METHODOLOGY FOR EVALUATING LIFE CYCLE ENVIRONMENTAL LOAD OF RAIL INFRASTRUCTURE PROVISION

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ABSTRACT

This study aims to establish a methodology to evaluate the environmental impact throughout the entire life cycle of a railway as a preliminary survey of a railway project. Despite the fact that the role of railways has drawn attention as a viable environmentally-friendly transportation system, the effect of rail transport is generally discussed only in terms of its operating stage. For a more precise study of emission control in the development of new railways, it is also important to note that not only the emission from operation but also from the provision of infrastructure and rolling stock should be factored into the amount of emission. Furthermore, since the shift of passengers from other competing transportation modes may contribute to total emission reduction, this should be also taken into account.

Therefore, this study aims to establish a methodology to evaluate the total environmental load of the railway project from the construction thorough disposal, with the application of the life cycle assessment (LCA). It also takes into consideration the extended life cycle environmental load (ELCEL), which includes the effects of the environmental load reduction by decreasing alternatives to railway lines such as automobile traffic.

The results of the case studies vary depending upon the characteristics of the projects. In some cases rail projects are not always effective for emission reduction. However, the results show that this method is available for a true environmental evaluation of new railway projects in the planning phase. Though those case studies are conducted only from the view of measuring emission reduction by the railway project, this study also proposes the practical application of this method to design the project such as 'which transportation mode is most suitable for emission reduction' or 'which route or structure is most suitable for emission reduction'. We consider this method to be quite valuable for the evaluation of rail projects in the developing countries where rail transit is expected to develop significantly.

Keywords: Extended Life Cycle Environmental Load (ELCEL), Factor of environmental load

1. INTRODUCTION

As environmental awareness has been expanding on a global scale, the role of railways has drawn attention as a viable environmentally-friendly transportation system. And such discussions have been based primarily on the average value of greenhouse gas emitted during the operation of this transportation mode in Japan.[1)] However, this average value is not applicable for a more precise study of emission control in the development of new railways, because the amount of emission varies due to conditions such as the load factor, the length of the line haul, etc. And it is also important to note that not only the emission from service but also from the provision of infrastructure and rolling stock should be factored into the amount of emission. Furthermore, the decrease of passengers of other competing transportation modes may contributes to the total emission reduction and should be taken into account.
Kato et al [2)] proposed the evaluation method of the Extended Life Cycle Environmental Load (ELCEL), which expands the boundary of environmental effects to other transportation modes adding to the conventional LCA method. In other words, it evaluates not only the environmental load from the railway itself but also that from other alternative transportation modes (mainly road transportation). Although it has been followed by some studies of rail developmen[3)-6)], those are specific for existing infrastructures and not applicable for an evaluation of new project.
This study aims to establish a methodology to evaluate the total environmental impact of a new rail project as a preliminary survey with the concept of ELCEL. At first, the emission of carbon dioxide (CO_2) of the railway project from the construction stage to the disposal stage was evaluated with the application of the Life Cycle Assessment (LCA). Next, the scope of the evaluation was extended to neighbouring transportation modes. As a result, the total environmental impact of the new rail project was evaluated.
Though many similar themes have been studied in this field, those are mainly on the policy for low-carbon transportation or climate change and studies from the view of transport planning are few. This study aims to support those existing studies from the view of transport planning. Also, this study focuses on CO_2 as a major component of greenhouse gases. This study is to be applied to show an index of social effects brought by new railways.

2. LIFE CYCLE ASSESSMENT FOR RAILWAY PROJECT

2.1 LCA

Life Cycle Assessment (LCA) is a methodology used to evaluate the environmental effects of products from the cradle to the grave. In this study, LCA was used to measure an environmental impact of a railway project, including the construction of the infrastructure and rolling stock, maintenances, operations, and disposal (Figure 1).
Although LCA usually estimates the emissions of various environmental loads (called 'Inventory Analysis') and evaluates the impacts of the emission on the environmental, this study focused on the CO_2, the main greenhouse effect gas.

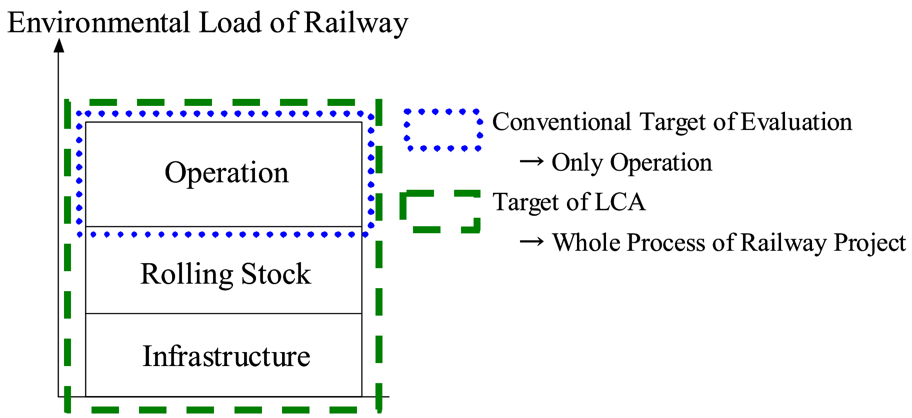

Figure 1 – LCA on Railway Development

2.2 Extended LCA

Conventional LCA is available to evaluate environmental impacts from a single project. 'Extended Life Cycle Environmental Load (ELCEL)' is an extended concept of LCA to evaluate impacts from other infrastructures which are affected by the new project. In other words it allows for the evaluation of the external impacts from the new railway to the neighbouring road transportation. Thanks to this concept, the total reduction of the emission due to the decrease of the number of cars can also be counted (Figure 2).

