A Study on Greenhouse Gas Emission of Urban Railway Projects in Tokyo Metropolitan Area

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Abstract: This study shows how to measure CO_2 emissions caused by railways through the life span from construction to disposal. It is now common global concern that CO_2 reduction is vital for conserving the global environment. Amidst this growing awareness railways have attracted significant attention as an environmentally-friendly transportation due to its low CO_2 emission. But in many studies the amount of CO_2 is calculated only during operation and doesn't include emissions during the phase of construction of related infrastructure and rolling stocks. Railway is not a truly environmentally-friendly transportation mode if it isn't proven to emit less compared with others during the whole life cycle. In this paper, we introduce the method to calculate CO_2 emission from the construction of infrastructure with the application of Life Cycle Assessment (LCA) and the result of a case study.

Key Words: *Life Cycle Assessment (LCA), Environmental Load, Railway Construction*

1. INTRODUCTION

Protection of the global environment has become a shared global concern in recent years. In this trend, railways have been revived as an environmentally-friendly transportation mode due to its low emission of CO_2 compared to other modes. But this approach only notes the

emissions during the operation phase. The total output of emissions involving the construction of infrastructure has not been counted.
This paper outlines the study regarding the calculation of environmental load by railway transport including the construction process from obtaining the materials to the disposal with the concept of Life Cycle Assessment (LCA). This study also contains the effects of automobiles by the new railway as the extended LCA concept. As a result railway transport was proved as a generally environmentally-friendly transportation mode even when taking into account the emission from construction.
In this study, we targeted the amount of CO_2 because it shares 95% of greenhouse gases (Others are methane, nitrogen oxide, hydrofluorocarbon, perfluorocarbon, silicofluoride, etc).

2. CURRENT SITUATION OF ENVIRONMENT AND CLIMATE CHANGE

The amount of world green house gases (primarily CO_2) resulting from human activity has increased dramatically in recent years (refer Figure 1). This has an effect of atmospheric warming and results in the air temperature having become 0.74 degree hotter during the one century from 1906 to 2005 (Figure 2). The IPCC fourth assessment predicts that the air temperature will rise by 4 degrees in the next century in a worst case scenario of the continuing high level of industrial development with the current consumption level of fossil energy consumption (also Figure 2).
This global warming is believed to bring about climate change which causes such harmful effects as augmenting natural disasters, decreasing water resources, and so forth. We are in a critical moment in which we can prevent these phenomena from getting worse.
Figure 3 shows the amount of CO_2 emissions by countries. It is the key condition to decrease the emissions not only in the industrial countries but also newly developed countries such as China or India.
In the example of Japan, CO_2 emissions from transportation shares 19% of the total emissions. In the emission from transport, automobile attributed for 87% (Figure 4). As shown in Figure 5, railway transport emits less than one seventh the CO_2 of automobiles. This is the reason that railway transport is an environmentally friendly mode and it is said moving passengers from auto to rail usage with result in less emission of CO_2.
However, the reliance on convenient automobiles is still high (Figure 6) and it is also a cause of serious traffic jams (Figure 7) and environmental and time consuming problems. The environmental approach is a highly persuasive means for enlightening common people to use railway transport.

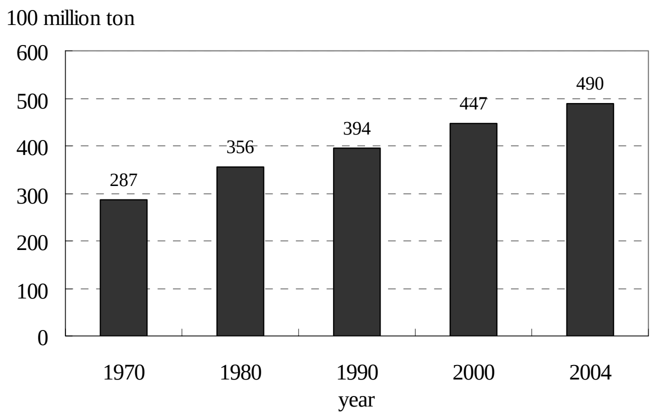
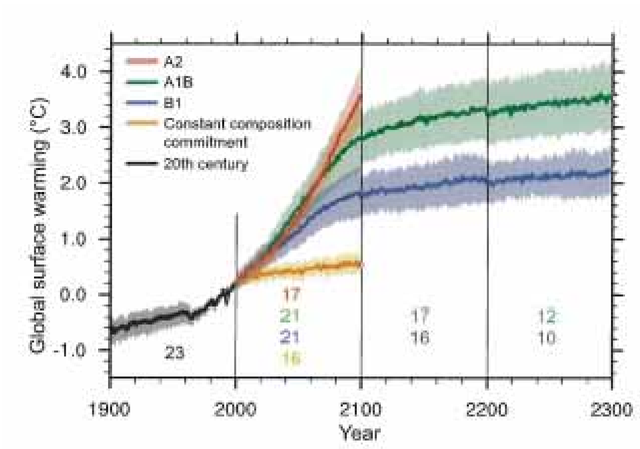


