Realization of Two Types of Compact City - Street Activeness and Tramway -

Hideyuki Nagai[1(✉)] and Setsuya Kurahashi[2]

[1] Department of Risk Engineering, Graduate School of Systems and Information Engineering, University of Tsukuba, Tokyo, Japan
s1530156@u.tsukuba.ac.jp

[2] Graduate School of System Management, University of Tsukuba, Tokyo, Japan
kurahashi.setsuya.gf@u.tsukuba.ac.jp

Abstract. The purpose of this research is to verify the effectiveness of the combination of the introduction of a tramway with introducing a public facility for urban residents and implementing a policy to promote activeness around it, on urban sprawl. By using an agent-based model (ABM), which was built for simulating urban structure changes through autonomous behavior of urban residents, this research clarified that, depend on the urban initial state, the combination of these policies can lead the two different types of compact city: the polycentric-form and the monocentric-form.

Keywords: Agent-based model · Urban design
Urban sprawl · Compact city · Land use

1 Introduction

1.1 Urban Sprawl Issues

The world population has rapidly increased during our current century along with the previous century, and continued urbanization has taken place at various places around the globe [13]. Many researchers and experts predict that this unrelenting urbanization will not fade but continue to advance [26]. Under such circumstances, urban sprawl has attracted much attention as one of the issues that has been most widely discussed in the past few decades, coming under fire as an unsustainable form of urbanization.

Urban sprawl is commonly defined by the following land-use characteristics [10,15,21,30]:

- Expansion of urban area in outer fringe (undeveloped) area
- Low-density development
- Scattered development (multi-direction)
- Leapfrog development (discontinuity)

T. Miller et al. (Eds.): PRIMA 2018, LNAI 11224, pp. 35–50, 2018.
https://doi.org/10.1007/978-3-030-03098-8_3

- Commercial strip development

Urban sprawl is often criticized because of its following negative impacts [10,12,21,31]:

- Increase in traffic congestion and commuting time, air pollution, and increase in energy consumption
- Increase in infrastructure maintenance and operation cost
- Hollowing out in urban central area, economic disparity, employment imbalance, and loss of neighboring community
- Loss of agricultural and natural land

These negative impacts cannot be disregard, since urban sprawl causes greater environmental impacts than other land-uses [6].

In the future, Japan will definitely have a shrinking as well as ever-aging population. At the same time, the population has continued to concentrate in large city regions. These reasons have given rise especially to a concern about the serious negative impact caused by urban sprawl [2].

1.2 Shift into Compact City

Researchers and experts have studied a shift into "Compact City", as a countermeasure against urban sprawl [15,19].

Compact city does not have a generally accepted definition. It is, however, commonly defined by the following characteristics [5,8,15,33]:

- High-density
- Concentration of development
- Development in public transportation network

Two forms are found for city center:

- Monocentric-form
- Polycentric-form

It has been proved that compact city can overcome some of the negative impacts driven by urban sprawl. Many studies have also indicated that a compact city can enhance quality of life by offering a broad range of choices with regard to lifestyle and behavior including residences, travel, and shopping goods [8].

Considering the urban dynamics including sprawl as complex phenomena of mutual interactions of a wide variety of autonomous entities, such as individuals, households, and firms [7,18,24], however, highlights the difficulty in direct control of the urban dynamics.

1.3 Purpose of This Research

With these in mind, this research built an agent-based model (ABM) to simulate urban structure changes through the induction of autonomous daily travel and residential relocation of urban residents rather than the compulsion. And based on this ABM, this research verified the following points:

- The introduction of a tramway in the central urban area has been actively promoted in recent years. Is the combination of the introduction of a tramway with introducing a public facility for urban residents and implementing a policy to promote activeness around it effective in controlling urban sprawl?
- Is the combination of these policies also effective in improving existent urban sprawl?

2 Related Works and Position of this Research

To build the simulation model, this chapter referred to the findings of two research fields, agent-based land-use/transport interaction (LUTI) model and revitalization of urban central area.

2.1 Agent-Based LUTI Model

Urban sprawl is a special kind of land-use change, urban spatial expansion along a city boundary. Land-use changes come from its complex driving forces and their interactions [18,24]. Above all, the fundamental principle that land-use impacts transport and vice versa has been acknowledged by many scholars and supported by empirical findings [3]. These research efforts have culminated in the development of operational urban land-use/transport interaction (LUTI) models as decision support systems.

And recently, researchers have supported a concept to express the real-world complicated system including a city as a macro-level state that is generated by micro-level collective interactions of multiple autonomous agents [9]. The activity-based disaggregate modeling approach particularly emphasizes the point that each agent learns, modifies, and improves its own activities through interactions with the environment (including other agents) where the agent is located. Based on the above-mentioned concept of complexity science, this modeling approach is referred to as the agent-based model (ABM) [7,17,29].

