuals, groups or organisations who are influenced by a proposed project or who can affect the project and its implementation (Lindenau and Böhler-Baedeker, 2014). Around the implementation of LRT, stakeholders comprise global and local actors with different decision-making powers, interests, and behaviours. These range from the institutional authorities who decide upon the LRT scheme and land use change at the higher-level decision-making end to the individuals such as residents and tourists who use the LRT or other vehicles (Johnson et at.,2016). In other words, differential level of involvement of stakeholders will affect the implementation of public transport schemes in terms of spatial and quantitative dimensions and hence contribute to changes in system (Johnson et at.,2016).

As for the higher-level decision-makers, anticipating and responding to the behaviours of LRT users at local scale are therefore indispensable. Users are travelling with certain spatial pattern according to the state of the environment, such as the proximity of LRT station, accessibility to certain land use/activities, and the location of tourism hot-spots (Diem-Trinh Le-Klähn & C. Michael Hall, 2014). These behaviours differ across time and space with individuals having different tastes or observed preferences and constraints. To simulate this, an aggregated application of Geographical Information Systems (GIS) and agent-based modelling (ABM) provides an accessible way to model the interactions between individuals and physical environment (Guo et al.,2008). GIS is a system for visualisation and analysis of spatial data that can further be embedded into a scalable simulation environment, where ABM is a computational modelling approach to simulate the bottom up decisions of agents and their non-linear behavioural patterns in space by a series of predefined rules governing the interactions of agents (Robinson et al., 2012; Wang and Deisboeck, 2013). In a system being modelled, ABM can be built from a stock-flow model to capture the individuality of agents and to provide a deeper insight into their emerging spatial-dependence behaviours across space and time

(Batty, 2007; Borshchev & Filippov, 2004). Thus, taking users' behaviours in the LRT scheme decision-making, we propose to combine ABM and GIS with SD on their strengths of mimicking an elaborate engagements of stakeholders as well as the spatial-temporal urban dynamics representation.

2. Study Area

Plans for the light rail transit date back to the 2011 urban rezoning plan for Kaohsiung Multi-Function Economic and Trade Park (高雄多功能經貿園區) which was subsequently termed the Asia New Bay Area (亞洲新灣區) which involved 600 hectares of coastal land redevelopment for accelerating the process of economic restructuring in Kaohsiung. In the project, the implementation of light transit system was aimed at improving the accessibility and reducing the need for motorized travel by utilising the light rail for linking the new innovative technology and exhibition landmarks in proximity alongside the waterfront area (Chen, 2012; van Der Bijl, R., Van Oort, N., & Bukman, B., 2018). The 19.5 billion TWD (New Taiwan Dollar) first-phase project's construction began in mid-2013 and was fully put into service in September 2017. In the first year of operation, the annual patronage of light rail recorded approximately 3.3 million passengers (Kaohsiung Rapid Transit Cooperation, 2019). The 8.7km rail line runs from 6:00 to 23:00, departing every 6 minutes with a maximum capacity for 360 passengers 'carriage per journey.

The light rail development in 2018 came to a launch of the second phase construction in connecting the light rail with the existing metro network in the central urban area. However, the plan was halted by the Kaohsiung government in early 2019 owing to the uncertainty around its economic efficiency in boosting the tourism and regional redevelopment (Hung et al.,2013; Chen, 2016). While a certain plan of the second phase light rail will increase the carrying capacity of the first phase rail by extra carriage installation, the location of the second phase is under debated. We know of no study, however, that considers the effect of two-phase light rail on the interaction process with tourism and land use across space and time.

The geographical area of this study is based on the buffered 500m of the first phase light rail transit stations as referring to the common walkability areas of tourists (Roukouni et al., 2012) (Fig. 1). The flagship tourism facilities, light rail, and infrastructures in Asia New Bay Area are covered. The land use of study area is shown in Figure 2.

[Figure 1 near here]

[Figure 2 near here]

3. Methodology

The research framework in examining LRT development effects on Tourism in Asia New Bay Area is divided into three sections (Fig 3). First, a stock-flow model is built based on the System Dynamics' causal loop diagram (CLD) which consists of five related sub-systems (tourism, transport, population, housing, and economy) to measure the quantitative and temporal effects between the LRT development and its related sectors.