Figure 1 World Green House Gas by Human Activity (From IPCC fourth assessment Report)



They represent low(B1), medium(A1B), high(A2) scenarios with respect to greenhouse gas concentrations.

Figure 2 Prediction of Global Surface Warning (From IPCC fourth assessment Report)

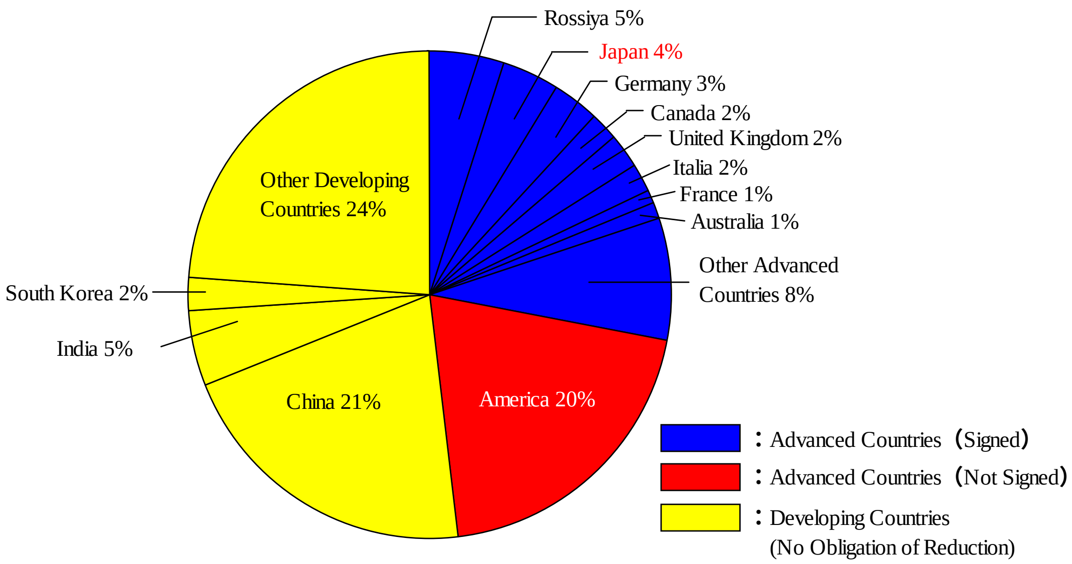


Figure 3 The Amount of CO_2 Emissions by Countries in 2007
(From International Energy Agency)

