Conditional Equilibrium Analysis System of Service Level and Budget Allocation for Road Pavement by Deterioration Model of MCI

Masato Miyata[1], Takashi Nishioka[1], Masanobu Nishiura[1],
Takahiro Hayashi[1], Tadashi Okutani[2], Ryoma Hiraoka[1], Seigo Nasu[3]
Kochi University of Technology

(space)

ABSTRACT**:** Asset management is the main stream for road structures, yet the management system to determine service standard and maintenance/repair level is not established. For example of road pavement these are set by traffic volume, by road grade, or just by the road condition.

This study is to establish methodology to determine appropriate service level and budget allocation for infrastructure management, in this case for road pavement, with a new evaluation system of infrastructure value by applying depreciation model which can evaluate correctly asset conditions corresponding to maintenance/repair pattern. Management system also assures accountability of budget allocation by this numerical method. Service standard and maintenance/repair level was derived from equilibrium point at the service market of driver's demand function (satisfaction function) and service providing cost function. Driver's demand function was set up as an outcome (=satisfaction level to road condition) index. Service providing cost function was derived by evaluating the optimized maintenance/repair pattern based on the lowest life cycle cost for the required asset value necessary to provide certain service level.

If we treat roads as service markets, this equilibrium analysis is able to determine the service level and budget allocation in various roads in accordance to the equilibrium point of satisfaction level and service level. It is also possible to determine the satisfaction level of drivers among roads under budget restriction by conditional equilibrium analysis, such as setting equal satisfaction standard for every road.

KEYWORDS: Appraisal method of public, Finance and institution theory, Maintenance/repair for civil engineering facilities

1. INTRODUCTION

Asset management is the main stream for road structures, yet the management system to determine service standard and maintenance/repair level is not established. For example of road pavement these are set by traffic volume, by road grade, or just by the road condition. This study is to establish methodology to determine appropriate service level and budget allocation for infrastructure management, in this case for road pavement, with a new evaluation system of infrastructure value by applying depreciation model which can evaluate correctly asset conditions corresponding to maintenance/repair pattern. Management system also assures accountability of budget allocation by this numerical method.

2. SERVICE LEVEL, ASSET VALUE AND POLICY EVALUATION

If the practical degradation model of New Depreciation Model for pavement can be set, and asset value can be measured by taking the service level which is traveling speed, environment and safety, it is possible to obtain maintenance pattern and maintenance cost. Use of demand function with marketing activity can take how mach does driver could pay money for policy. And create supply function from cost of service level by maintenance/repair and calculate equilibrium point of demand /supply, it can be decided service level of pavement or policy strategy.

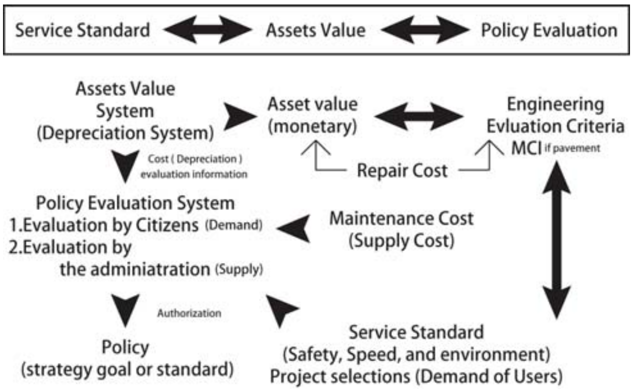

Figure 1. Service Level, Asset Value and Policy Evaluation

3. DETERMINATION OF A TARGET SERVICE LEVEL WITH THE EQUILIBRIUM POINT OF A DEMAND FUNCTION AND A SUPPLY FUNCTION

The service level of user dissatisfaction level can change demand. In fact, to set service level as satisfaction level, this is possible to get benefit that dissolve dissatisfaction as upraise service level. In addition, supply is the repair cost of service level to maintenance. If demand function and supply function were made, the best budget allocation in each road could be decided by the equilibrium point when there is no budget restriction. Two or more roads with their dissatisfaction level, each road can decide service level.

