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## Analysis for effectiveness of bridge management plan focused on the economic value by multi-agent simulation

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### Abstract

In recent years, it has been said that the majority of the Japanese bridge which were built in the period of high economic growth in danger. When performing a maintenance and service for such bridges, various discussions have been made as to how to optimize the management. In this analysis, for management approach of the bridges, we propose a management approach that emphasizes the economic value of the bridge. The effect of proposed method is verified using a multi-agent simulation model in comparison with the durability value based on the conventional method.

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**Keywords:** Bridge Management; Multi-Agent-System; Simulation.

### 1. Introduction

Maintenance of deteriorated infrastructure is an important issue for most nations. In the U.S., after the world economic crisis of the 1930s, much social infrastructure was constructed through the “New Deal”. After five decades, the U.S. infrastructure has deteriorated severely. Choate and Walter wrote “America in Ruins” in 1981 to sound an alarm about its decaying infrastructure [1]. The useful life of structures such as bridges is roughly 50 years.

In Japan, many infrastructure projects were constructed during the 1960s, the era of high economic growth. Bridges older than 50 years will account for 43% of all bridges in 10 years, as estimated by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) [2]. Moreover, aging of the Japanese population is continuing. The economically productive population has started to decrease. The budget to repair deteriorated infrastructure in Japan has decreased during the last 10 years. It is difficult to expect its increase. The maintenance scheme for increasing deteriorated social infrastructure with decreasing budget is a key issue.

Triggered by the proposals of Choate and Walter, research into mathematical model for prediction of the deterioration of bridges has progressed. The Markov process model was applied for the long-term change of state of the bridge [3],

and the Genetic Algorithms (GAs) were applied as optimization methods for repairing bridges [4].

Based on these studies, the Life-Cycle Cost (LCC) for minimizing the maintenance scheme has been proposed, [5] [6]. From these studies, it was observed that preventive maintenance is a better than ex-post maintenance for LCC minimization.

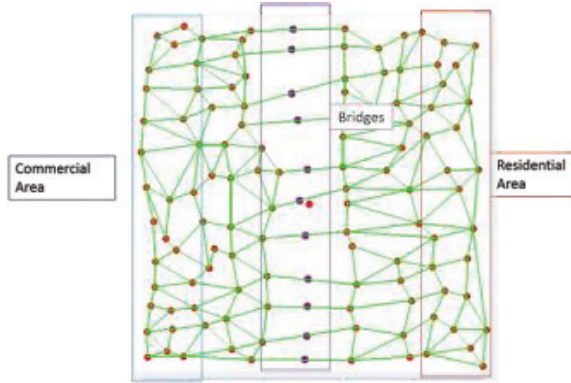
However, those earlier studies examined only the bridge deterioration. In contrast, a new maintenance scheme proposed in this study investigates not only bridge deterioration but also the economic value of the bridges. The economic value of bridges is evaluated in this study using multi-agent simulations [7] [8].

### 2. Simulation Model

In this model, transportation is expressed by the road network model. The whole area is divided by a river into two areas. A residential area is situated on the right side, with a commercial and office area on the left. Individual agents must cross the river for economic activity, usually to go to work or to go shopping every day. Therefore, bridges are fundamentally important for economic activity in this model. A government agent influences individual agents and bridges and collects income taxes from individual agents once a year

to support the budget and to conduct inspections and repair bridges based on the budget.

Fig. 1. Multi-Agent Simulation Model



### 2.1 Individual Agents

As described above, individual agents do two actions: working in their offices on a weekday and enjoying a weekend in commercial facilities. They start for their destinations from their houses at the same time in a day. They will wait until all agents arrive at their destinations. When all agents finish their actions, they will leave the office or commercial facility to go home simultaneously. The end of a day comes when all agents return home. Offices of the individual agents are fixed, but target commercial facilities might differ on weekends.

#### 2.1.1 Movement and Route Choice

An Optimal Velocity model [9] is applied for individual agents' movement. An agent controls its velocity referring to standard optimal velocity  $V_{opt}$  based on the distance from the agent ahead with sensitivity.

$$V_n = \frac{dx_n}{dt}, \quad \frac{dV_n}{dt} = a[V_{opt}(\Delta x) - V_n]$$

$$V_{opt}(\Delta x) = V_b \left[ \tanh\left(\Delta x - \frac{x_c}{b}\right) + \tanh\left(\frac{x_c}{b}\right) \right] \quad (1)$$

$$\Delta x = x_n - x_{n-1}$$

In these equations,  $x_n, V_n$  are agent n's position and velocity,  $a$  denotes the sensitivity of the agent to control velocity.  $\Delta x$  signifies the distance from the agent ahead,  $x_c$  denotes standard distance and  $b$  represents the deceleration constant. In this model,  $a$  is 1,  $V_b$  is 1,  $x_c$  is 10 and  $b$  is 3.

Next, the route choice of individual agents is explained. When they leave their homes, offices, and commercial facilities, the agents choose the routes and bridges they expect to use.

The route choice algorithm of individual agents is based on the stochastic model. Shortest routes via the respective

bridges are determined using Dijkstra's algorithm. Each agent calculates the selection probability of each route through the bridge by Eq. (2).  $P_k$  signifies the probability to select the route via the  $k$ -th bridge,  $Cost_k$  denotes the expected time with the route via the  $k$ -th bridge and  $N_b$  represents the number of the unbroken bridges. In this simulation, the actual time for the previous day was used as  $Cost_k$ .

$$P_k = \exp\left(\frac{1}{Cost_k}\right) / \sum_{i=1}^{N_b} \exp\left(\frac{1}{Cost_i}\right) \quad (2)$$

Bottleneck traffic jam [10] was reproduced in the simulation. If the number of agents at node of the entrance of a bridge exceeds its traffic capacity, the node turns into traffic jam mode and no more agents can enter to this bridge. Individual agents search detour route when a node turned into traffic jam node. By detouring, time for travel increases and result in increase of  $Cost$ . When all agents arrive at their destinations, all nodes are reset to the normal mode.

#### 2.1.2 Economic Activity and Utility of Individual Agents

Individual agents work in their determined offices on weekdays based on the performance pay system. Every day they attain achievements based on their given wage capability ( $W$ ). They receive the sum of their daily achievements as their monthly salaries at the end of month. On weekends, they go to commercial facilities chosen at random and enjoy shopping based on their consumption capability ( $C$ ). They enjoy leisure time based on their leisure time capacity ( $L$ ).

The wage capability  $W$ , consumption capability  $C$  and leisure time capacity  $L$  of each individual agent set by normal distribution. Average of  $W$ ,  $C$  and  $F$  are set to Japanese workers' average monthly income, average monthly outcome and average daily refresh time in weekend by the survey of Statistics Japan [11] [12]. Each standard deviation of those is set to uniform random numbers shown in Table 1.

In addition to this,  $C$  and  $F$  of an agent are doubled if the agent arrives at the destination earlier than the normal time, both  $C$  and  $F$  of an agent are halved if the agent arrives at the destination later than the normal time. This doubling is done to increase the difference of an individual's consumption and leisure time with different bridge situations.

Table 1. Capability and Capacity of Individual Agents

Parameters	Average	Standard Deviation
Wage $W$ (yen)	14,581	500-1500
Consumption $C$ (yen)	9360	500-1500
Leisure time $L$ (min)	300	50~150

In this study, "utility" is introduced to assess the social value of the bridge management scheme. Utility in this study is defined as cardinal utility, which is the numerical degree of satisfaction in a state [13]. The individual agents'

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