Secondly, a Geographical Information System is adopted to form the initial environment in Agent-based model which comprises of the locational land use categories, land use transition probability and the touristic suitability map. These environmental setting drive the state of spatial units in terms of land use and touristic degree in ABM. To simulate the stochastic land use transition process from one state to another with proximity effect of land use, CA-markov is applied to predict the probability of touristic related land use change. As for anticipating the adaptive spatial behaviours of tourists, a set of independent variables (land use type, tourism spots, degree of accessibility) were normalised with fuzzy logic as the probabilistic touristic suitability degree to replicate the travelling decision-making process of tourists.

Thirdly, the ABM is applied to simulate the CA-markov, touristic suitability, and model the spatial-dependence patterns of tourists across space and time. In this part, ABM synthesizes the individuality of the annual number of tourists importing from the stock-flow model while feeding the bottom-up changes of touristic related land use area (recreational and commercial) to the system as the capacity for tourism development.

The simulation time period is from the operation of first phase LRT (2016) to the next 30 years of operation (2046) which includes the implementation time period of second phase LRT and the urban redevelopment project duration. For distinguishing the transport policies and its effects in future, this paper adopts three scenarios to evaluate the effects of LRT scheme hereafter, which are (1): the business as usual (BAU) scenario based on the uninterrupted implementation of two-phases LRT scheme; (2): the cancellation of LRT (CLRT) scenario based on the future urban transport system will run without the two-phases LRT; (3): the cancellation of second phase LRT only (C2LRT) scenario based on the no increase on carrying capacity of first phase LRT. In order to investigate the different behavioural pattern of tourists in responding to the implementation of LRT and touristic suitability variation, the agent-based simulation is based on the scenarios of BAU and CLRT.

[Figure 3 near here]

3.1 System Dynamics modelling

In modelling an interactive and causal iterative process system on LRT development, extant SD frameworks are built based on the causal relations between transport, population and economy (Wang et al., 2008; Fontoura, W. B. et al., 2019). We expand the observed dimension in tourism to suit the context of this paper. The simulation is developed following the steps to use an SD method (Morecroft, 2015).

The relations between subsystems are shown in figure 4. The causal loop diagram (CLD) illustrates the major feedback mechanism between variables which shows the process of how they are inter-related and their role for producing positive reinforcement or negative balancing loops. The arrows indicate the cause and effect relation between subsystems (Sterman, 2000). There are four major feedback loops in the stock-flow model, as:

(R1) Annual Number of Tourists $\xrightarrow{+}$ Employment Opportunity $\xrightarrow{+}$ Business Development $\xrightarrow{+}$ Annual Number of Tourists

As the annual number of tourists increases, the growth in tourism development promotes the opening of new business, as well as the employment opportunities and employed persons, it then results in a positive impact on business development. The relation between thriving business and the inflow of tourists is directly proportional.

(R2) Business Development $\xrightarrow{+}$ Population $\xrightarrow{+}$ Residential Development $\xrightarrow{+}$ Land Development $\xrightarrow{+}$ Employment Opportunities $\xrightarrow{+}$ Business Development

The second loop is the business growth and its relations with population and economic variables. As an increase in business development and population is directly proportional (Wang et al., 2008). It then increases the development on residential, infrastructural amenities, and the subsequent increment of employment opportunities lifts the business development.

(R3) Population $\xrightarrow{+}$ Residential Development $\xrightarrow{+}$ Population

Coupled with the previous loop, the relation between economic development and population is directly proportional (Wang et al.,2008). As the increment of population promotes the demand of houses and residential development, it increases the number of households who choose to live in the area

(B1) Annual Number of Tourists $\xrightarrow{+}$ Road Traffic $\xrightarrow{+}$ Traffic congestion $\xrightarrow{-}$ Annual Number of Tourists

This loop contains the relation between tourism and road traffic condition. As the rise of tourists stimulates the number of trips on road traffic which is directly proportional with traffic congestion. It lowers the visiting motivation of tourists in order to evade the influence of congestion. (Shailes, A. et al., 2001; Xu et at., 2012)

(B2) Annual Tourists $\xrightarrow{+}$ Passengers of LRT $\xrightarrow{-}$ The degree of traffic congestion

The increase in the annual number of tourists leads to a higher patronage of light rail transit which is inversely proportional with the degree of road traffic congestion (Xu et al., 2012).