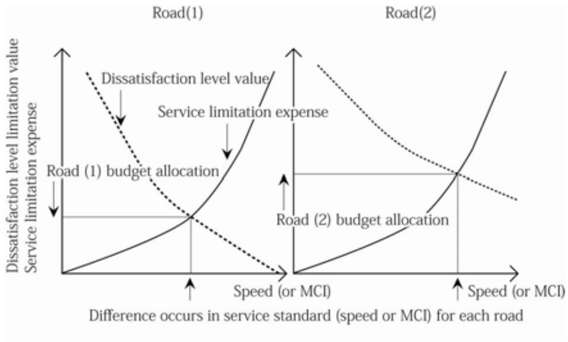

Figure 2. Example of equilibrium analysis

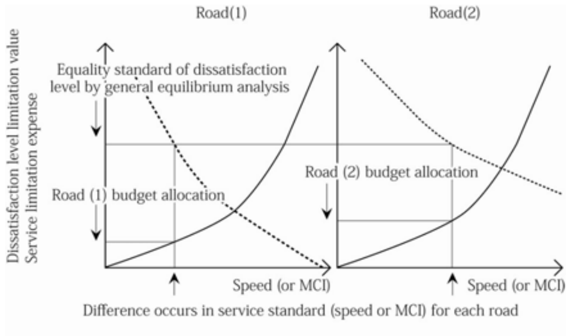

Figure3. Equilibrium analysis below budget restriction

However, the budget restriction is occurring in a general way. Two or more roads must remain in equilibrium simultaneously and there are required service levels lower than point of reach equilibrium as dissatisfaction level and marginal cost. For example, if administration can provide each roads service level of traveling speed for driver's dissatisfaction level, it is possible for equilibrium analysis that keep define dissatisfaction level of all roads. The condition of dissatisfaction level for driver can be changed. Do set dissatisfaction level of each road as total of roads dissatisfaction level at minimum and incorporate various constrained restriction. Administration must set equilibrium restriction adequately through researching driver's concept of values or demand.

4. DERIVATION OF THE DEMAND FUNCTION ON PAVEMENT

4.1 SECTIONALIZE DEMAND FUNCTION

Decide the area from traffic volume and speed limit, and actually drove there. After that, define 0 dissatisfaction level of road condition as a favorable speed and decide the favorable speed in each classified area. In addition, this dissatisfaction level has evaluated as a driver's well-rounded and plotted favorable speed on graph. This graph shows favorable speed is related to traffic volume and speed limit. From this analysis, There exist a relation that when traffic volume density increases, the favorable speed allows down in each speed. Then15 areas can be established corresponding to traffic volume 10000 car/day with speed limit as 40km/h, 50km/h and 60km/h.

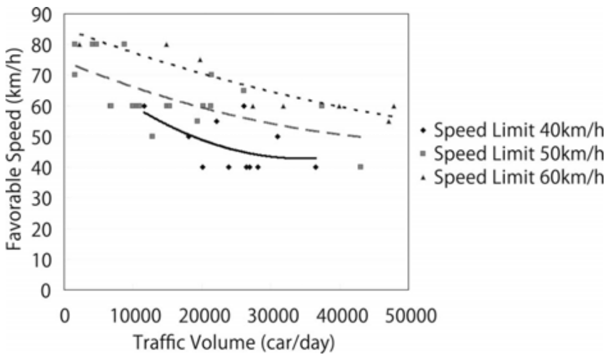

Figure 4. Traffic volume, speed limit and favorable speed

4.2 CRITERION OF DISSATISFACTION LEVEL

It is necessary to fix dissatisfaction level of driver's speed to make demand function. Then, dissatisfaction level was evaluated as 0%, 20%, 80% and 100%. Dissatisfaction level's grades are written on Table 1.

Table 1. Criterion of dissatisfaction

Dissatisfaction level	Evaluation
100%	0km/h, Don't want to drive
80%	Can't stand with this speed
20%	Not to feel uneasy
0%	Comfortable speed, Not worrisome at all

4.3 PREPARE DEMAND FUNCTIONS

From all of these data, demand function consisting of 3 linear and 4 points (0%, 20%, 80% and 100%) can be drawn by evaluated dissatisfaction level. In addition, traffic volumes are 0-9999 car/day, 10000-19999 car/day, 20000-29999 car/day, 30000-39999 car/day and 40000-49999 car/day.

