Gravity-Driven Agent-Based Model for Simulation of Economic Growth a Point Along a Highway

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Abstract. Aim of this research is to get number of rest area visitors. As the simulation method, gravity model (GM) used to generate potential that can attract agent to Pendle between the two cities and to visit a rest area and agent-based model (ABM) used to govern the motion of agents from one city to the other and for entering and leaving the rest area. As the results, it observed that meaningful pattern could interpreted monthly. By differencing two types of agent, the red and the blue ones, where the first need to use rest area and the second not, composition of agent has also a role in determining number of rest area visitor. In addition, as implication there is also favourable rest area due to distance from the city where the agents are coming from. Finally, it concluded that composition of agents and position of rest area influence number of rest area visitors.

1. Introduction
It is interesting to study how a highway induced economic growth around it. Rest area are important sites along a highway, that can be considered as points with economy potential. Agent-based model (ABM), which is driven by gravity model, is used to perform the study. On average, effect of highway construction on other sectors are greater compared to the effect of other sectors and after that the induced economic growth had been increasing [1]. The emergence of a new set of economic opportunities and a change in the pattern of relationships between the environment and social actors have been induced by a highway improvement [2]. Whether traffic congestion has impact on slowing economy is still debateable since a critical disconnect exists between research and practice [3], and policies to overcome this problem must also take into account the rebound and feedback effect [4]. Expansion of a highway is not a long term solution [5], that will have impact on environment unless transportation modal sharing is used [6], where the spatial variation in road network and its driving patterns relating economy and population [7].

Evolution in the term of economic growth of a point along a highway, i.e. a rest area, is simulated using agent-based model (ABM), where some of the rule in ABM is derived from gravity model (GM). With this approach number of agents or vehicles visiting rest area can be predicted and it is assumed to be proportional to impact to economy of the area. Conventionally, agents can have four important characteristics, such as perception of their environment (and also other agents), performance in the form of moving, communicating with other agents and interacting with their environment, memory for their previous actions and states, and policy in the form of a set of rules, heuristics or strategies to overcome their present situation [8]. ABM is chosen since it is able to accommodate a holistic approach in economy [9] and also bioeconomy [10], where in this work the agents will represent vehicles that pendel between two cities, with possibility to dock on a rest area. From time duration an agent spending in a rest area, economy effect can be predicted.
Reducing travelling time between two cities by opening new route is a common solution, but usually it does not calculate the effect of this change to the growth of some economic points along the path of the new route. In the case of highway, the only possible points are the rest areas. People and their cars are represented by agents who are travel and back between the two cities like a swinging pendulum with their on characteristic period. Each city has its own “mass” that attracts agents to orbit around them, such as workplace, market, information, customer, and other features. A person who lives at city A but work at city B has to travel every day through the highway. The need of this person is changing with time. During the day he requires a workplace but during the night he need a home. Since city A provides “mass” in the form of home and city B provides it in the form of workplace, he should leave city A in the morning to orbit around city B until afternoon, and then leave city B to orbit around city A in the night. During orbit change between the two cities he can choose different path, which is chosen to be the highway in this work. Due to characteristics of each agent, such as level of daily planning, vehicle quality, health, weather, and other aspects, it can transit to a rest area at some position or not. During it transit economic transaction can be occurred such as accessing toilette, filling gas to the car, buying snacks, or simply a pause. Characteristics of every agent can be generated using a hypothetical distribution and then used in the simulation. Every type of economy transaction will be weighted and then accumulated in each day to obtained daily income for an economic point. Best and worse scenarios can be modelled. Work day and holy day will also show differences. Homogeneity of agents will also have interesting influence.

Economic growth of a rest area is assumed only as function of number of visiting agent. Aim of this work is to simulate agents travelling between two cities through a highway with a probability of the agents in visiting the rest area. Gravity model and agent-based model are used as method in this work.