The ABM initially applied to the land-use model as a spatially-explicit cellular automaton (CA) form. In the CA-based land-use models, which serve as a typical application in social science, the state of each individual cell in the model space indicates the specific land-use. Such models have subsequently continued to develop as hybrid agent-based urban models through relaxation of the basic assumptions. A series of these models have contributed to express complicated macro-level land-use patterns of cities including clusterization and sprawl as self-organization through micro-level adaptive behavior of agents. Such models have served to explore urban growth scenarios.

There have been, however, only a small number of applications of agent-based models to express agents spatially-explicitly both as households or firms relocating and as individuals using traffic networks in parallel. One such model to be called the seamless agent-based LUTI model is the bipolar formed urban dynamics simulation model by Taniguchi [32]. In this model, changes in distribution of residences emerge through the daily travel of individual residents (households) and their relocations which are spatially-explicitly expressed [32].

2.2 Revitalization of Urban Central Area

Recently, particularly in advanced nations, revitalization of urban central areas that hollowed out along with urban sprawl has become a critically important issue. Jacobs [20] has emphasized the attractiveness of a city as a lively and bustling place which has served as a market for exchange from the time before the establishment of the concept of nation or trading by using currency [20]. And researchers and experts have reevaluated the importance of informal public spaces for activities of local residents in the way of an antithesis to urban development on an inhuman scale as well as another way to regain people in urban central areas. The two factors are vital to forming such public space. First, such public space needs to serve as a hub for people in their daily lives so that they can visit there casually while they are out. Second, such public space needs to generate "street activeness" set in an open space, such as a street or a plaza, around the public space.

Library as an Urban Hub. As for urban hubs, public complexes based mainly on libraries have recently attracted much attention. The representative one is the series of Idea Store in London, U.K. [1]. Several pioneering libraries built and put into operation recently in Japan are also relevant to these cases[1]. These public libraries, while offering the library service as the core function, provide a wide variety of other services. These may include attached commercial facilities, such as cafes, and facilities that promote learning and civic activities. They also try to enhance convenience for visitors by various policies including the extension of opening time. By doing so, they aim to serve as a hub for local culture.

Street Activeness. Street activeness indicates a lively situation where individuals gather and stroll around downtown while enjoying exchanges, such as encountering various people, contacting various shopping goods, and experiencing other services [27]. Therefore, it can bring about not only usefulness or efficiency, but also creative, cultural, or recreational benefits. From an economic point of view, it has been long argued that the density of interactions by various people propels economic activity [25]. From a sociological point of view, the following positive feedback has been demonstrated empirically: the number of people that visited a certain place including their sojourn time they spent there can derive positive evaluations for the place, such as cheerful and lively atmosphere, and at the same time these positive evaluations attract further activities [22].

2.3 Position of This Research

By integrating the above-mentioned conceptual framework, Nagai [27] built the agent-based model (ABM) to consider qualitative benefit obtained by using infor-

[1] E.g., Musashino Place in Tokyo, Japan (2011), Takeo City Library in Saga, Japan (2013), Gifu Media Cosmos in Gifu, Japan (2015), Art Museum & Library, Ota in Gunma, Japan (2017).

mal public space and being in such a place, along with the daily travel of urban residents. And they clarified that the synergistic effects of some policies, such as locating of the public space and promoting activeness in such a place, are effective to maintain a compact urban structure [27]. On the other hand, an introduction of tramway is well known as one of the measures to reduce traffic congestion, save energy consumption, and reduce air pollution in urban area. In recent years momentum for introduction of tramway has also been raised in Japan [28]. Additionally, especially in Japan a large part of the land is mountainous, thus the area suitable for urbanization is relatively small [23]. And the population is also declining [2]. For these reasons, improvement of many cities that have already sprawled is considered to be more important. This research develops the conceptual framework introduced by Nagai [27] to verify whether the introduction of a tramway is effective in maintaining a compact urban structure, and whether it is also effective in improving an urban structure that has already sprawled.

3 Simulation Model

Based on Nagai [27], this research developed the experimental model in various factors including the change of the initial experimental state, the introduction of a tramway, and parameter refinement. The overview of the experimental model was described below according to the ODD (Overview, Design concepts, and Details) protocol.

3.1 Purpose

By modeling and running the ABM that abstracted a city and activities of the residents in the city, this research verified the effects of controlling the urban structure, which was planned according to the zoning with separation between residences and job locations, based on the combination of the introduction of a tramway with introducing a public facility for urban residents and implementing a policy to promote activeness around it. Additionally, this research verified the effects of improving the urban structure, which has already sprawled, based on the combination of them.