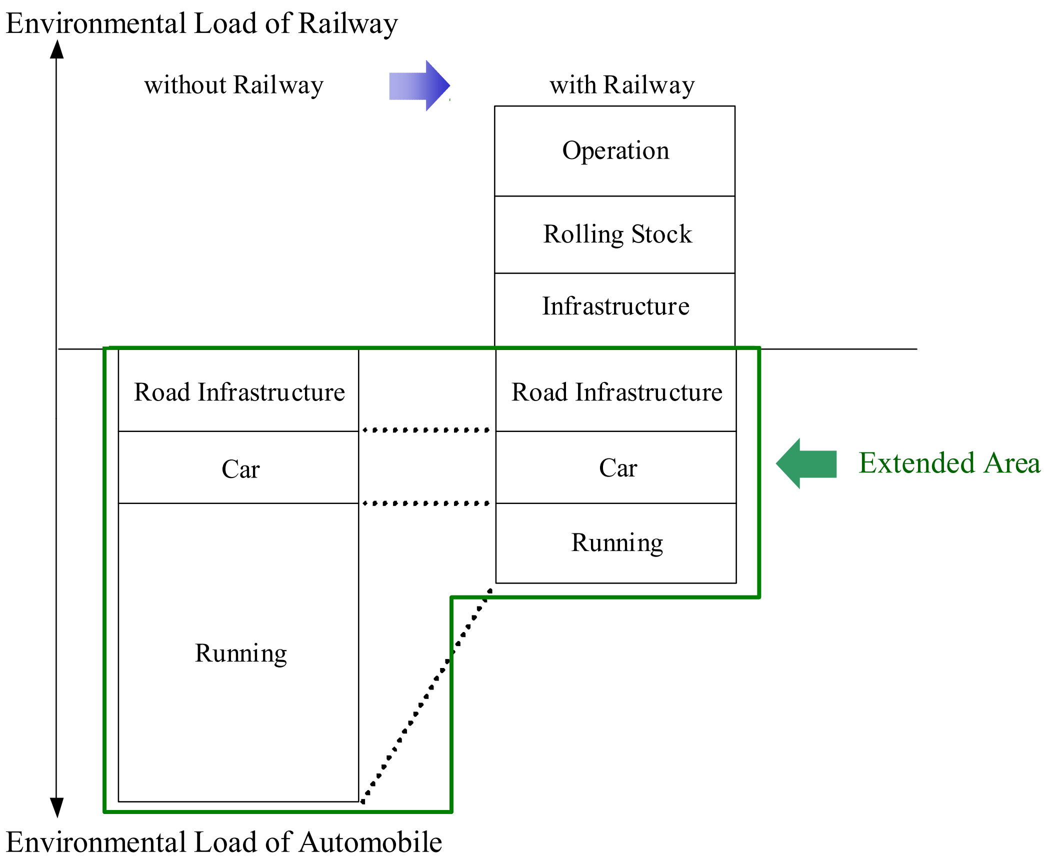

Figure 2 – Extended LCA on Railway Development

2.3 Views of Evaluation

Views of the evaluation should be focused on in this analysis. Examples are shown below:

- View of evaluation 1: How much the new line contributes to a lower emission
- View of evaluation 2: Which route of the new rail line has the least impact
- View of evaluation 3: Which transportation mode has the least emissions

2.4 Scope of the Study

2.4.1 Life Span

The Life span of a targeted project is decided with the consideration of the lifetime of the structures and the project term. In Japan, a term of 30 years or 50 years (including the construction period) is commonly used in financial analyses or useful life.

2.4.2 Scope of Analysis

In the case of evaluating a single rail project (impacts only from the project itself), targeted impacts are from construction, operation, and maintenance in the project. On the other hand, in the case of including impacts to other transportation modes, LCA must be extended to such other modes with the concept of ELCEL (Figure 3).

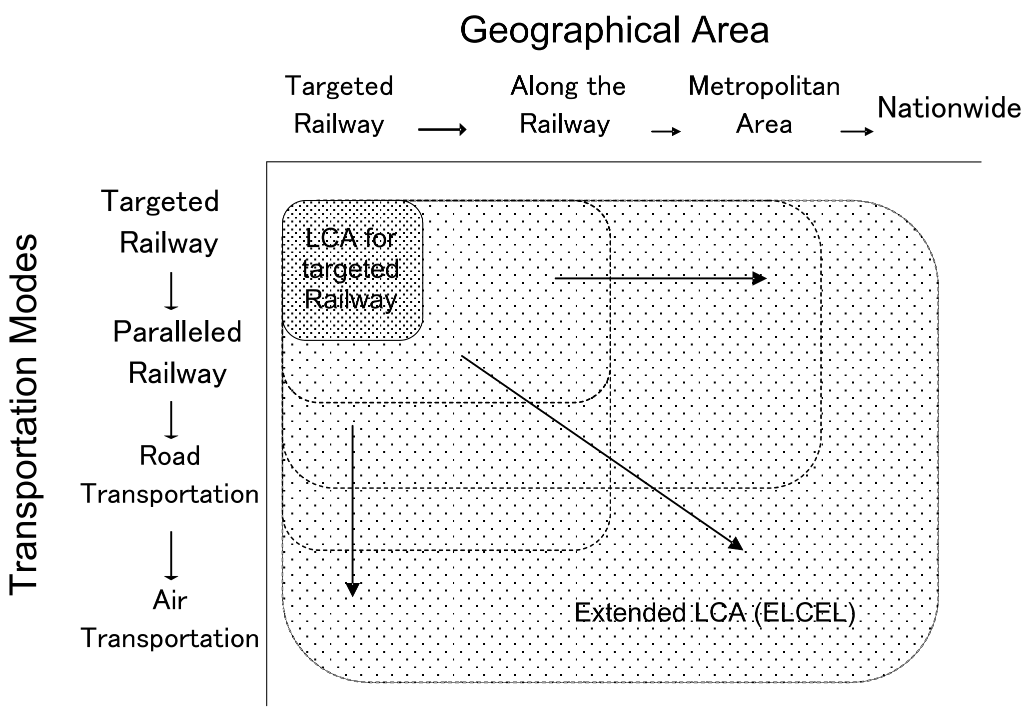

Figure 3 – Scope of Extended LCA (ELCEL)

2.4.3 Geographic Scope

The geographic scope of the study is also extended in the same way as an extension of the targeted transportation modes in the application of LCA (Figure 3).

3. METHOD FOR MEASUREMENT OF ENVIRONMENTAL IMPACT

In this study, we measured an environmental impact of the railway construction with an environmental emission factor in each stage from construction to disposal.

3.1 Standardization of Elements in Infrastructure

As the purpose of this study was to develop a methodology which was to be implemented in the planning stage where there was no detailed design, it was not realistic to expect precise blueprints or construction procedure manuals. For this reasons, we decided to consider the railway system as an aggregation of the structures (like parts of plastic models) as shown in Figure 4 and set standard models under each structure. Figure 4 shows the breakups of the ‘cut and cover a tunnel’ process as an example. Then we conducted the Life Cycle Inventory Analysis on each standard model and measured the environmental load in the entire system by combining the results of the analysis.