(B3) Annual Tourists $\xrightarrow{+}$ Tourist Crowded Index $\xrightarrow{-}$ Annual Tourists

Alike the traffic congestion effect on tourism, the increment of tourists exacerbates the extent of crowdedness in recreational and commercial land which affects the visit willingness and results in the decrease of tourists.

The next step in SD is the structure of the Stock and Flow Diagram (SFD) to identify the system variables by resource accumulations and change rates (Sterman, 2000). In this study, the SFD is shown in Figure 5 and all variables and corresponding equations in the SFD are recorded in tables S1, S4-S6 in the supplementary information.

[Figure 4 near here]

[Figure 5 near here]

3.1.1 Transport and tourism states on LRT scenarios

The LRT development scenarios differentiate the carrying capacity of LRT, the patronage of LRT, and the road traffic volume. In CLRT, the road traffic serves as the single transit mode while an additional mode of LRT is situated in BAU and C2LRT. Since the carrying capacity of LRT is contingent on the installation time of extra carriages, the differences within scenarios distinguish the number of tourists and its related variables in SFD on traffic congestion, the level of tourists crowded, and tourists leave (table 1). The number of annual tourists is summed by the enter and leave flows of tourists, where the outflow of tourists is dependent on the degree of congestion as the extent of visiting motivation (Shailes, A. et al., 2001; Xu et at., 2012). The degree of traffic congestion is evaluated by the ratio of road traffic volume to road capacity (Vafa-Arani et al., 2014; Yang et al., 2014). In this case study, the degree of traffic congestion is defined as the annual average ratio of road traffic users (including tourists and residents) to the road area, i.e. unit of road area share by road traffic users.

For the congestion level in touristic related land use, it is calculated by the ratio of annual average tourists to the summation of recreational and commercial area, as the level of tourists crowded variable. The influence of tourists crowded level, the extent of road traffic congestion on the annual increment of tourists is based on the density and interpersonal distance preference (Sorokowska, 2017). Three levels of density are adopted in the SFD are maximum, extreme and tolerable, which accordingly inputted as 2.1 (person/m^2), 1.18 (person/m^2), and 0.78 (person/m^2). Each range of the density influences the tourists leaving rate in order to evade the influence of road traffic congestion (Institute of Transportation, 2011, Shailes, A. et al., 2001).

[Table 1 near here]

3.3 Land use transformation

The rule of land use transition is built by the Markov chain model and Cellular Automata (CA), hereafter the CA-Markov. The Markov process is posited that the state of a cell at a certain time is a function of its preceding state (Takada, Miyamoto, & Hasegawa, 2010). Based on this assumption, it is possible to predict the state of land use in future within a stochastic process. The input of Markov chain model is a pair of land use images from 2006 and 2014 National Land Use Investigation Data, it determines a transition matrix recording the probability of land use that are expected to change from each land use type to another type.

Besides the time effect, the CA model emphasises the geospatial proximity effect on land use transition, it postulates that each land use cell has a current state and knowledge propagated from neighbour cells through space, and results in the adaptive and self-organising behaviours (Benenson and Torrens,2004). The combined CA-markov approach simulates the land use for the next 30 years based on the previously defined transition matrix. The spatial effect between cells is defined as a Moore 3x3 contiguity filter which creates spatial contiguous weights in simulation, thus the furthest cells share lower effects than the nearest cells (Subedi, Subedi, & Thapa, 2013).