3.2 Entities and Scales

Entities are a planar urban schematic and household agents who act in the urban schematic. Both are spatially-explicit. Figure 1 shows the urban schematic. This is the abstraction of a part of typical regional cities in Japan, where a central business district (CBD) and bedroom towns connected by railway. They were planned according to the zoning with separation between residences and job locations. Therefore, they are also regarded as the polycentric-form compact city, which is composed of multiple hubs linked with traffic networks and sharing their own role [5,33]. In the urban schematic, two domains are located: the residence district and the central business district (CBD). The residence district is the aggregation of residences, which are the starting point and the final destination of each household agent's daily travel which corresponds to commuting. CBD is the aggregation of job locations, which are also a halfway point of the travel. Two railway stations, the residence station and the central station, are located at the centers and they are connected by a railway. Additionally, a highway is located 500 m north of the railway. Furthermore, three tramway routes are radially installed around the central station as a hub (see next section for details). To simplify the simulation, uniform and high-density sidewalks and roads are located on this whole urban schematic. With the assumption, household agents can freely travel on this space on foot, by bicycle or private automobile.

In the residence district, as the initial location, residences of the same number as household agents, 1,000, are located randomly based on normal distribution centering on the residence stations. One household agent corresponds to 10 households in the real-world. Similarly, in CBD, job locations of the same number are also located. Additionally, one public facility such as a complex mentioned in the previous section: a public facility for stopping off (PFS), is located in the central area.

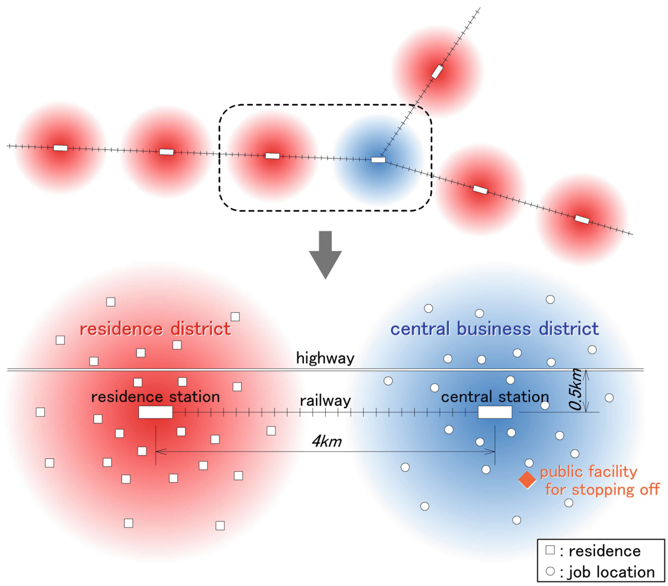

Fig. 1. Urban schematic

3.3 State Variables of Household Agent

State variables of household agent are as follows:

- Position of the residence
- Position of the job location
- Type of linked trip selected currently
- Value list of linked trips (updated based on daily travel cost)

In this research, the position of a job location corresponding to a certain household agent is always fixed. A linked trip indicates the series of travels of each household agent from the starting point to the destination.

3.4 Process Overview and Scheduling

Each household agent does daily travel based on the value list of linked trips, and fixes travel mode in one way through the learning period of repeating this daily travel 30 times. After that, for 1/10 of all household agents that are randomly chosen, relocate their residences. The change in land-use pattern is brought about through these residential relocations. In this research, after the loop process of residential relocation is repeated 20 times, the simulation stops processing.[2]

3.5 Sub-model of Daily Travel

Each household agent repeats daily travel according to the selected linked trip. The representative travel mode is either of the following: on foot, by bicycle, train, private automobile, or tramway. The initial representative travel mode of all household agents is train according to the original urban planning philosophy. Each household agent leaves the residence for the job location. And after all household agents arrive at each job location, they leave for PFS. After arriving and staying there, finally they return to the residence. When the household agents return to the residence, the total travel cost C is calculated according to the equation below.

$$C = w_t C_t + w_c C_c + w_f C_f - w_P P$$

C_t, C_c, C_f, and P indicate time cost, charge cost, fatigue cost, and activeness value. w_t, w_c, w_f, and w_P indicate each preference bias. The preference biases of all agents are assumed to be equal. According to this cost, the household agent updates the value V_i of the selected i-th linked trip, according to the equation below.

$$V_i \longleftarrow \alpha(-C) + (1-\alpha)V_i$$

[2] This model assumes that 30 times of daily travels (a single loop process of residential relocation) represent two years in the real-world. Therefore, 20 loop processes of the residential relocation correspond to simulating 40 years of urban dynamics in the real-world.