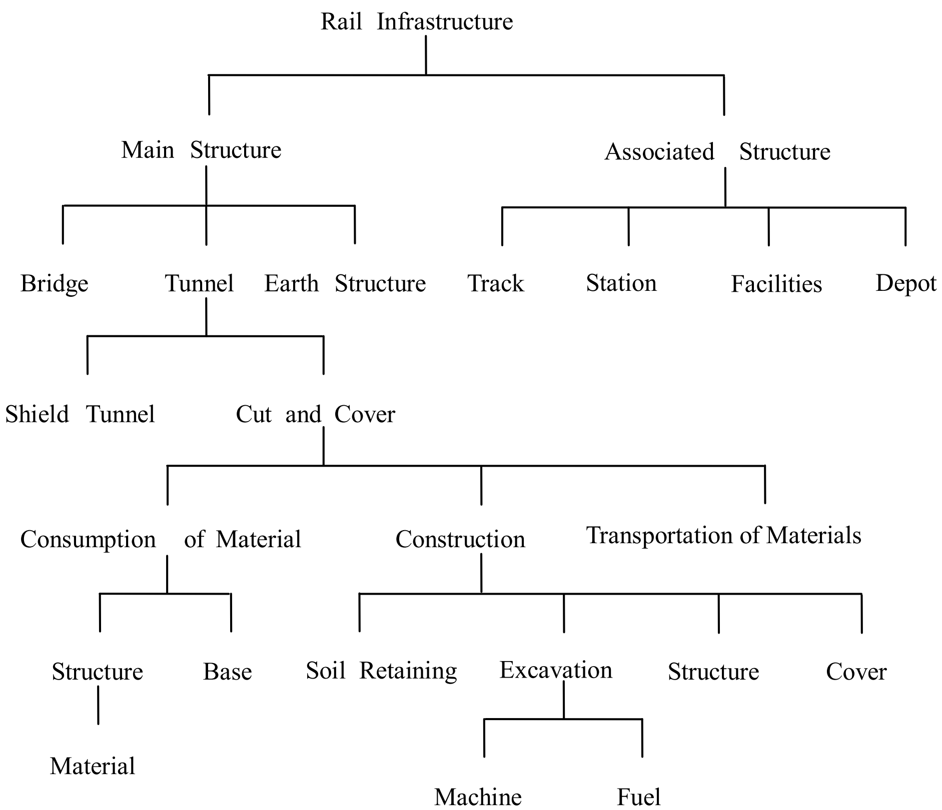

Figure 4 – Divided Elements (Example of Cut and Cover Tunnel)

3.2 Definition of Environmental Emission Factor

In this study, main and associated structures and rolling stock of the railway are evaluated. These evaluations are divided into three phase: building-manufacturing, operation-maintenance, and disposal (Table 1).
In particular, for each standard infrastructure, we calculated the consumption of each material and number of construction procedures per element, as shown in Figure 5, based on the standard design of railway infrastructures and the standard method of estimation. Then we evaluated the necessary materials and energy amounts per each stage of construction, maintenance and operation. By multiplying the result with the environmental emission factor of CO_2, set by the Japan Society of Civil Engineers[7)] and other technical societies, we set the environmental emission factor for each infrastructure.

Table 1 – Evaluated Structures and their Phases

The Aimed Structures for Evaluation		Corresponding Phase	
Main Structure	Earth Structure : Embankment, Cut Bridge : Viaduct, Bridge Tunnel : Excavated Tunnel, Cut and Cover	Const-ruction	Consumption of Material
			Transport of Material
			Construction
Associated Structure	Track : Concrete Track, Ballasted Track Station : Civil Work, Architecture, Associated Equipments Electric Facility : Electric Power Line, Electric Substation, Traffic Control (Signal, Turnout), Communication	Const-ruction	Consumption of Material
			Transport of Material
			Construction
		Maintenance	
	Depot	Const-ruction	Consumption of Material
			Transport of Material
			Construction
Rolling Stock	Rolling Stock	Manu-facture	Consumption of Material
			Manufacturing, Assembly
		Maintenance	
		Operation	
		Disposal	

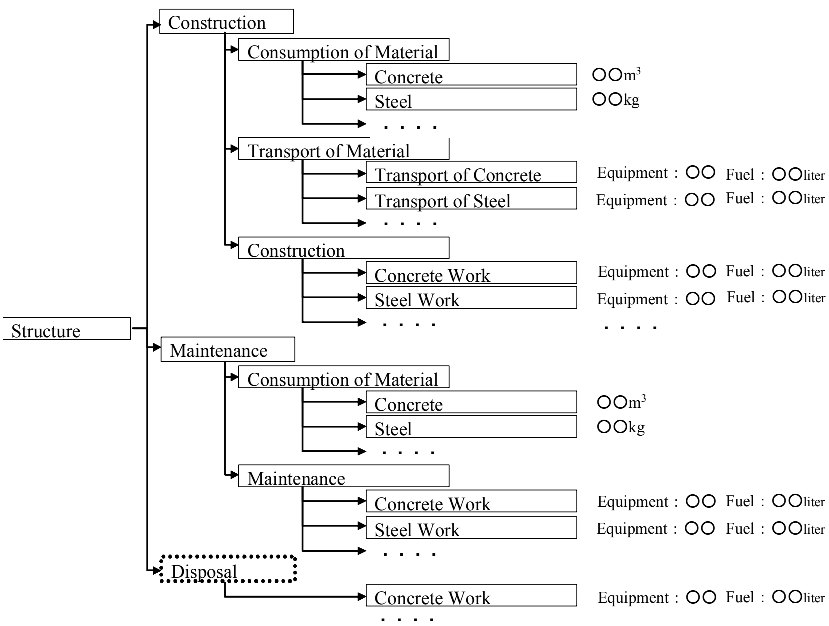

Figure 5 – Elements for Environmental Emission Factor

3.2.1Emission from Consumption of Resources

The CO_2 emission from the consumption of resources was calculated, first by calculating the CO_2 emission per material by multiplying the consumption of each material, which was calculated per structure element, with the CO_2 emission factor; then by adding all the results. Although various research institutions use different CO_2 emissions intensity, we adopted the one recommended by the Japan Society of Civil Engineers' LCA Subcommittee because they have conducted wider and more detailed reviews of evaluation subjects.