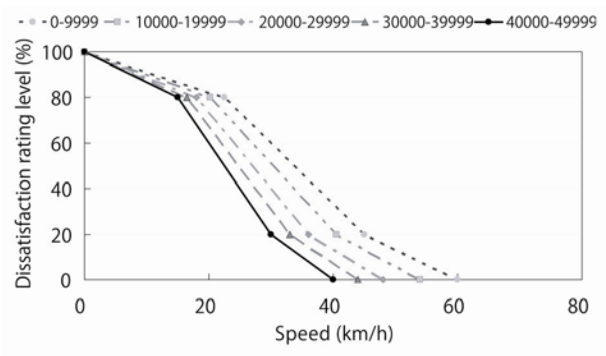

Figure 5. Demand function -Legal speed 40 km/h-

5 DERIVATION OF THE SUPPLY FUNCTION ON PAVEMENT

5.1 MAINTENANCE/REPAIR METHOD FOR GENERATE MINIMUM LCC

Life Cycle Cost (LCC) is the most important consideration when generating supply functions. LCC may shift when service level or repair method is changed in service period. Therefore, on pavement asset management, it is necessary to construct minimum LCC and chose best choice of repair method for service level. However, now CR (cut and overlay) deterioration Model is only used. In fact, this research use CR deterioration model only as repair method.

5.2 MAKING OF DETERIORATION CURVE

5.2.1 About MCI

In order to make the deterioration function of the road, the investigated data base about MCI is analyzed. The road pavement is comprehensively evaluated by MCI. The evaluation equation consists of crack, C(%), rut, D(mm), and flatness, σ(mm). C, D and σ substitute for four evaluation expression to MCI. By calculation result, MCI is decided as minimum value. MCI is evaluated by ten levels, and the tenth level has the best condition.

5.2.2 About analytical data

The following figure explains analytical data. A small point on the time axis is set to be an initial value. Date is obtained every three years. The difference in the measurement value in three years is defined as ⊿C. Rut and flatness are similarly defined as ⊿D and ⊿σ.

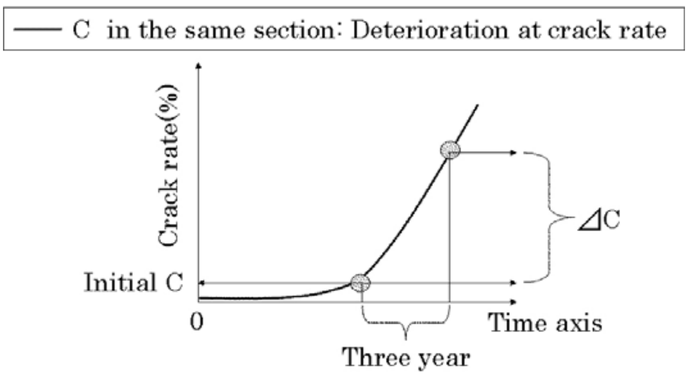

Figure 6. Explanation of analytical data

5.2.3 Extraction method by mode value

The figure below shows relative frequency of the valuation (amount of the change) in each state of deterioration. The deterioration curve which becomes the mainstream of maintenance and repair is analyzed in C(%) in construction method CR. By evenly dividing a lot of analysis data, a curve corresponding to a physical characteristic can be made. More than half of data used in analysis have 0 % of initial value. Deterioration characteristics vary in the state of no crack or some cracks. When there is no crack (0 %), a different treatment is used. When there is no amount of change (0%), a different treatment is also used. The more deterioration occurs, the more dispersion occurs. This could be due to repairing frequency and kinds of pavement. The use of the amount of the change with the highest relative frequency leads to extraction of the points with the highest probability of deterioration. Bigger the initial value, the bigger will be ⊿ C(%) dispersion. The amount of the change with the most frequency is extracted to be the amount of the change in each deterioration state. The order of an initial value is assumed to show deterioration. The mode value is considered to be the amount of the change with the highest likeliness of deterioration. Similarly D and σ are analyzed, and a deteriorated amount of the change is obtained.

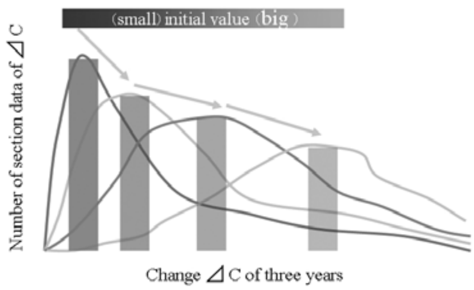

Figure 7. Initial value C ⊿ C distribution

5.2.4 MAKING THE DETERIORATION CURVES FOR C, D, AND σ

The number of data which extracted by the mode value assumed to be a number of samples. Variation (the amount of the change) in three years which is shown in article 4.2 was calculated in one year. The relation between an initial value and variation (the amount of the change) was distributed in ascending order in the number of samples using the absolute value in an initial value. Next, the number of samples was calculated in 10 years. The approximation curve was made from a physical characteristic of asphalt and it was made into function. The approximation curve was integrated in year of passage and the state of C (%), D (mm) and σ (mm) are shown. C shows sudden deterioration as time passes. This is due to the fact that cracks increase geometrically from one to two, from two to four.