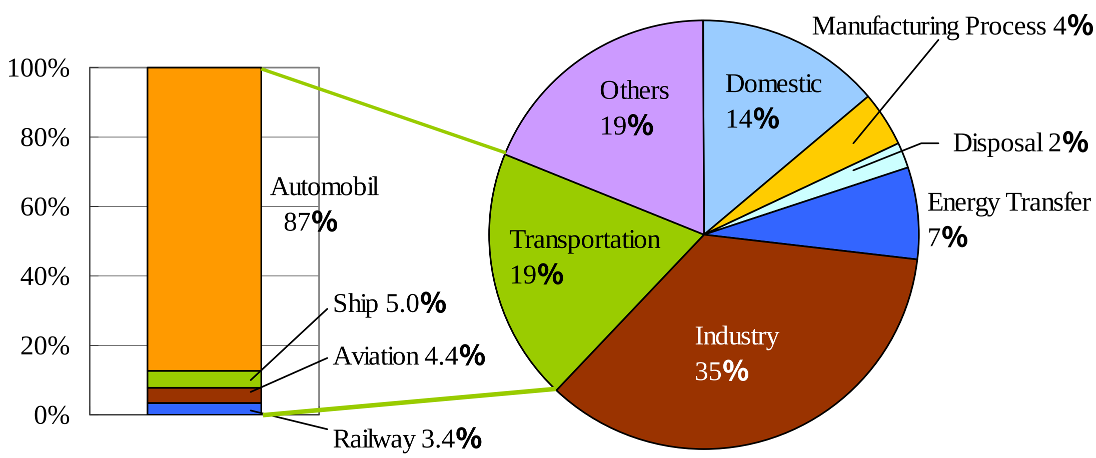


Figure 4 The Amount of CO_2 Emissions by Sector and Transportation Mode in Japan in 2008
(From National Institute for Environmental Studies)

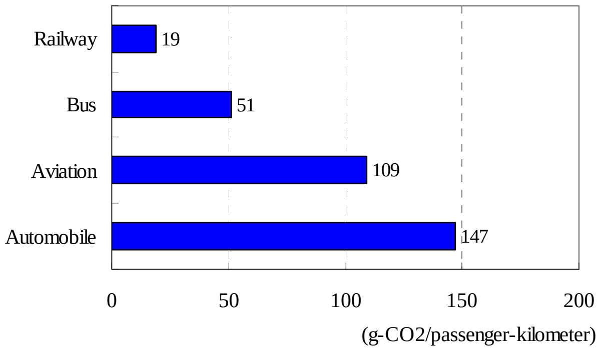


Figure 5 Basic Unit of CO_2 by Transportation
(From environment ministry Japan)

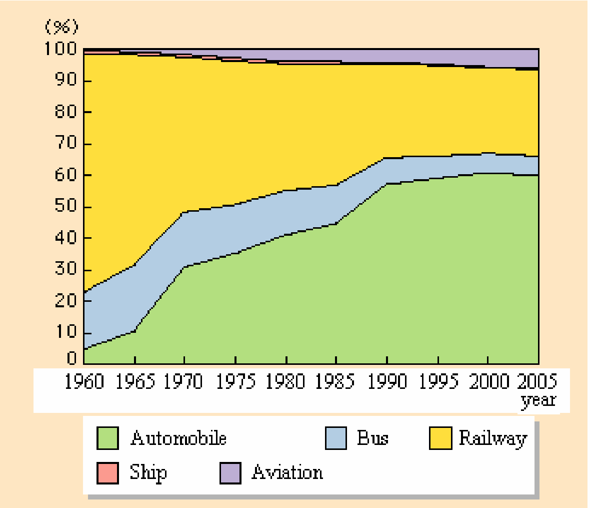


Figure 6 Share of Passenger Transportation
(From MLIT Japan)

Figure 7 Traffic Jam in Japan

3. THE METHOD FOR EVALUATION OF RAILWAY CONSTRUCTION WITH LCA

With the consideration of the movement of global environment protection, this study aims at the analysis of the effects of railway construction on the environment with the concept of LCA.

3.1 About LCA

LCA is the concept to evaluate the environmental effects of products through the life cycle from the cradle to the grave. It contains the methodology from collecting of resources to the disposal of the products themselves. This can show the whole true environmental effects of the products life cycle.
This study appropriates this LCA concept to measure the environmental impact of the lifespan of a railway project, including the construction of infrastructure and rolling stock, those maintenances, infrastructure operation, and disposal (Figure 8).