3.2.2 Emission from Transportation of Resources

The CO_2 emission from the transportation of resources for construction is a sum of the emission created when the resources are transported using transport machines and the emission which comes from such machines (when the machines are manufactured, etc.).
The total machine operation time is calculated by calculating the number of transport and the machine operating time per unit and multiplying these figures. In addition, the CO_2 emission per operation time unit can be calculated based on the machine output and fuel consumption rate when the machine is operated. The CO_2 emission by machine operation is calculated by multiplying the above total machine operation time with the CO_2 emission per operation time unit.
The machine operation time is calculated by multiplying the number of transports with the machine operation time per unit. Also, the life cycle CO_2 emissions intensity per machine operation time unit is calculated based on the total machine operation time and the life cycle CO_2 emission per the mass of the machine. The CO_2 emission of the machine itself is calculated by multiplying the above machine operation time with the life cycle CO_2 emissions intensity per machine operation time unit.

3.2.3 Emission from Construction Work

The CO_2 emission from the construction work consist of the CO_2 emission created when the construction work requires machinery and the CO_2 emission which comes from the machinery. We do not repeat the calculation method because it has already been explained in the previous section.

From above, we calculated the CO_2 emissions intensity shown in Table 2, using the method explained in Chapter 3. Among all the CO_2 emissions intensity, the tunnel's emission intensity was the largest. The CO_2 emission of underground stations was approximately ten times larger than that of the elevated stations. Therefore, when conducting analysis related to the 'View of evaluation 2' set in section 2.3, it is necessary to select the route after considering the structure with the least environmental load.

Table 2 – Emission Factor of CO_2 in Each Structure

Item			Emission factor	Unit
Structure (Main Structure, Associated Structure)	Viaduct (8=H, L=57.0m+Adjacent Girder 13.0m)		7.21	ton-CO_2/m
	Viaduct at Station (H=9m, L=61m)		11.3	ton-CO_2/m
	Pier H=10m (Two 20m-girders, Cast-in-site Pile)		158	ton-CO_2/set
	Pier H=10m(Two 100m-trusses,Cast-in-site Pile)		593	ton-CO_2/set
	Pier H=17m(Two 70m-trusses,well-sinking Steel Pipe Pile)		1,852	ton-CO_2/set
	Bridge (Reinforced Concrete Girder, L=20m)		3.10	ton-CO_2/m
	Bridge (Pre-stressed Concrete Girder, L=47m)		3.75	ton-CO_2/m
	Bridge (Steel Truss, L=414.5m)		10.9	ton-CO_2/m
	TBM Tunnel (Diameter 9.8m)		8.85	ton-CO_2/m
	Cut and Cover Tunnel (Diameter 10m)		16.1	ton-CO_2/m
	Blasted Tunnel (Diameter 10m)		14.3	ton-CO_2/m
	Embankment (W=10.7m, H=6.0m)		6.02	ton-CO_2/m
	Cut (W=10m H=6.0m)		3.29	ton-CO_2/m
	Slab Track (Gauge 1,067mm)		0.292	ton-CO_2/m
	Ballasted Track (Gauge 1,067mm)		0.356	ton-CO_2/m
	Elevated Station (Civil work, Architecture, Equipment)		3.81×10^{3}	ton-CO_2/station
	Underground Station (Civil work, Architecture, Equipment)		3.12×10^{4}	ton-CO_2/station
	Depot		5.88×10^{3}	ton-CO_2/Depot
	Electric Circuit		5.44×10^{-2}	ton-CO_2/m
	Electric Power Supply		51.5	ton-CO_2/set
	Signal		1.52	ton-CO_2/set
	Turnout		8.99	ton-CO_2/set
	Telecommunication System		6.59×10^{-3}	ton-CO_2/m
Maintenance	Rail		14.4	ton-CO_2/million・car・km
	Overhung Electric Line		0.152	
	Rolling stock (Pantograph, Brake, Wheel, etc)		6.81	
Rolling Stock	Aluminium Body (20m×10car train)	Manufacturing	93.9	ton-CO_2/car
		Disposal	0.662	ton-CO_2/car
	Stainless Body (20m×10car train)	Manufacturing	66.8	ton-CO_2/car
		Disposal	0.662	ton-CO_2/car

3.3 Environmental Impact in Railway Operation

Environmental impact in railway operation is estimated by environmental emission factor and shifted passengers by 'with-without' case study of the railway.
The number of shifted passenger is estimated by the number of passengers on each route and zoned station in the 'railway route choice model'. Environmental impact is estimated by multiplying emission factor by the electricity consumed by trains with the consideration of appropriate number of cars of a train and train acceleration (Figure 6).

3.4 Environmental Impact by car

Environmental impact by cars is calculated by multiplying the number of cars in each route by the environmental emission factor according to the speed. The number of cars in each route and average speed are estimated in the 'car transport distribution model' (Figure 6).
The traffic estimation models used to estimate the CO_2 emission when a train or car is in operation are shown in the appendix.