3.4 fuzzy membership

To replicate the probabilistic travelling decision-making process of tourists, fuzzy membership is applied to rank the spatial cells by the travel likelihood as the preference of tourists' movement (Kravets, P, 2010). In the fuzzy membership, each cell' degree ranges from 0 to 1 as highly unsuitable to most suitable, it indicates the continuous increment of non-membership to full-membership. Based on a set of touristic spatial factors (Boavida-Portugal, 2017), in this case study, the proximity to the touristic related land use is considered as the most suitable area for tourism development because of the cluster characteristic of tourism activities (Cunha, S. K. D., & Cunha, J. C. D. , 2005) including proximity to the higher density areas of stores (retail, catering & entertainment), proximity to hotels, as well as proximity to flagship tourism establishments. Other areas are considered as most suitable are related to the accessibility of transport infrastructures in terms of potential tourism development including the proximity to the LRT stations and proximity to the road network. The less attractive touristic areas of residential, industrial, idle, governmental land use are considered as less suitable for tourism development. The initial degree of suitability is applied in ABM as the state of cells.

3.5 Agent based simulation on LRT scheme

The ABM simulation aims at investigating the land use transition and tourists' behaviours around the light rail from 2016 to 2046. For a generic illustration of the ABM, the ODD protocol is adopted to explain the model from the overview, design concepts to the details of the model (Grimm et al., 2010). This section focuses on the features of the simulation while the scheduling, data source, and detailed sub-models' descriptions are stated in the supplementary information.

The land use transition of each cell is simulated based on the CA-markov theory with the pre-defined transition matrix and the spatial effect of land use in proximity to calculate the transition likelihood. On the other hand, the tourists' travel behaviours are grounded in the hypothesis of tourism movement priority which as the touristic suitability value of cell to drives the tourists' travel choices of moving into proximal destinations with higher value (Burton, 1995; Lau, G., & McKercher, B. ,2006). Through the cumulative land use transition and tourist's movement simulated annually, the ABM adopts the number of tourists' variable from the SFD as the simulated agents to predict the future LRT being tourism environment in a spatial-temporal explicit context and feeds the changes of touristic related land use to the SFD during the decision-making process. In this regard, the ABM synthesises the individuality of tourists and feedbacks on SD.

4. Result and Discussion

4.1 Transport and tourism dynamics

Shown in figure 6, the simulated annual number of tourists for next 30 years indicates that tourists in Asia New Bay Area will increase continuously since 2016, however, it is estimated that growth in tourists is unsustainable in the long term owing to the deteriorating road traffic congestion and limited carrying capacity of LRT. In three scenarios, the ceased increase of annual tourists as the result of deteriorating traffic congestion and intensifying tourism density (fig. 7). The traffic congestion in the BAU scenario will reach at the maximum level of 2.1 (people/m^2) in 2042 that leads to the plateau of tourists. As for the cancellation of two-phase LRT in CLRT scenario, the upsurge in road traffic congestion will lead to an earlier saturation of tourists due to the exclusion of LRT scheme in future development. In contrast, as the highest daily patronage of LRT occurs in BAU, the implementation of LRT will alleviate the level of road traffic congestion and reduce 0.3 (people/m^2) level of density in annual average comparing to CLRT and C2LRT scenario.

As observed the annual number of tourists in three scenarios will reach to a plateau once the level of road traffic congestion at maximum. Correspondingly, levels of road traffic congestion will be subjected to the annual carrying capacity of LRT. For the BAU scenario, the daily carrying capacity of LRT will increase from 20,000 passengers in 2016 to 30,600 passengers in 2027, it will mitigate the rapid growth on traffic congestion unit 2037. On the other hand, without the installation of extra carriages in C2LRT scenario, it will undergo a severer traffic congestion where the down-sized carrying capacity will cause the excess of tourists to travel by road.

[Figure 6 near here]

[Figure 7 near here]

4.3 Touristic Suitability Map

The initial touristic suitability map is shown in figure 6. The aggregated touristic suitability value of grid cells signifies that the higher suitability regions are laid in the proximity of the LRT route and existing tourism flagship facilities i.e. The Pier2 Art Center, Maritime Cultural & Popular Music Center, Kaohsiung Exhibition Center, and Dream Mall. In contrast, the southern and south-eastern regions situate a lower touristic suitability value because these areas are mainly in the vicinity of non-touristic related land use activities such as the residential, industrial and idle use. As for the ongoing redevelopment process in the Multi-use technology park, it is expected to be completed in 2022. The state of land use in ABM simulation will be changed from idle use to a tourism facility and linked to the higher touristic suitability value.