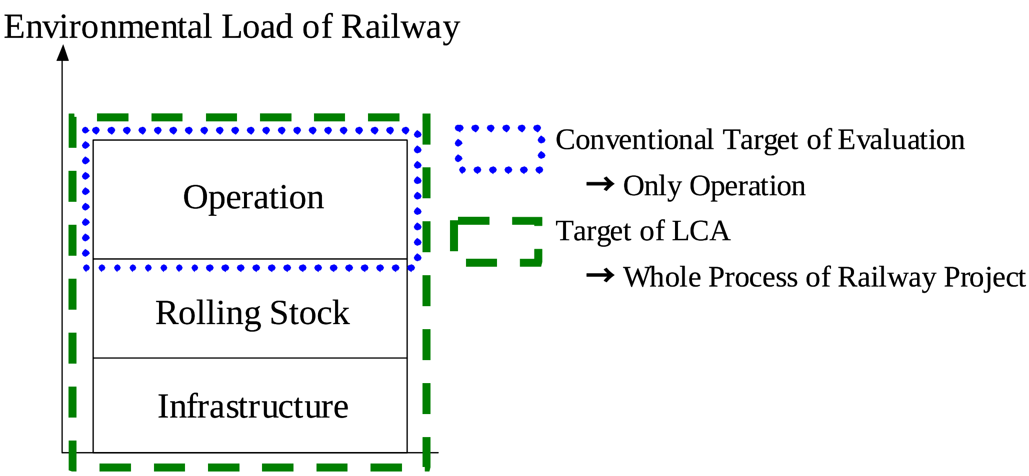


Figure 8 Target of Evaluation by LCA

3.2 Extended LCA

Railway construction may affect car transport and these effects also should be determined and evaluated. Figure 9 shows the extended LCA area. This study contains the effects of the reduction of environmental load by the decrease of the number of cars.

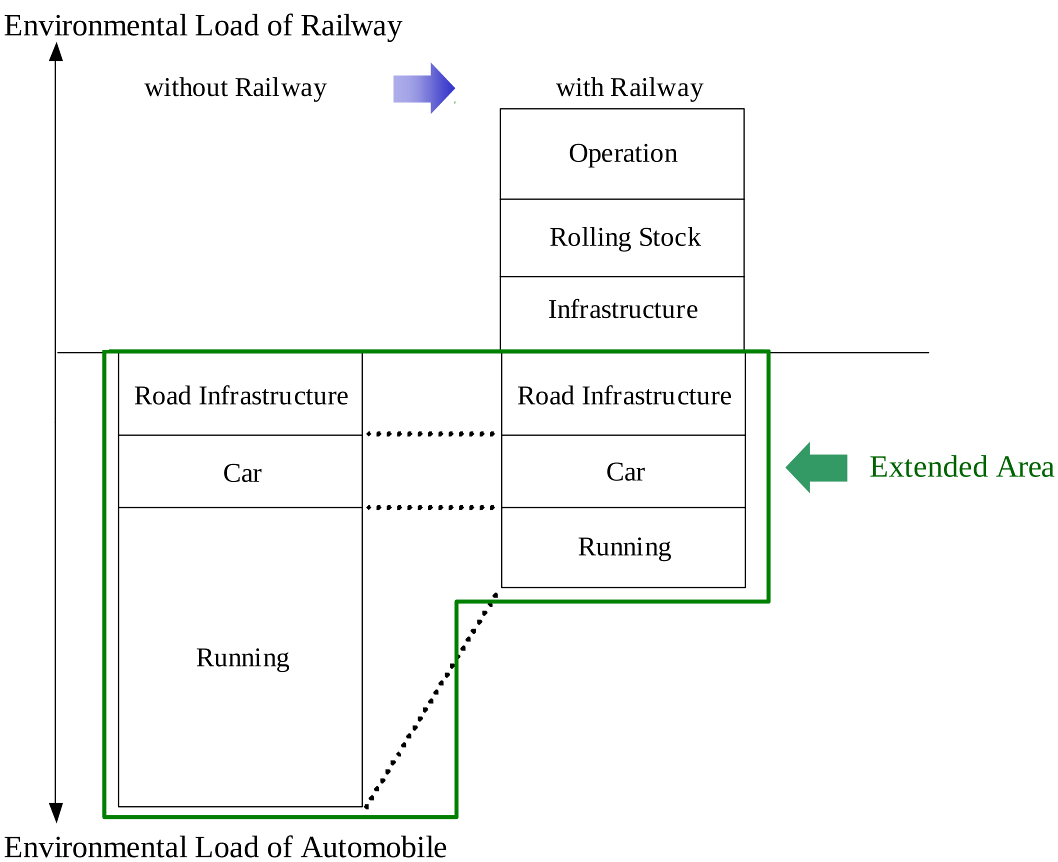


Figure 9 Concept of Extended LCA

4. THE METHOD FOR MEASUREMENT OF ENVIRONMENTAL LOAD

In this study, we measured the environmental load of railway construction with the setting of an environmental Basic Unit in each phase from the collection of resources to disposal (Figure 10).