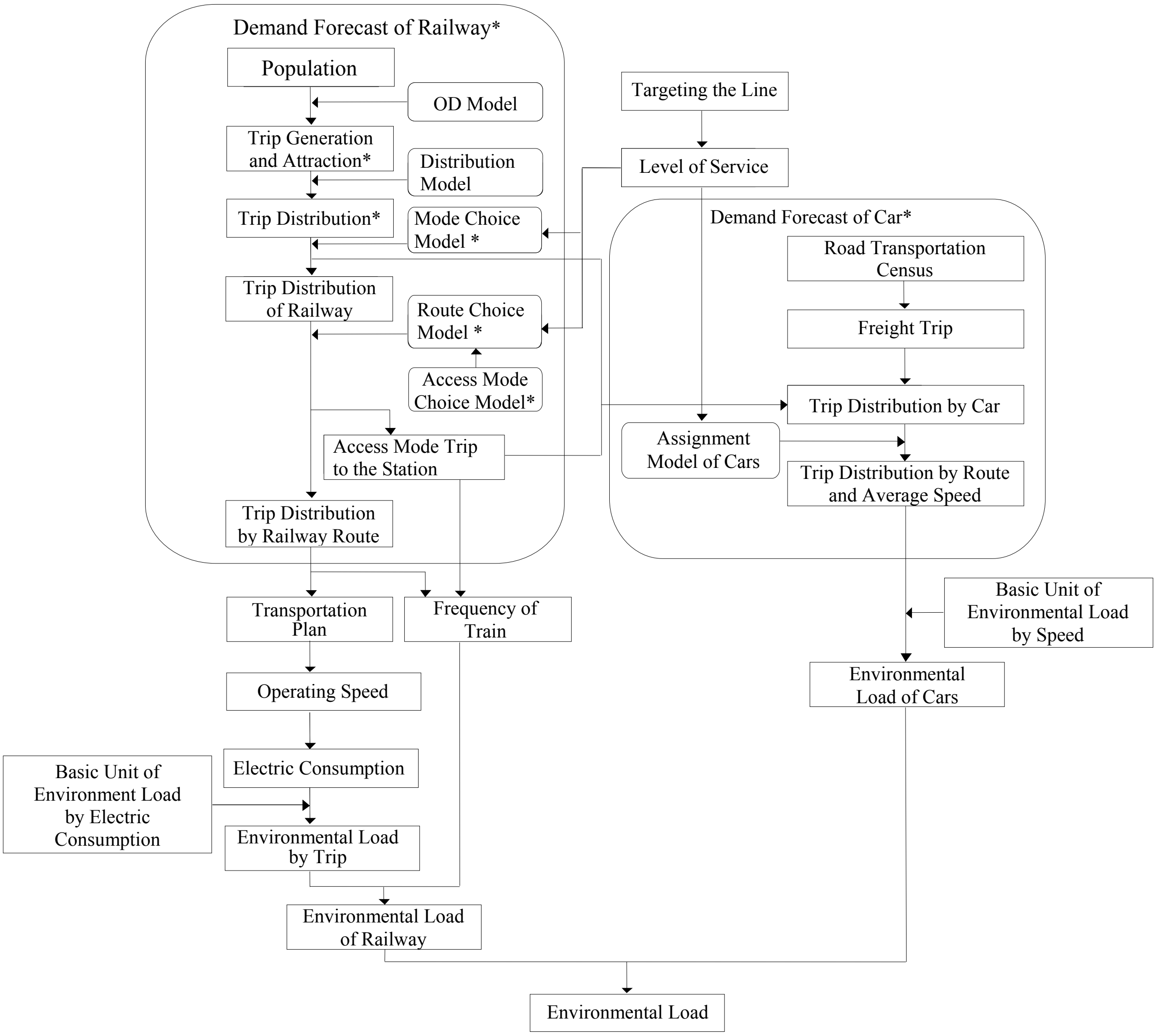

Figure 6 – Estimation of Environmental Load in Operation Phase

*Area of demand forecast model: Tokyo Metropolitan Area is targeted as a scope of demand forecast. The area is divided into 2,614 subareas with the consideration of life style and population distributing. Those subareas are connected by rails and roads in the model.

*Railway demand forecast system: This study applies existing demand forecast system which is already validated in many other studies with some renewal of the data. The system was originally established in the urban railway master plan for Tokyo Metropolitan Area by Ministry of Transport in 2000, Japan.

*Trip generation and attraction: Basic unit is the current number of trip generation and attraction per person in each subarea and applied for the demand forecast in each trip purpose (commuting, students' commuting, private, business).

*Trip distribution: Current patterns are used to calculate trip distributions in each trip purpose.

*Mode choice: Probability of mode choice among three transportation modes (rail, bus, and car) is estimated by Disaggregate Logit Model in each trip purpose. Variables are time, cost, transfer, car owning, etc.

*Route choice: Variables are time, cost, transfer, congestion, transportation to the station, etc.

*Access transportation to the station: Options are walk, bicycle, car, pick up, and bus. Variables are time and cost.

*Demand forecast of road transportation: Four types (passenger car, bus, small truck, large truck) are targeted on equilibrium distribution model with the consideration of easing of congestion.

4. CASE STUDIES

4.1 Environmental Impact from the Construction of Railway Infrastructure

In this study, one newly railway line in the Tokyo area is targeted for case study. The line is being constructed in the railway blank area and the length is 33 km. 80 trains run on one way on a weekday. A train consists of 8 cars and 90 thousands passengers are transported in a day (Figure 7).

The case study contains the calculation of the quantity of CO_2 emissions from main and associated structures and rolling stock in each phase (building-manufacturing, operation-maintenance, and disposal) (Figure 8, Table 3). The line consists of 31% of elevated structures or bridges, 11% of tunnels, and 58% of earthwork structures. Two cases of life cycle time are set as 30 years and 50 years. However, the structures' disposal is not included.

Table 3 shows that the CO_2 emissions at the construction stage of the main structures are the largest at 78% of the entire infrastructure. Figure 8 shows the accumulated CO_2 emission in the 50 years life time. 22 years after the inauguration, emission by operation-maintenance exceeds that by construction. However emission by construction still shares 43% of total emissions during 30 years and 32% during 50 years. We confirmed that when discussing the railway improvement from the environmental perspective, it was also important, from the view of the proportion of emissions, to consider the entire life cycle including the infrastructure - not just what is operating - from the view of sharing the emission.

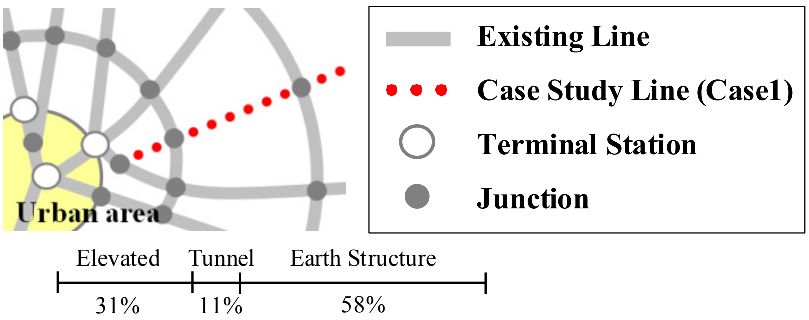

Figure 7 – Railway Line of Case Study 1

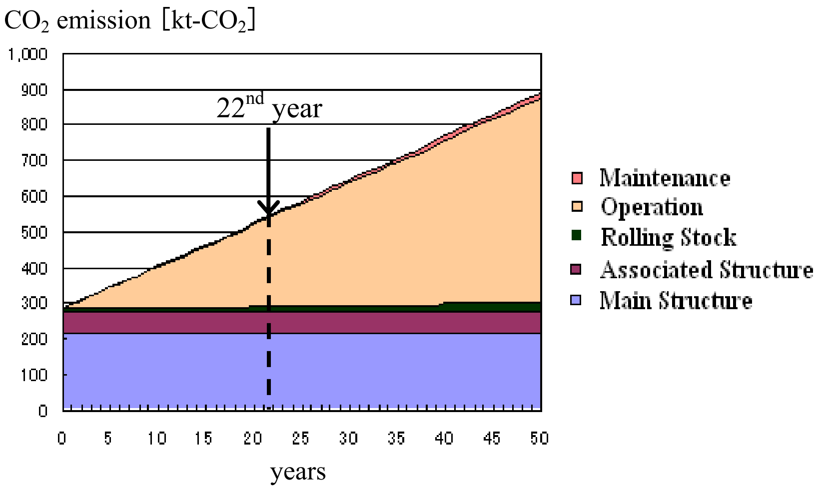

Figure 8 – CO_2 Emission during the life cycle time: 50 years (1,000-ton)