2. Method

GM in economy can be generally formulated as [11]

$$F_{ij} = K \frac{A_i^\alpha A_j^q}{D_{ij}^\gamma},$$  
(1)

where the term $F_{ij}$ represents the interaction force between city $i$ and $j$, which are separated with distance $D_{ij}$ and properties of each city can be accommodated in $A_i$ and $A_j$, respectively, e.g. income, population, transportation system, public facilities, etc. Related to a force there must be a field $\gamma$ of the force, which can also be used in economy model [12]

$$\gamma = \frac{M}{r^2},$$  
(2)

where $M$ is source mass, e.g. a city, and $r$ is distance from the source. In physics, relation between field strength and the related force is

$$E = \frac{F}{q},$$  
(3)

with $q$ a quantity that is affected by the force $F$ when it is located in position where the field $E$ exists. From equation (3) or (2) for this case, lines of vector field can be drawn. This lines will guide the motion of quantity $q$. The common vector representation of field from equation (3) at position $\vec{r}$ is as follow

$$\vec{E}(\vec{r}) = k \frac{q_s}{|\vec{r} - \vec{r}_s|^3} \left(\vec{r} - \vec{r}_s\right),$$  
(4)

where $\vec{r}_s$ represents position of the source of quantity $q_s$ and $k$ is simply a proportionally constant. In this work the field is simplified by a direction for an agent, which is stored in a direction matrix
which represents outward vector from a center point, with representation of each values are as follow 1 (↑), 2 (↗), 3 (→), 4 (↘), 5 (↓), 6 (↙), 7 (←), 8 (↖), dan 0 (·). If in a position there should be another direction exist, additional direction matrix $D$ can be used, where in the implementation all directional matrices will be superpositioned to form direction choices for motion of an agent. Random number can be generated for this purpose.

There is also another matrix required in this system beside the direction matrix, which is world matrix. This type of matrix represent the street where agent, e.g. vehicle, can move a long an empty area. A world with boundary wall and a center obstacle can be represented by

$$
W = \begin{bmatrix}
1 & 1 & 1 & 1 & 1 \\
1 & 0 & 0 & 0 & 1 \\
1 & 0 & 1 & 0 & 1 \\
1 & 0 & 0 & 0 & 1 \\
1 & 1 & 1 & 1 & 1
\end{bmatrix}, \quad (6)
$$

where value of 1 represents a forbidden position for agent to move to, e.g. wall, obstacle, and 0 represents empty space where agent can access.

The last required matrix is agent matrix, which represents agents position and types of them. Agent position should comply to previous world matrix, e.g.

$$
A = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 2 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0
\end{bmatrix}, \quad (7)
$$

shows three agents, two of type 1 and one of type 2, where they are in the space between surrounding wall and center obstacle according to world matrix $W$ in Figure 1.
Figure 1. Simulation system consists of some parts: (a) city A, (b) city B, (c) highway from A to B, (d) highway from B to A, (e) rest area in the way from A to B, and (f) rest area in the way from B to A, and (g) two different types of agent.

Using world matrix $W$, three direction matrices $D_1$, $D_2$, $D_3$ the simulation system can be drawn as shown in Figure 1 (Top), and with addition agent matrix $A$, the full system is drawn in Figure 1 (Bottom). There is also counting area, an area where counting of agents is performed. Four counting areas $CA$ are defined in the simulation. These areas are drawn as light green colored are in both part of figure 1.

There are two different types of agent used in the simulation. First type is agent without need to visit rest area (blue color) and the second type is with the need (red color). In the implementation the first type can only access direction matrices $D_1$ and $D_2$ with random choice and the last type can access all provided direction matrices. An example for random function is

$$i = f_{\text{random}}(i_{\text{start}}, i_{\text{end}}),$$

where $i = [i_{\text{start}}, i_{\text{end}}]$, where $i$ is index of direction matrix $D_i$.