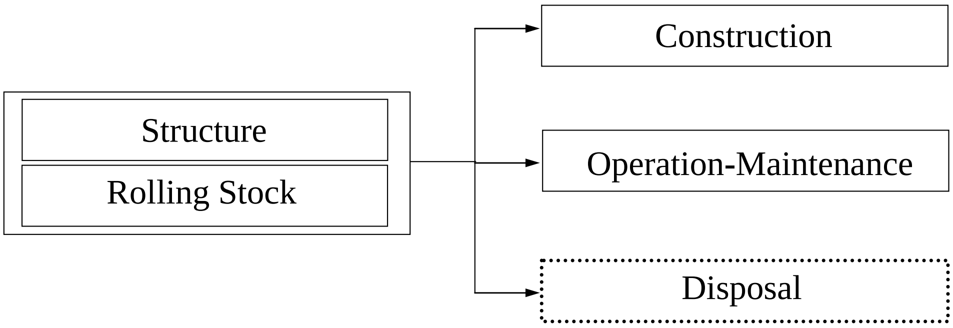


Figure 10 Environmental Load in Each Phase

4.1 Standardization of Elements of Infrastructure

For the calculation of environmental load from construction, it is to be desired to apply the precise data of the structure. However this study is to be implemented in the planning phase in which there is no detailed design of infrastructure. Therefore, it is not realistic to expect precise blueprints or construction plans for this analysis. By this reason, we applied easier measurement with the 'standardized elements' of infrastructure. Infrastructure can be divided into many elements shown as in Figure 11. Those divided elements were 'standardized' as the most typical form of the structure which is easy for Life Cycle Inventory Analysis. This method is to be considered accurate enough for the pre-study of the project.