Table 3 – CO_2 Emission by Rail Structure (Life Span: 50 years)

Item		Quantity	Emission (thousand・ton－CO_2)	Share	Others
Measuring Term：50 years					
Length of Line：32,580m					
Main Structure	Viaduct	7,580m	56.0	6.3%	
	Viaduct (Station)	1,000m	11.3	1.3%	※ 1station=200m
	Pier	36 set	36.0	4.1%	
	Bridge	1,600m	7.1	0.8%	
	Tunnel	3,440m	30.4	3.4%	
	Earth Structure	18,960m	77.6	8.7%	※ Embankment：5,599m, Cut：13,361m
	Subtotal		218.6	24.6%	
Associated Structure	Track	65,160m	23.0	2.6%	※ Length of Line × 2 (Double Track)
	Station	14 station	27.0	3.0%	※ Ground : 6station, Elevated : 5station, Underground :3station
	Electric Line	65,160m	3.5	0.4%	※ Length of Line × 2 (Double Track)
	Electric Substation	6 set	0.3	0.0%	
	Traffic Control	Signal:130 set Turnout:90 set	1.0	0.1%	※ 6 set / per station
	Communication	32,580m	0.2	0.0%	※ Length of Line
	Depot	1 set	6.3	0.7%	
	Subtotal		61.4	6.9%	
Rolling Stock	Manufacturing・Disposal		19.4	2.2%	
Operation			573.8	64.6%	
Maintenance	Rail Track	698.6million・car・km	10.0	1.1%	※ Rail
	Electric Line	698.6million・car・km	0.1	0.0%	※ Aerial Line
	Rolling Stock	698.6million・car・km	4.8	0.5%	※ Pantograph, Brake, Wheel
	Subtotal		14.9	1.7%	
Total			887.9	100.0%	

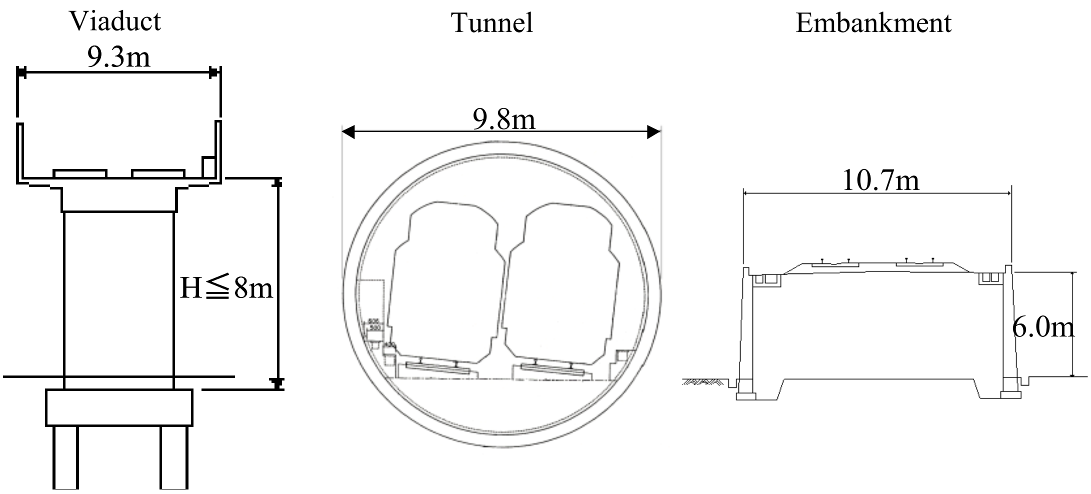

Figure 9 – Typical Examples of Standardized Structures on Case Studies

4.2 Extended LCA of Rail Project with ELCEL

Section 4.1 shows how to calculate the quantity of emission from a rail infrastructure. This section shows all of the impacts from the rail projects on CO_2 emission with extended LCA concept (ELCEL).

4.2.1 Case 1: Newly Constructed Line

This line is being constructed in the railway blank area (same as the case of 4.1). This new line has a large impact on reducing neighbouring road transportations and a large number of passengers shifted to the new rail. ELCEL evaluated the total CO_2 emissions along the corridor adding to the emission from the new line.
Figure 10 shows the result. New railway construction in the railway blank area introduces the diversion of passengers from automobiles transport and other railways to the new line and totally contributes to the reduction of emissions even when including the emissions from construction.