The following travel of the household agent is done according to the linked trip selected by the ε-greedy method based on this value. And each household agent fixes their travel mode in one way through the learning period of repeating this daily travel 30 times. This setting is based on the findings that individuals choose travel modes and routes rather boundedly rationally and habitually [16].

Activeness Value. Regarding a 500 m radius around PFS as the zone of influence, the implementation of a policy to promote activeness is considered. Here, it is assumed that street activeness can be generated when household agents, which travel on foot or by bicycle within this range, interact face-to-face, namely when they agglomerate geographically. During this time, relevant household agents acquire benefit brought about by the street activeness, which is mentioned in the previous section, as activeness value P.

$$P = min(\eta_{ac} D_{ac}, P^{max})$$

$D_{ac}(agent)$ indicates the number of other household agents traveling on foot or by bicycle within r_{ac} meter radius centering on the relevant household agent. η_{ac} indicates coefficient of activeness. The total travel cost is reduced by the amount obtained by multiplying the activeness value P with preference bias w_P. The coefficient of activeness can be regarded as a level of effort to bring further street activeness within the relevant range according to the agglomeration of pedestrians. This coefficient is enhanced by projects such as arranging comfortable sidewalks and cycling roads, arranging attractive retail stores, or holding attractive events. Improvement in this coefficient enhances the benefit for travel on foot or by bicycle in the relevant range, increasing a balanced total travel cost. Therefore, this coefficient can be regarded as a coefficient of gain. Hereinafter, the policy that corresponds to improvement of this coefficient of activeness is referred to as the policy to promote activeness.

3.6 Sub-model of Residential Relocation

After all household agents fix their travel mode in one way through the learning period, 1/10 of all household agents that are randomly chosen relocate their residence. To the relevant household agents, 10 of candidate residences are presented randomly. The total living cost of these candidates is the sum of total travel cost and land rent. The total travel cost is calculated by conducting virtual daily travel from a candidate residence based on the travel mode fixed by the relevant household agent through learning. The land rent for the candidate residence increases corresponding to the agglomeration of neighboring residences and job locations. In other words, the local interactions between households, and between a household and an environment, also impact the change in land-use pattern through the change in land rent. Each household agents relocate to the candidate residence of which the total living cost C^l is the minimum out of 10 candidates.

3.7 Initialization and Input Data

Setting values of parameters of the urban schematic and household agent were set carefully based on the various mainly empirical materials, including socio-demographic and other statistical data published by public authorities e.g., the ministry of land, infrastructure and transport [2], and previous studies, while assuming a regional city in Japan.

3.8 Indicators to Estimate Experimental Result

By observing the result of each experimental scenario according to the indicators shown below, changes in the urban structure were evaluated.

- Percentage of each representative travel mode
- Total CO_2 emission (expressed as percentage relative to the scenario A)
- Average travel time
- Standard deviation of distribution of residences (the initial values are 8)
- Distribution map of residences.

4 Experiment 1 - Introduction of Tramway

This section verifies the change of the urban structure, which was formed according to the zoning with separation between residences and job locations, based on the combination of the introduction of tramway with introducing a public facility for urban residents and implementing a policy to promote activeness around it, described in Nagai [27].

4.1 Conditions of Experiment 1

The simulation here assumes that the urban schematic tramway routes imitate the "Karlsruhe Model" [11], where the routes are shared with ordinary railways. Therefore, three routes are radially installed centering on the central station as shown on Fig. 2, and the routes pass through CBD. Each route has tramway stops at 400 m intervals like ordinary tramway services in the real world. Along with this, residents can also choose the additional following four types of linked trips. The first two are by train and tramway in combination, and the other two are by tramway.

The experiments were conducted under the conditions of the following two types for the location of a public facility for stopping off (PFS).

- A : not introduced (no implementation of the policy to promote activeness)
- E : urban central area, 0.5 km south and 0.5 Km east from the central station

E was the most effective location to maintain compact urban structure in Nagai [27]. And the four types, 0, 10, 20, and 30, for coefficient of activeness. Hereinafter, each of these experiments is expressed e.g., scenario At, Et0 − 30,

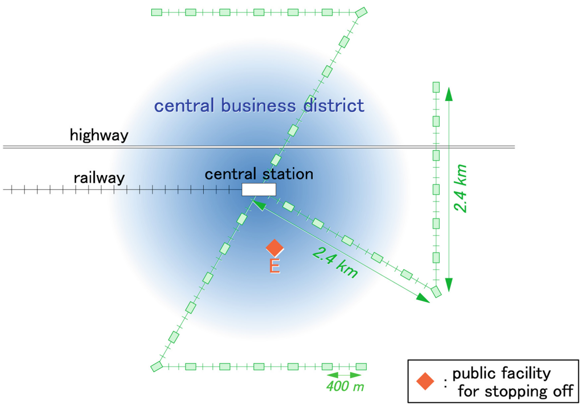

Fig. 2. Schematic of tramway routes

by combining the symbols of A and E indicating the location of PFS, the initial letter t for the word of tram, and the coefficient of activeness. Additionally, this section reproduces scenario A, where PFS was not introduced, and a policy to promote activeness around it was also not implemented, to compare with the new scenarios and validate the simulation model.