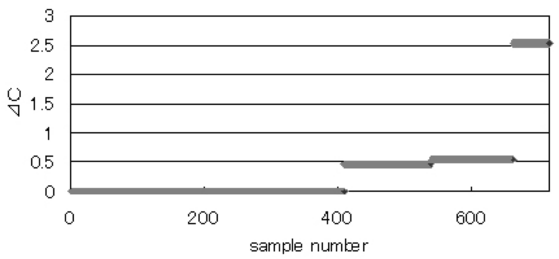

Figure 8. Deriving process 1 of deterioration curve

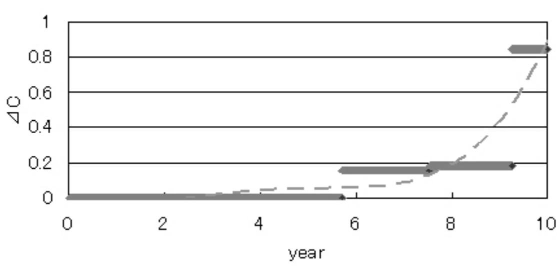

Figure 9. Deriving process 2 of deterioration curve

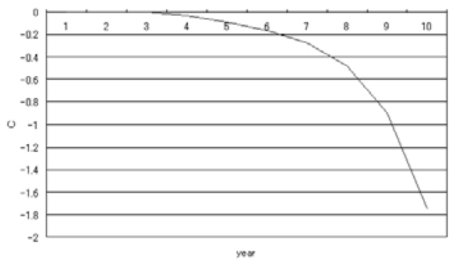

Figure 10. Deriving process 3 of deterioration curve

5.2.5 DETERIORATION FORECAST OF MCI

The passage year was substituted for the deterioration model type of C, D, and each σ. The calculated value was substituted for the model type of MCI. MCI in the passing year is forecasted. From the interview, it is said that repairing by CR method reaches the recovery state of (C, D, σ)=(0%, 0mm, 2.4mm) and MCI=9.4. However the lowest value of D was 2mm in data. Assuming that the recovery rate was (C, D, σ)=(0%, 2mm, 2.4mm) and MCI=9.0, deterioration of MCI was forecasted.

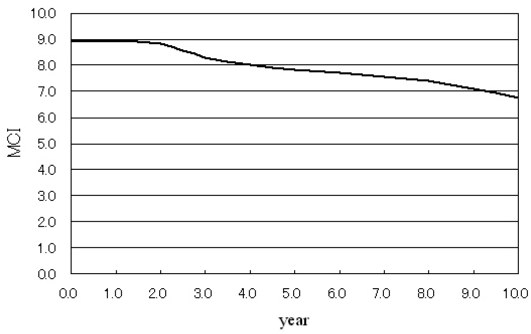

Figure 11. MCI deterioration forecast

5.3 CONVERSION CURVE

Supply function is a service level (as Maintenance control index (MCI).) corresponding to repair cost of maintain it. Demand function is a service level (as travel speed) corresponding to dissatisfaction level. Therefore, to make equilibrium of supply and demand, it clearly requires the relationship of MCI and travel speed as service level. Then construct linear model with hypothecated MCI and travel speed of driver's needs. For example this model, when MCI is 2, pavement condition is not good and can't drive high speed. While on the other hand, when MCI is 10, pavement condition looks like flat or such a not deteriorated pavement and driver can comfortably drive. In addition, experience was also incorporated. After that, conversion curve function was constructed (1). For the future, conversion curve should approximate like a driver's feeling.