3. Results and discussion

The two cities, which gravitate agents in the form of direction matrix $D$, are simply drawn as two circular trajectories. While in one of the cities agent can move around until it can escape the city at start time $t_{\text{start}}$. Agents are only allowed to orbit a city between $t_{\text{stop}}$ and $t_{\text{end}}$, which represents the rest time for the drivers. Such policy to reduce congestion, while assuming that it will impact the economy (Sweet, 2011), such as night shift travelling is not considered in this work and also the rebound and feedback effect (Hymel et al., 2010).

Simulation parameters are as follow $N = 72$, $N_1 = 36$, $48$, $72$, $N_2 = N - N_1$, $W$, $D_1$, $D_2$, $A$, $t_{\text{stop}} = 0$ (00:00), $t_{\text{start}} = 75$ (06:00), $t_{\text{max}} = 300$ (24:00), $\Delta t = 1$, and initial configuration of agents as in Figure 2.

Figure 2. Initial configuration of agents, with different behaviour: without need to visit rest area (blue) and with the need (red), for scenario (a) 0, (b) 1, (c) 2, (d) 3.

Every day at 00:00 the stoplight is red until 06:00 and then green (not drawn) from 06:00 – 24:00. After $30t_{\text{max}}$ or about one month the simulation is terminated. Mid configuration about three weeks is shown in Figure 3 and final configuration after one month is given in Figure 4.
Visually, there are no significant or unique pattern for each scenario in mid or final configuration, since pattern of agents are dynamically change during simulation. (See Figure 4)

Typical results of number of vehicles from city A to B (NAB), from city B to A (NBA), visiting rest area in the way from A to B (NRA1) and visiting rest area in the way from B to A (NRA2) are given in Figure 5

From the results there is no guarantee that a red agent will visit the rest area since it depends also on its position before approaching the rest area and when it is in the right place, it’s still has only 1/3
probability to visit the place. Blue agents will not visit the place but it can be a barrier to the red ones, which can prevent the red ones to visit it.

For future plan agent should be able to change its state while travelling from one city to another, e.g. blue agent will turn into red one, and after visiting a rest area the agent should be in better condition, e.g. red agent turn into a blue one. With this new future, the simulation system will be more realistic than what in the present work [13].

Results in Figure 5 are drawn each simulation time, where a day is about 300 simulation time. In figure 6 the observation parameters $N_{AB}$, $N_{BA}$, $N_{RA1}$, and $N_{RA2}$ are drawn for each day to shown how the they evolve daily with variation of agent types.

$$c = \frac{N_{\text{red}}}{N_{\text{red}} + N_{\text{blue}}}, \quad (9)$$

where $N_{\text{red}}$ stands for number of the red agents and $N_{\text{blue}}$ for the blue ones. Unfortunately, those parameters still have no significant pattern, whether drawn every simulation time (Figure 5) or daily (Figure 6).

![Figure 6](image)

**Figure 6.** Typical results of: (a) $N_{AB}$, (b) $N_{BA}$, (c) $N_{RA1}$, and (d) $N_{RA2}$, for different value of fraction of the red agents $c$.

Interesting patterns are observed when those parameters are aggregated in a month and correlated to fraction of the red agents as shown in Figure 7.
By increasing fraction of the red agents, who need to use rest area, number of agents in a month on the way from city A to city B and vice versa will decrease, but number of agents visiting rest areas will increase. Slightly fluctuations are due to probability of an agent in visiting or not visiting the rest areas. Further sampling could give a better statistics and smoother relation. Figure 7 (right) shows that nearest rest area ($N_{RA1}$) always has higher value than the farther one ($N_{RA2}$). This distance is seen from the city where the agents are coming from. It is natural that when agents need to use a rest area, it will choose the nearest one.

4. Conclusion

Variation of initial configuration shows the influence of composition of agents, with need to visit rest area compared to the other ones without the need, in visiting the rest area, if observed data is aggregated monthly. It is also found that nearer rest area is also favorable than the farther one.

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