4.2 Results of Experiment 1

Table 1 shows the quantitative result of scenario A, At, and Et0 − 30. Figure 3 shows the final distributions of residences of the same scenarios.

The result of scenario At, when compared with scenario A, shows that the percentage of private automobile users decreased by close to 30 points, while the percentage of train (and tramway in combination) users increased accordingly. Along with this, the sprawl on the periphery of CBD was improved, and the total CO_2 emission also reduced considerably.

The results of scenario Et0 − 30 show that, in scenario Et0, the percentages of each travel mode and the sprawl level were almost the same as scenario At. As advancing the policy to promote activeness, however, the percentage of private automobile users got decreasing gradually. When the scenario reached Et30, the percentage of private automobile users decreased to less than 10%, and the percentage of train (and tramway in combination) users increased to more than 75%. Along with this, the cluster of residences of train users around the residence station was maintained quite clearly. Additionally, the percentage of tramway users increased to more than 15%. And the total CO_2 emission also reduced to less than 30%.

Table 1. Result of Experiment 1

Scenario	Percentage of representative travel modes						CO_2 emission	Travel time	Standard deviation	
	Walk	bicycle	Train	Automobile	train + Tram	Tram			x-cor	y-cor
A	1.3%	2.4%	7.3%	89.0%	0.0%	0.0%	100.0%	9.3 min	22.9	9.8
At	1.4%	2.6%	15.0%	49.7%	27.9%	3.5%	66.6%	20.6 min	17.0	8.4
Et0	1.1%	2.3%	14.4%	53.7%	25.3%	3.2%	91.1%	33.5 min	17.5	9.1
Et10	1.2%	1.5%	11.3%	21.6%	57.1%	7.4%	48.1%	39.4 min	13.9	7.8
Et20	1.2%	1.3%	9.5%	10.4%	65.7%	11.9%	32.9%	44.7 min	13.3	7.6
Et30	1.0%	1.1%	7.9%	7.1%	67.6%	15.3%	28.6%	47.6 min	13.7	8.0

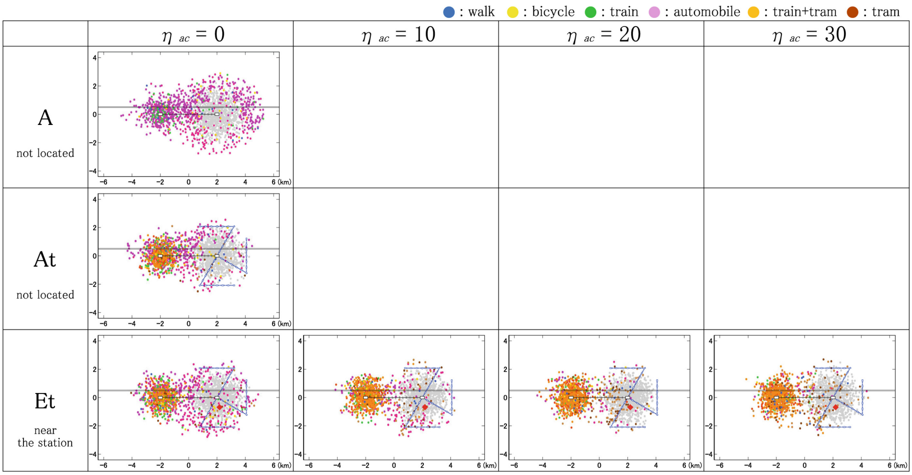

Fig. 3. Residences' final distribution of Experiment 1

5 Experiment 2 - Setting Urban Sprawl as Initial State

This section verifies the effect on improving the existent urban sprawl based on the implementation of the same policies including the introduction of tramway, described in the previous section.

5.1 Conditions of Experiment 2

This section sets the final state of scenario A as the experimental initial state. Most of the residences were distributed on the periphery of CBD as sprawl, and the percentage of private automobile users reached close to 90%. This shows the state after 20 loop processes of residential relocation (corresponding to 40 years) from the zoning with separation between residences and job locations. The edge routes of tramway also pass through the suburb area with sprawled residences.

The experiments were conducted under the conditions of the two types for the location of PFS and the four types for coefficient of activeness, like the previous section. Hereinafter, each of these experiments is expressed e.g., scenario SAt, SEt0 – 30, by combining the initial letter S for the word of sprawl, the symbols of A and E indicating the location of PFS, the initial letter t for the word of tram, and the coefficient of activeness. Additionally, scenario SEt30+, which was run for twice as long as SEt30, was executed.