MCI = S / 10 + 2,   But if S >= 80, MCI = 10.0   *
S = Travel speed   (1)

5.4 SUPPLY FUNCTION

To construct supply function, the 2003 fiscal year pavement conditions data were used. Pavement conditions data can sectionalize about 100m and total section in Kochi prefecture are 3361. Then, intended for 30 year service period, repair cost of unit area for the year not dip from service level that is set in period was calculated. First, set up MCI level of maintenance, calculate term of next repair by MCI deterioration function. Next, divide MCI such a more than maintenance level or less than maintenance level. The area under maintenance level should repair as quickly and start service after repaired. Furthermore, calculate period of not under maintenance level area and decide number of maintenance/repair in each area for 30 years. Further, decide maintenance/repair area with multiplication number of maintenance/repair and pavement area, because pavement area is different from all area. After that, multiply maintenance/repair unit cost times area equals LCC of pavement area for 30 years. Maintenance/repair unit cost of pavement area for the year can be calculated with the division of LCC and all pavement area with service period (2).

$$Cost = \frac{\sum_{i}^{n} (Ni \times Di) \times C}{\sum_{i}^{n} Di \times Y} \qquad (2)$$

$Cost$ = maintenance/repair unit cost of pavement area for the year (Yen/Year · m^2)
n = Number of area Y = Service period (30 years)
Ni = Number of maintenance/repair at area i
Di = Pavement area at area i (m^2) C = maintenance/repair cost (Yen / m^2)

MCI of maintenance levels are 0.1 sectioning. After that, supply function is decided. In addition, supply function's X axis; MCI was changed travel speed by conversion curve and maintenance/repair cost was installed 2000 Yen/m^2 irrespectively thickness of asphalt and assortment.

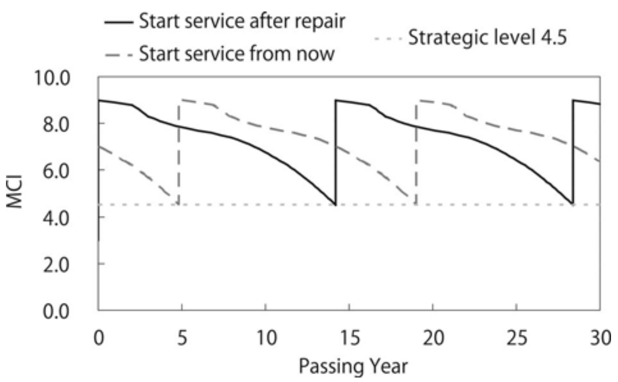

Figure 12. Degradation of MCI by passing year and recovery by repair

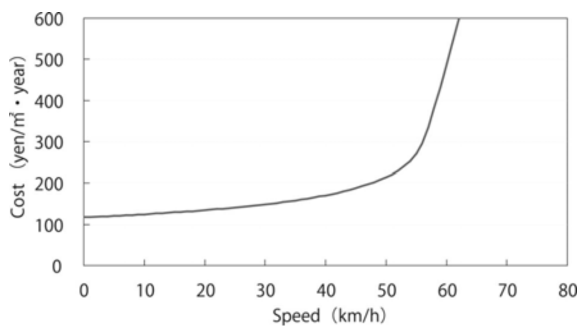

Figure 13. Supply function

6 EQUILIBRIUM ANALYSIS

6.1 DETERMINATION OF SERVICE LEVEL

AND BUDGET ALLOCATION

Using decided demand function and supply function, enforce equilibrium analysis. When Equilibrium restriction is “50% Dissatisfaction level in all pavement roads”, service level and maintenance/repair cost can decide like figure 14 and 15.

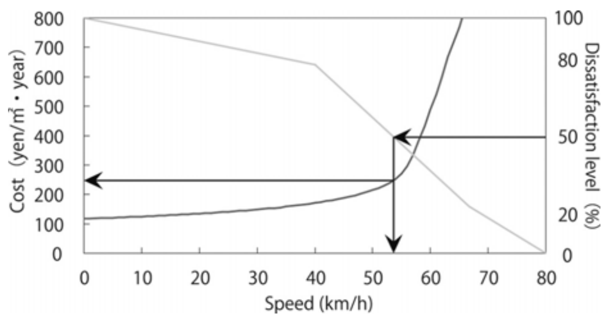

Figure 14. Equilibrium analysis

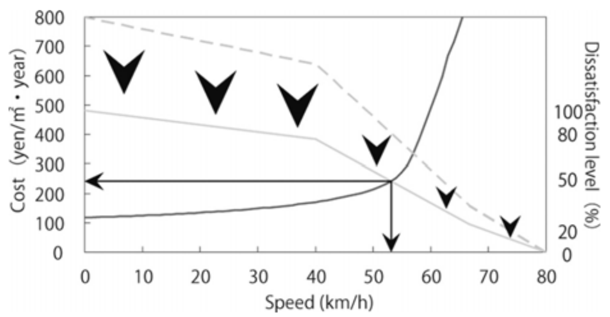

Figure 15. **Equilibrium analysis as dissatisfaction level is 50%**

6.2 TRANSFER FOR COST OF DISSATISFACTION LEVEL

If 50% dissatisfaction level of conspired equilibrium can be set, it is possible to change from dissatisfaction level to cost, because demand and supply reached on the equilibrium point. That able to know how mach does driver could pay money for maintenance/repair cost of dissolve dissatisfaction.