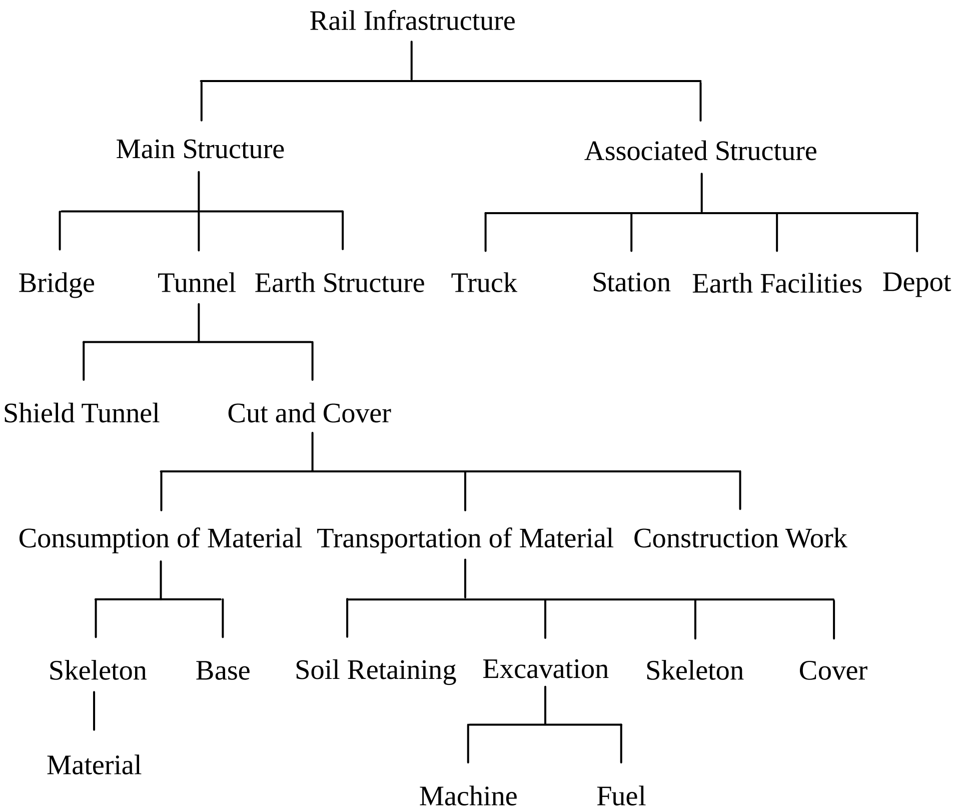


Figure 11 Divided Elements of Railway Infrastructure

4.2 The Setting of Basic Unit for Environmental Load in each structure

In this study, the aimed structures for evaluation are: main structure, associated structure, and rolling stock. Those objects are divided into the phases: 'building-manufacturing phase', 'operation-maintenance phase', and 'disposal phase' to measure the load (Table 1). Each structure or rolling stock is assumed as a standard specification. Required resources or energies are calculated in each element (Figure 12). Then total energies or resources are accumulated in each phase. The basic unit of each structure is calculated by multiplying the quantity of energies or resources in each structure by the basic unit of environmental load which is authorized by Japan Society of Civil Engineers or other organizations.

Table 1 The Aimed Structures for Evaluation in This Study

The Aimed Structures for Evaluation		Corresponding Phase	
Main Structure	Earth Structure : Embankment, Cut Bridge : Viaduct, Bridge Tunnel : NATM, Shield Tunnel, Cut and Cover	Construction	Consumption of Material
			Transport of Material
			Construction
Associated Structure	Track : Slab Track, Ballasted Track Station : Civil Work, Architecture, Equipment Electric Facility : Electric Line, Electric Substation, Traffic Control(Signal, Turnout), Communication	Construction	Consumption of Material
			Transport of Material
			Construction
		Maintenance	
	Depot	Construction	Consumption of Material
			Transport of Material
			Construction
Rolling Stock	Rolling Stock	Manufacturing	Consumption of Material
			Manufacturing and Assembly
		Maintenance	
		Operation	
		Disposal	