5.2 Results of Experiment 2

Table 2 shows the quantitative result of scenario SAt, SEt0 – 30, and SEt30+. Figure 4 shows the final distributions of residences of the same scenarios.

The result of scenario SAt shows that the percentage of private automobile users increased further, and the sprawl of their residences on the periphery of CBD also advanced further, unlike scenario At.

The results of scenario SE0 – 30 also show that both the decrease in the private automobile users and the cluster of residences of train users around the residence station were not observed, unlike the series of Et. Particularly in scenario SEt0 – 20, the percentage of private automobile users increased further, and the sprawl also advanced further, like scenario SAt. In advancing the policy to promote activeness, however, the percentage of private automobile users decreased, and the percentage of tramway (and train in combination) users increased and reached close to 50% in total in scenario SEt30.

Furthermore, the results of scenario SEt30+, where scenario SEt30 was run further, shows that the percentage of tramway (and train in combination) users reached close to 90% in total. Along with this, the total CO_2 emission also reduced considerably, and the following two clusters of residences were formed. One is the cluster by residents commuting by train and tramway in combination (about 20%), on centering the residence station. The other is the cluster by residents commuting by tramway alone (about 70%), along tramway routes from the center to the periphery of CBD.

Table 2. Result of Experiment 2

Scenario	Percentage of representative travel modes						CO_2 emission	Travel time	Standard deviation	
	Walk	Bicycle	Train	Automobile	Train + tram	Tram			x-cor	y-cor
SAt	0.8%	1.3%	1.5%	93.4%	1.3%	1.7%	89.3%	7.5 min	27.3	11.7
SEt0	0.7%	0.9%	1.7%	94.1%	1.5%	1.2%	95.4%	20.9 min	21.6	14.2
SEt10	0.6%	0.6%	1.7%	94.5%	1.4%	1.2%	97.1%	21.1 min	21.9	14.2
SEt20	0.8%	0.7%	1.4%	91.8%	1.9%	3.3%	94.8%	21.3 min	21.9	14.3
SEt30	2.3%	0.9%	4.1%	44.9%	12.3%	35.6%	54.2%	37.4 min	22.5	14.2
SEt30+	0.8%	0.9%	1.4%	10.0%	19.4%	67.5%	20.6%	43.7 min	20.5	12.9

6 Discussion

6.1 Estimation of the Experimental Results

By combining the introduction of tramway with introducing a public facility for stopping off (PFS) and implementing a policy to promote activeness around it, the percentage of private automobile users decreased, when compared with

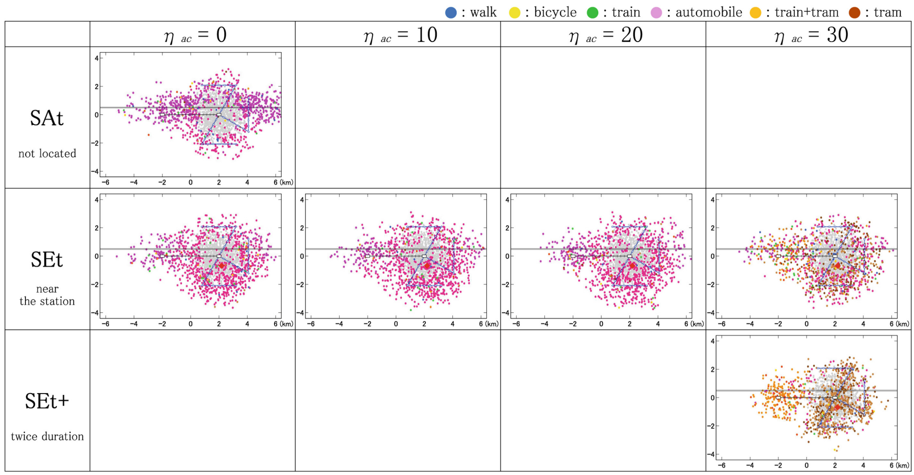

Fig. 4. Residences' final distribution of Experiment 5

the cases when no policies were implemented. And the percentage of train (and tramway in combination) users increased accordingly. Along with this, the total CO_2 emission reduced, and the compact urban structure, which was formed according to the zoning, was maintained. These suggest that the synergistic effects of the introduction of tramway, the proper location of the public facility for urban residents, and the policy to promote activeness around it, could impact positively on a both static and dynamic urban environment. This also seems to be because the policy to promote activeness, which is incentive to stroll about downtown, was effective to increase the percentage of tramway users, like the two transport policies in Nagai [27].