For all pavement roads, there maintenance speed were decided, MCI and maintenance/repair cost and figure 12 is a conclusion of maintenance/repair cost for the year. When all pavement roads dissatisfaction level is 50%, total maintenance/repair cost of pavement area for the year is about 540,000,000 Yen. In addition, it can decide various maintenance/repair patterns by changing dissatisfaction level 1% sectioning.

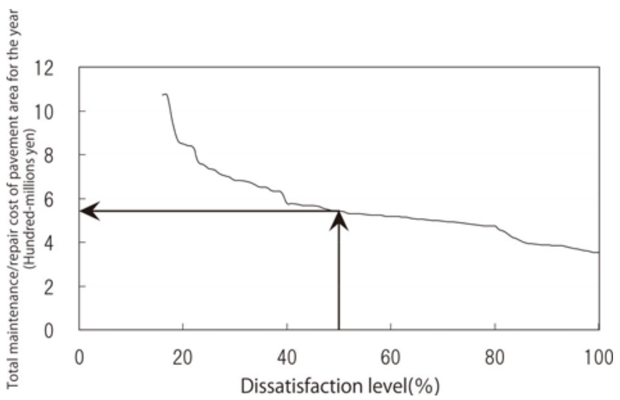

Figure 17. Dissatisfaction level and cost for the year

Traffic volume	Speed limit (km/h)	Confortable speed (km/h)	Corresponding MCI	Area (m²)					Cost (Yen/year・m²)	Total maintenance/repair cost for the year (Million Yen)				
				Route 32	Route 33	Route 55	Route 56	All route		Route 32	Route 33	Route 55	Route 56	All route
0-9999	40	—	—	—	—	—	—	—	—	—	—	—	—	—
	50	43	6.3	354,795	290,230	510,992	7,062	1,163,079	180.0	69.6	54.4	95.7	1.1	220.7
	60	53	7.3	5,858	0	90,109	0	95,967	240.3	1.6	0.0	22.9	0.0	24.5
10000-19999	40	30	5.0	0	0	47,235	0	47,235	148.6	0.0	0.0	7.9	0.0	7.9
	50	39	5.9	0	110,278	235,082	209,397	554,756	167.7	0.0	18.7	44.1	40.2	102.9
	60	48	6.8	107,033	0	0	0	107,033	201.8	26.0	0.0	0.0	0.0	26.0
20000-29999	40	27	4.7	5,610	38,648	43,934	134,087	222,279	143.8	0.8	5.2	7.5	21.4	34.9
	50	34	5.4	0	76,706	136,555	58,337	271,597	156.0	0.0	13.2	24.9	10.7	48.8
	60	43	6.3	0	0	44,914	0	44,914	180.0	0.0	0.0	9.0	0.0	9.0
30000-39999	40	25	4.5	64,900	66,172	0	0	131,072	140.9	9.1	8.8	0.0	0.0	17.9
	50	33	5.3	0	17,556	0	46,698	64,254	153.9	0.0	2.6	0.0	7.4	9.9
	60	41	6.1	0	0	92,100	0	92,100	173.6	0.0	0.0	18.1	0.0	18.1
40000-49999	40	40	4.3	12,636	0	0	0	12,636	170.6	1.7	0.0	0.0	0.0	1.7
	50	31	5.1	28,831	0	0	69,211	98,041	150.4	4.0	0.0	0.0	10.0	14.0
	60	40	6.0	34,795	0	32,629	0	67,424	170.6	6.4	0.0	6.5	0.0	12.9
Total traffic area				614,458	599,589	1,233,549	524,791	2,972,386	—	119.1	102.9	236.5	90.7	549.3

Figure 16. Maintenance/repair cost for the year of 50% dissatisfaction level

7 CONCLUSION

The proposed system can determine service level and budget allocation for road pavement. In addition, it can establish accountability of maintenance/repair system by determining in line maintenance/repair cost as evaluation of dissatisfaction.

In this research, only driver's dissatisfaction was included. But it is necessary to study about several benefits of society as noise and vibration for the future. In addition, there is a necessity to develop policy evaluation system by this method.