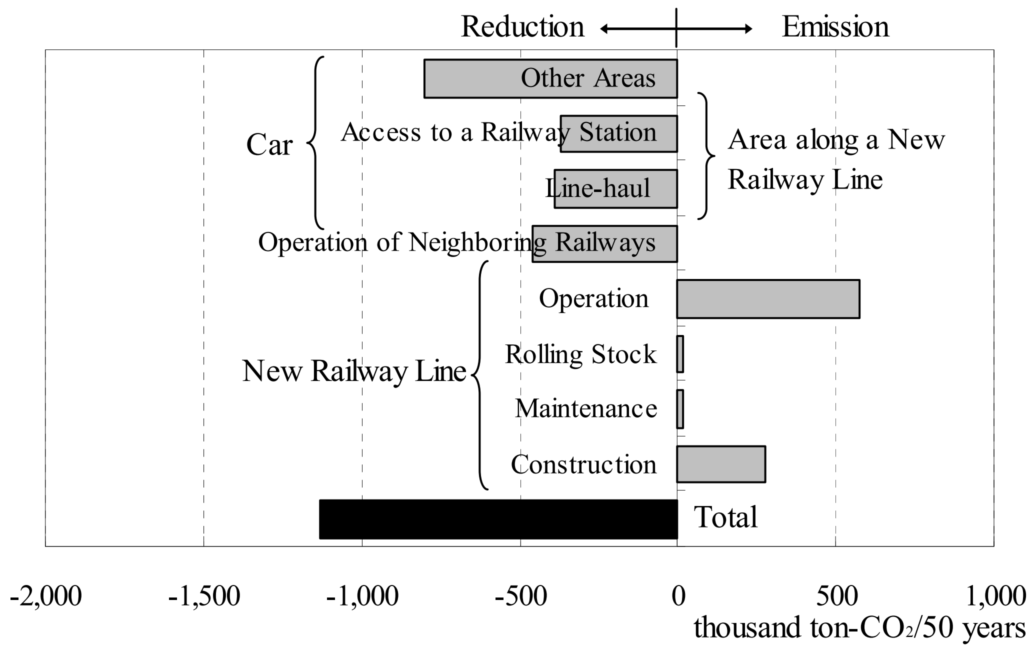

Figure 10 – Extended LCA on Newly Constructed Line in Rail-blank Area

4.2.2 Case 2: New Line Extended to Existing Line as Bypass

The same analysis was implemented with another railway line different from 4.2.1. The line was a competitor for the existing line. It was a short, bypass line which was extended from a radial line and connected to a circular line. The length of the line is 7 km. 90 trains run on one way on a weekday. A train consists of 6 cars and 20 thousands passengers are transported in a day. The line consists of 64% of elevated structures or bridges, 25% of tunnels, and 11% of earthwork structures (Figure 11).

The analysis revealed that the reduction in the CO_2 emission in the life cycle including the construction stage of the railway was not achieved because (1) the passengers of the new line were simply changing from the neighbouring railways and much shifting from the car to the railway was not expected, and (2) The scheduled speed of the new line was slower than competing line (Figure 12). On the other hand, the CO_2 emission when the neighbouring railways were in operation has increased. In this study, we changed the number of train operations to the changes in the number of passengers. Passengers changed from the competing lines with high transport efficiency to the case-study line with low transport efficiency or to the existing line connected to the case-study line. This caused the increase in the CO_2 emission when the neighbouring railways were in operation.

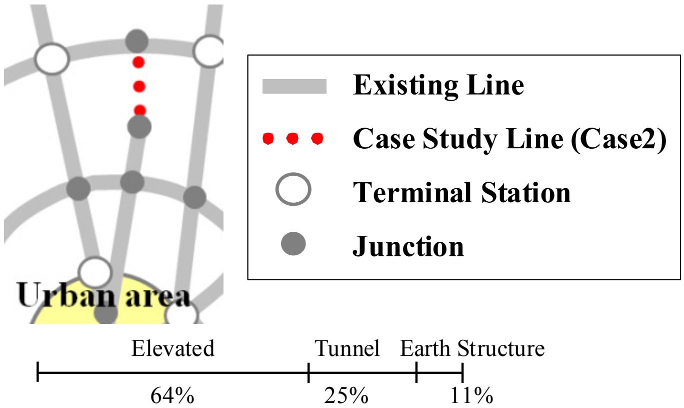

Figure 11 – Railway Line of Case Study 2

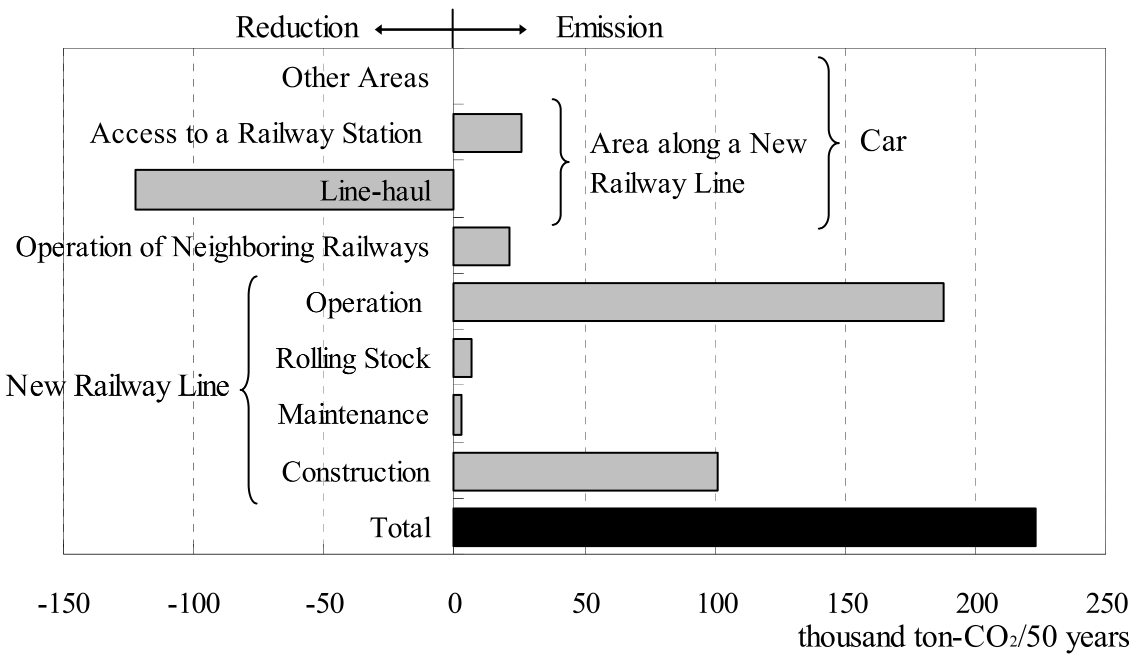

Figure 12 – Extended LCA on Newly Constructed Line along Existing Line

5. CONCLUSION

This study is to establish a practical methodology to evaluate the total environmental impacts from railway projects with the combination of life cycle assessment for the rail infrastructure and extended LCA (ELCEL) for neighbouring transportation systems. Case studies show both good and not good results according to the characteristics of the targeted project. It means that this method is valid as a quantitative tool for objective evaluation of environmental impacts from a rail project on the planning stage.

Though this paper contains the study of evaluation for a single project from the view of contribution to reducing emissions, this method is also applicable to the comparison study of alternative routes or transportation modes.

We consider that this method is available for the evaluation of all new railway projects including intercity railways. And we also consider that this method will be available with some modifications for many railway projects throughout the world especially developing countries where a lot of new rail projects are expected (Fukuda's Study [5)]).