On the other hand, where the initial state was sprawl mainly with private automobiles, the introduction of tramway could not serve to control further sprawl and use of private automobiles. When combined with the introduction of the public facility and the implementation of the policy to promote activeness, however, most of the private automobile users switched to tramway use, although it took a long period. This suggests that once residents established the lifestyle of low-density residence in suburb and commuting by private automobile, that becomes robust, irreversible, and very difficult to be upset.

As for the residence distribution in the same scenario, most of the residences that are distributed along the tramway routes deviated from the initial polycentric-form compact city, which was planned according to the zoning with separation between residences and job locations. This, however, can gain the following positive evaluations of a monocentric-form compact city. First, the residents can establish a life where residences and job locations are nearby based mainly on use of public transportations, resulting in being free from traffic congestion and air pollution. Second, mixed land-use provides the residents with a broad range of social activities, while revitalizing the central urban area.

Simply put, the policy to promote activeness is a policy to lead people to walk by giving them incentives. On the other hand, many successful cases of introducing tramway in the real world are characterized with combining the introduction of tramway with other policies which serve as a benefit for people traveling on foot. That is, this experiment clarified that the introduction of tramway can exert a profound effect only when combined with policies, which lead tramway users' walk before and after they use a tramway, and how it can offer great benefits.

6.2 Validation of the Simulation Model

Because of the property of emergence in complex self-organizing systems, ABMs should be assessed based on validity rather than one-to-one correspondence or correlation measures [34]. Pattern-Oriented Modeling (POM) procedure is an effective validation procedure. In POM procedure, after identifying the observed patterns in the real-world characterizing the system to be modeled, the ABM is evaluated by whether the observed patterns are reproduced [29]. This section validated the simulation model according to the concept of POM.

In scenario A for the first experiment, the residence distribution significantly changed from separation between residences and job locations to sprawl where most of the residences on the periphery of CBD. This can be regarded as the reproduction of the growth process of a concentric low-density suburb based on the monocentric urban model which was proposed by Alonso [4] and subsequently supported by many related researches. This can be also regarded as the reproduction of the fact that many cities in Japan's urban areas have consistently expanded since the high economic growth period [14]. Furthermore, the travel mode used by most of the household agents living in suburb has switched from train to private automobiles. This can be also regarded as the reproduction of the fact that the main travel mode in commuting has switched from train to private automobiles, and the road traffic has reached saturation, especially in regional cities [2].

The purpose of the model is not to reproduce the real society precisely, but to analyze the mechanism of highly abstracted urban dynamics by a small number of elements and simple rules. Nevertheless, the simulation model reproduced the above multiple social phenomena which were not directly incorporated into the model. Therefore, these reproductions demonstrate that the simulation model can explain the real society to a certain level, and the experimental results of this research are valid.

7 Conclusion

The purpose of this research was to verify the effectiveness of the combination of the introduction of a tramway with introducing the public facility for urban residents and implementing the policy to promote activeness around it, on urban sprawl. So, this research built an agent-based model (ABM) for simulating urban structure changes through autonomous daily travel and residential relocations of urban residents. By using this model, the simulations were conducted based on the assumption of setting zoning with separation between residences and job locations as the initial state and combining these policies. These were followed by other simulations based on the assumption of setting urban sprawl as the initial state and combining these policies. As a result, these experiments clarified the following points and how they were.

- The synergistic effects of the introduction of a tramway, the proper location of a public facility for urban residents, and the policy to promote activeness around it, are effective in maintaining a polycentric-form compact urban structure in accordance with the initial plan.
- The introduction of a tramway targeting the urban sprawl can exert a profound effect only when combined with the above-mentioned policies, which lead tramway users' walk before and after using the tramway, although it takes a long period.
- A monocentric-form compact urban structure, which differs from the initial plan, is realized along with the above-mentioned point, improving the living environment for the residents and revitalizing the urban central area.