[Figure 8 near here]

4.3 Land use change in Asia New Bay Area

The classified land use transition matrix and the dynamic changes from 2016 to 2046 are shown in table 2 and figure 9. For the non-touristic related land use, the amount of land is remained steady which are the road, rail, and others type of land use which including agriculture, forests, ports, rivers, government agencies, public facilities, and medical.

It is estimated that the recreational and industrial land use will decrease significantly because of the previous urban de-industrialisation process. Geographically, these two types of land use are situated in the southern, southern-eastern region in Asia New Bay Area while the rest of the recreational area scattered over the centre and northern regions. Temporally, these areas will be radically transformed into idle land use due to a higher transition probability and the spatial effect of land use in proximity. The industrial land will decline from 72.44 hectares to 23.36 hectares while the recreational land will decrease notably near a half of its amount from 2016. It is concluded that based on the historical land use transition events, the industrial and recreational areas will mostly be changed into idle land use.

In contrast, the residential land use will be surged for the next 30 years based on its consistency state and spatial features. The residential areas are mainly located in the northern, and southern regions of Asia New Bay Area. Since the residential area will be remained largely unchanged (87.31%) and its proximity with encircled idle and cultural land use cells, the amount of residential land is estimated to significantly rise from 204.16 hectares to 259.32 hectares.

[Table 2 near here]

4.4 Spatial-temporal pattern of tourists

The tourists' travel patterns across time are shown in figure 9, based on the CA-markov and the degree of touristic suitability drive the state of grid cells and the adaptive behaviours of tourists on searching for the travel destination. As the two scenarios presented, the implementation of LRT is estimated to attract the tourism activities alongside the LRT route and centralise the tourists in the proximity of flagship facilities and LRT stations in the BAU scenario. On the other hand, tourists will be distanced form LRT stations in the CLRT scenario. Moreover, tourism activities will become more concentrated in the southern and south-eastern region. As the Dream Mall and the completion of Multi-use technology park in 2022 will increase the surrounding touristic suitability and attract tourists travelling in the proximity. Nonetheless, the spatial pattern shows that the heightened degree of touristic suitability and the form of land use in the southern region will become mutually exclusive in future because of the consistent proliferation of idle land for the next 30 years.

[Figure 9 near here]

5. Conclusion

Light rail transit (LRT) have been deemed as a vital infrastructure for revitalising cities by reducing vehicle dependency and inducing an efficient use of land resource. In the rapid de-industrialisation context of the Kaohsiung Asia New Bay Area, although the implementation of a first-phase LRT is widely perceived as an enormous success since its operation in 2017, the construction of second phase LRT was halted owing to the uncertainty around its benefits for tourism and regional redevelopment. This study contextualised the evaluation of the LRT scheme and its implications for the future tourism and land use planning within a systematic and spatial-temporally dynamic model. Furthermore, the presented model attempts to address the decision-making concerns on LRT by delineating the spatial-temporal dynamics and involvements of stakeholders from the higher-level end of institutional authorities who decide upon the LRT and land use policies to the local recreational pattern of LRT users.

In this case study, a hybrid method combining the System Dynamics (SD), Geographical Information Systems (GIS) and Agent-based modelling (ABM) is adopted to investigate the causal relations between LRT scheme, tourism, and land use. Three LRT development scenarios are tested to evaluate the effects on future tourism and the transport system as the feedback on policy-making. The result suggested that the number of tourists will be proliferated steadily since 2016, however, this trend will be uncertain in the long term due to the exacerbation of road traffic congestion. Accordingly, a higher carrying capacity from the second phase of LRT scheme will be constructive to alleviate the degree of congestion. As for the spatial patterns of tourists, it is estimated that the implementation of LRT will attract most tourists travelling in proximity of flagship facilities and LRT stations. Nonetheless, the forms of land use in southern Asia New Bay Area in future is expected to be incompatible with touristic development because of the rapid increase in idle land.

With a step forward in the fruitful public transport-led urban regeneration, the inter-twined relations between transport, tourism, and land use is scrutinised and concluded as the decision basics in terms of their capacity, function, trend, and location. For decision-makers on public transport scheme planning, the framework presented in this study can be utilised as a reference for future regional planning and transport management.

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