As a next stage of this study, a more precise definition of environmental emission factors is to be done, including making new emission factors for other structures such as deeper tunnels.

APPENDIX

1. Transportation Mode Choice Model

Share of transportation modes are calculated with Disaggregated Logit Model based on the data of Tokyo Person Trip Survey 1998.

$$P_i = \frac{\exp(V_i)}{\sum_{j \in J_n} \exp(V_j)}$$

$$V_i = \theta_1 X_1 + \theta_2 X_2 + \cdot\ \cdot\ \cdot$$

P_i : Choice Probability of Transportation 'i'

V_i : the deterministic component of utility

θ : Parameter for Explanatory Variable

X : Explanatory Variable

Parameters

		Commuter	Student Commuter	Private	Business
Time	Minute	-0.0278 (-11.4)	-0.0310 (-6.5)	-0.0293 (-10.0)	-0.0697 (-12.4)
Cost	Yen	-0.000559 (-2.6)	-0.00251 (-5.1)	-0.00210 (-6.6)	-0.00166 (-3.4)
Car own	Car	0.636 (6.2)	0.173 (0.9)	1.08 (6.6)	0.783 (4.1)
Dummy	Rail	1.80 (21.9)	0.728 (4.4)	0.722 (6.5)	0.888 (6.6)
Number of Transfer	Rail	-0.269 (-5.9)	-0.481 (-6.2)	-0.211 (-3.4)	-0.399 (-4.9)
Constant	Car	-0.927 (-8.0)	-3.47 (-12.5)	-2.62 (-15.1)	-3.29 (-14.7)
	Bus	-1.47 (-16.6)	-2.01 (-12.8)	-0.742 (-8.7)	-0.39 (-3.1)
Hit Ratio		75.3%	85.4%	71.1%	81.0%
Likelihood ratio		0.236	0.211	0.164	0.278
Number of samples		4,781	2,673	2,251	1,850

() :t-value

2. Transportation Mode Choice Model

Distribution of railway routes is calculated with Disaggregated Logit Model based on the data of Tokyo Metropolitan Transportation Census 2000.

$$P_i = \frac{\exp(V_i)}{\sum_{j \in J_n} \exp(V_j)}$$

$$V_i = \theta_1 X_1 + \theta_2 X_2 + \cdot\ \cdot\ \cdot$$

P_i : Choice probability of railway route 'i'

V_i : the deterministic component of utility

θ : Parameter for Explanatory Variable

X : Explanatory Variable

Parameters

		Commuter	Student Commuter	Private	Business
Line haul time	Minute	-0.0673 (-11.7)	-0.0653 (-7.8)	-0.0658 (-4.4)	-0.0726 (-4.1)
Transfer time	Minute	-0.0923 (-13.1)	-0.0842 (-9.4)	-0.0866 (-3.5)	-0.0890 (-3.3)
Cost	Yen	-0.00260 (-4.2)	-0.00683 (-5.3)	-0.00352 (-3.5)	-0.00226 (-1.7)
Log sum for the selection model of access transportation		0.698 (16.8)	0.942 (10.0)	0.739 (4.4)	0.991 (3.8)
Congestion		-0.00596 (-2.2)	-0.00629 (-2.1)	—	—
Hit Ratio		74.2%	62.3%	66.0%	65.0%
Likelihood ratio		0.348	0.322	0.369	0.307
Number of samples		2,589	1,382	209	180

() :t-value

3. Transportation Mode Choice Model for Station Access

Choice probability of transportation mode for station access is calculated with Disaggregated Logit Model based on the data of Tokyo Person Trip Survey 1998.

$$P_i = \frac{\exp(V_i)}{\sum_{j \in J_n} \exp(V_j)}$$

$$V_i = \theta_1 X_1 + \theta_2 X_2 + \cdot \cdot \cdot$$

P_i : Choice probability of station access 'i'

V_i : the deterministic component of utility

θ : Parameter for Explanatory Variable

X : Explanatory Variable

Parameters

		Commuter	Student Commuter	Private	Business
Time	Minute	-0.138 (-20.0)	-0.0838 (-5.6)	-0.130 (-7.0)	-0.0771 (-3.8)
Cost	Yen	-0.00551 (-9.0)	-0.00879 (-4.6)	-0.0121 (-5.6)	-0.00593 (-2.2)
Constant	Walk	0.532 (5.3)	1.74 (6.5)	0.149 (0.5)	0.728 (1.7)
	Bicycle	-1.54 (-14.0)	0.981 (3.1)	-1.61 (-4.4)	-1.56 (-3.5)
	Car driving	-4.93 (-28.2)	—	—	—
	Car pick up	-3.65 (-29.5)	-1.87 (-6.4)	-2.94 (-8.4)	-2.34 (-5.8)
Hit Ratio		61.1%	66.3%	63.5%	59.9%
Likelihood ratio		0.277	0.410	0.334	0.309
Number of samples		3,300	566	534	279

() :t-value

4. Equilibrium Distribution Model on Demand Forecast of Road Transportation

Conditions of the Model are shown below:

Item	Content
Number of Subareas	2,614
Network	Link: 15,703, Node:10,348
Link Performance Function	BPR Function $t_a(x_a) = t_{a0} \cdot \left\{ 1 + \alpha \cdot \left(\frac{x_a}{\gamma_a \cdot C_a} \right)^{\beta} \right\}$ t_a : Travel Time of Link *a* (minute) C_a : Possible Volume of Link *a*(/hour) γ_a : Conversion to daily volume α =0.48, β =2.82※
Time Value	Car : 56 yen/minute Bus : 496 yen/minute Small Truck : 90 yen/minute Large Truck : 101 yen/minute

Based on Standard Parameter by Japan Society of Civil Engineers

Error ratio between simulation and true volume of trunk roads (expressway and highway) in 1999 is shown below with %RMS.

$$\%RMS = \frac{ABS \cdot RMS}{\left(\sum X_{ij} / n\right)} \cdot 100$$

$$ABS \cdot RMS = \sqrt{\frac{\sum \left(x_{ij} - \hat{x}_{ij}\right)^2}{n}}$$

n : Number of samples,
X_{ij} : True volume of traffc
$\hat{x}_{ij}$: Simulated volume of traffic

Road	%RMS
Expressway	29.8%
Highway	33.2%
Total	33.1%

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