References

1. Idea store strategy. https://www.ideastore.co.uk
2. White paper on land, infrastructure and transport in 2016 - the ministry of land, infrastructure and transport. http://www.mlit.go.jp/hakusyo/mlit/h28/index.html
3. Acheampong, R.A., Silva, E.: Land use-transport interaction modeling: a review of the literature and future research directions. J. Transp. Land Use **8**(3), 11–38 (2015)
4. Alonso, W.: Location and Land Use. Toward a General Theory of Land Rent. Harvard University Press, Cambridge (1964)
5. Anderson, W.P., Kanaroglou, P.S., Miller, E.J.: Urban form, energy and the environment: a review of issues, evidence and policy. Urban Stud. **33**(1), 7–35 (1996)
6. Batisani, N., Yarnal, B.: Uncertainty awareness in urban sprawl simulations: lessons from a small US metropolitan region. Land Use Policy **26**(2), 178–185 (2009)
7. Batty, M.: Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals. The MIT press, Cambridge (2007)
8. Behan, K., Maoh, H., Kanaroglou, P.: Smart growth strategies, transportation and urban sprawl: simulated futures for hamilton, ontario. Can. Geogr./Le Géographe Can. **52**(3), 291–308 (2008)
9. Benenson, I.: Multi-agent simulations of residential dynamics in the city. Comput. Environ. Urban Syst. **22**(1), 25–42 (1998)
10. Brueckner, J.K., Mills, E., Kremer, M.: Urban sprawl: lessons from urban economics. Brookings-Wharton papers on urban affairs, pp. 65–97 (2001)
11. De Bruijn, H., Veeneman, W.: Decision-making for light rail. Transp. Res. Part A: Policy Pract. **43**(4), 349–359 (2009)
12. Deal, B., Schunk, D.: Spatial dynamic modeling and urban land use transformation: a simulation approach to assessing the costs of urban sprawl. Ecol. Econ. **51**(1), 79–95 (2004)

13. Desa, U.: World urbanization prospects, the 2011 revision. Final Report with Annex Tables. United Nations Department of Economic and Social Affairs, New York (2012)
14. Eaton, J., Eckstein, Z.: Cities and growth: theory and evidence from France and Japan. Reg. Sci. Urban Econ. **27**(4–5), 443–474 (1997)
15. Ewing, R.: Is Los Angeles-style sprawl desirable? J. Am. Planning Assoc. **63**(1), 107–126 (1997)
16. Fujii, S.: An empirical test of hypothesis on influence of travel behavior on residential choice behavior: a fundamental study on transportation measures for promoting compact cities. JSTE J. Traffic Eng
17. Gilbert, N.: Agent-Based Models. No. 153. Sage, Thousand Oaks (2008)
18. Gimblett, R., Daniel, T., Cherry, S., Meitner, M.J.: The simulation and visualization of complex human-environment interactions. Landscape Urban Planning **54**(1), 63–79 (2001)
19. Howley, P., Scott, M., Redmond, D.: An examination of residential preferences for less sustainable housing: exploring future mobility among dublin central city residents. Cities **26**(1), 1–8 (2009)
20. Jacobs, J.: The Economy of Cities. Vintage Books, New York City (1969)
21. Johnson, M.P.: Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environ. Planning A **33**(4), 717–735 (2001)
22. Kakoi, M., Nakamura, R., Saito, S.: Causal structure modeling of consumer's decision-making on selection of commercial facilities. Fukuoka Univ. Econ. Rev. **54**(3–4), 241–256 (2010)
23. Koike, H., Morimoto, A., Itoh, K.: A study on measures to promote bicycle usage in Japan. In: VeloMondial 2000-World Bicycle Conference, pp. 19–22. Citeseer (2000)
24. Ligtenberg, A., Bregt, A.K., Van Lammeren, R.: Multi-actor-based land use modelling: spatial planning using agents. Landscape Urban Planning **56**(1), 21–33 (2001)
25. Lucas, R.E.: On the mechanics of economic development. Econ. Soc. Monogr. **29**, 61–70 (1998)
26. Martine, G., Marshall, A., et al.: State of world population 2007: unleashing the potential of urban growth. UNFPA (2007)
27. Nagai, H., Kurahashi, S.: Bustle changes the city - facility for stopping off and modeling urban dynamics. Trans. Jpn. Soc. Artif. Intell. **32**(1), D-G26_1 (2017)
28. Nawrocki, J., Nakagawa, D., Matsunaka, R., Oba, T.: Measuring walkability and its effect on light rail usage: a comparative study of the usa and Japan. Urban Transp. XX **138**, 305 (2014)
29. Railsback, S.F., Grimm, V.: Agent-Based and Individual-Based Modeling: A Practical Introduction. Princeton University Press, Princeton (2011)
30. Schneider, A., Woodcock, C.E.: Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. Urban Stud. **45**(3), 659–692 (2008)
31. Scott, D.M., Kanaroglou, P.S., Anderson, W.P.: Impacts of commuting efficiency on congestion and emissions: case of the hamilton CMA, Canada. Transp. Res. Part D: Trans. Environ. **2**(4), 245–257 (1997)
32. Taniguchi, T., Takahashi, Y.: Multi-agent simulation about urban dynamics based on a hypothetical relationship between individuals' travel behavior and residential choice behavior. Trans. Soc. Instr. Control Eng. **47**(11), 571–580 (2011)
33. Tsai, Y.H.: Quantifying urban form: compactness versus' sprawl'. Urban Stud. **42**(1), 141–161 (2005)
34. Wu, F.: Calibration of stochastic cellular automata: the application to rural-urban land conversions. Int. J. Geograph. Inf. Sci. **16**(8), 795–818 (2002)