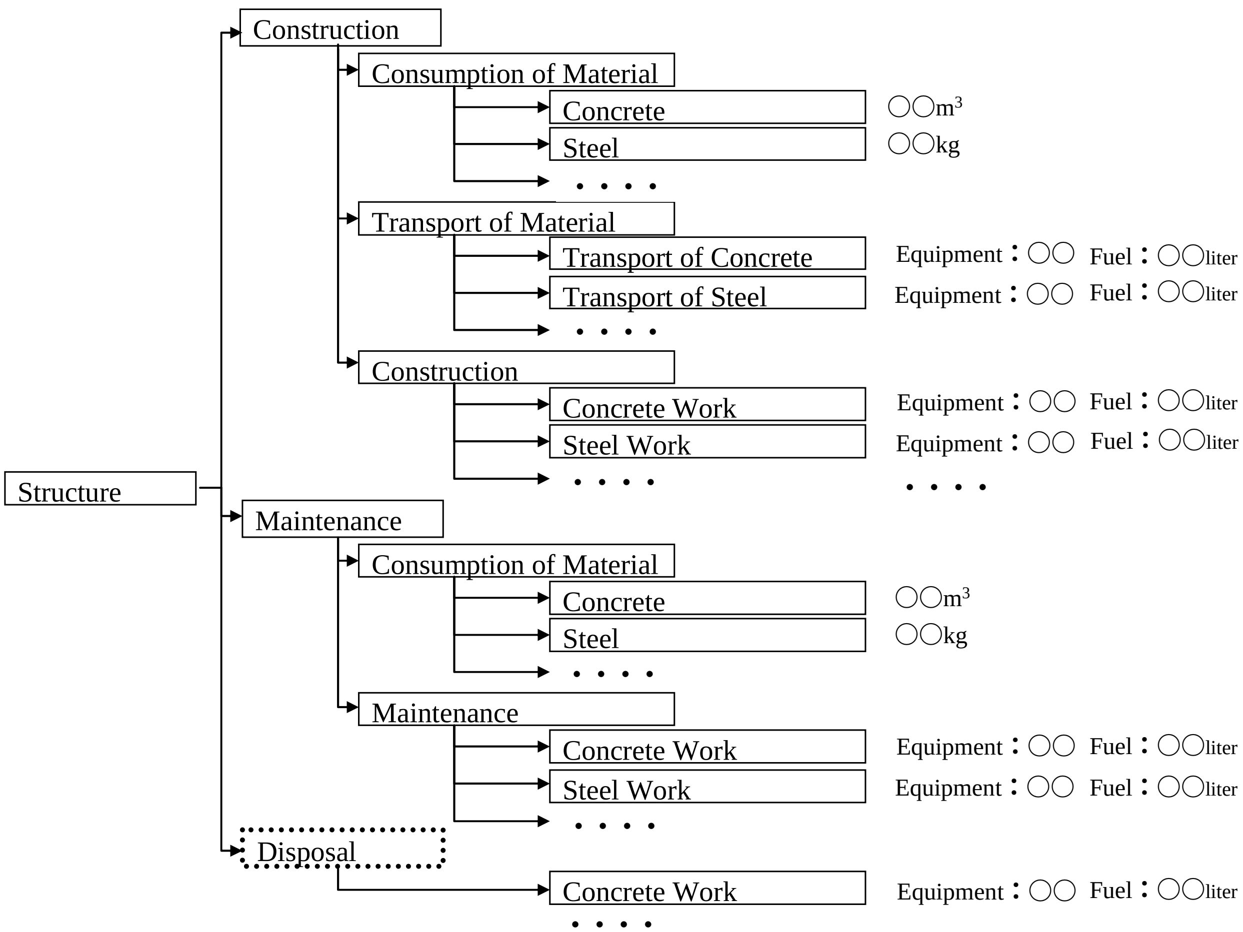


Figure 12 Elements for the Calculation of Basic Units of Environmental Load by Structures

4.2.1 Emission from Resources

CO_2 emission by the consumption of resources is summed up from each structure which is calculated by multiplying the quantity of resources and its basic unit of CO_2 emission. In this case, ‘consumption’ means collection and refinement of materials.

4.2.2 Emission from Transportation of Resources

CO_2 emission by the transportation of resources is the fuel consumption of transporters.

4.2.3 Emission from Construction Work

CO_2 emission in construction is the fuel consumption of machines.
Table 2 shows the basic unit of CO_2 emission in each structure.

4.3 The Method for Estimation of Environmental Load in the Railway Operation

Environmental load in the railway operation is estimated by the environmental basic unit and the passenger shift by the with-without case study of the railway.
The number of passenger shift is estimated by the number of passengers on each route and zoned station in the ‘railway route choice model’. Environmental load is estimated by the multiplying the basic unit by the electricity which is calculated by the train number suitable for passengers and train acceleration (Figure 13).

4.4 The Method for Estimation of Environmental Load in Automobile Operation

Environmental load in the automobile operation is calculated by multiplying the number of cars in each route by the environmental basic unit according to the speed. The number of cars in each route and average speed are estimated in the ‘car transport distribution model’ (Figure 13).

Table 2 Basic Unit of CO_2 Emission in Each Structure

Item			Basic Unit	Unit
Structure (Main Structure, Associated Structure)	Viaduct (H=8m, L=57.0m+Adjustment Girder 13.0m)		7.21	ton-CO_2/m
	Bridge (RC Girder, L=20m)		3.10	ton-CO_2/m
	Shield Tunnel (Diameter 9.8m)		8.85	ton-CO_2/m
	Embankment (W=10.7m, H=6.0m)		6.02	ton-CO_2/m
	Cut (W=10.3m, 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/site
Maintenance	Rail		14.4	ton-CO_2/million・car・km
	Aerial Line		0.152	ton-CO_2/million・car・km
Rolling Stock	Aluminum 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

※ In these Choice Models and Assignment Model, the probabilities are calculated by disaggregate analysis.

- In Mode Choice Model, the modes are rail, bus, and automobile. Parameters are time, cost, number of transfer, number of owned cars, central dummy, and constant.
- In Railway Route Choice Model, parameters are time, cost, transfer, overcrowding, and logsum from Access Choice Model.
- In Access Mode Choice Model, the modes are walk, bike, Park&Ride, Kiss&Ride, and Bus. Parameters are total time, total cost, and constant.
- In Assignment Model of Cars, The number of cars by links is estimated by user equilibrium assignment which contains private cars, buses, small trucks and large trucks.

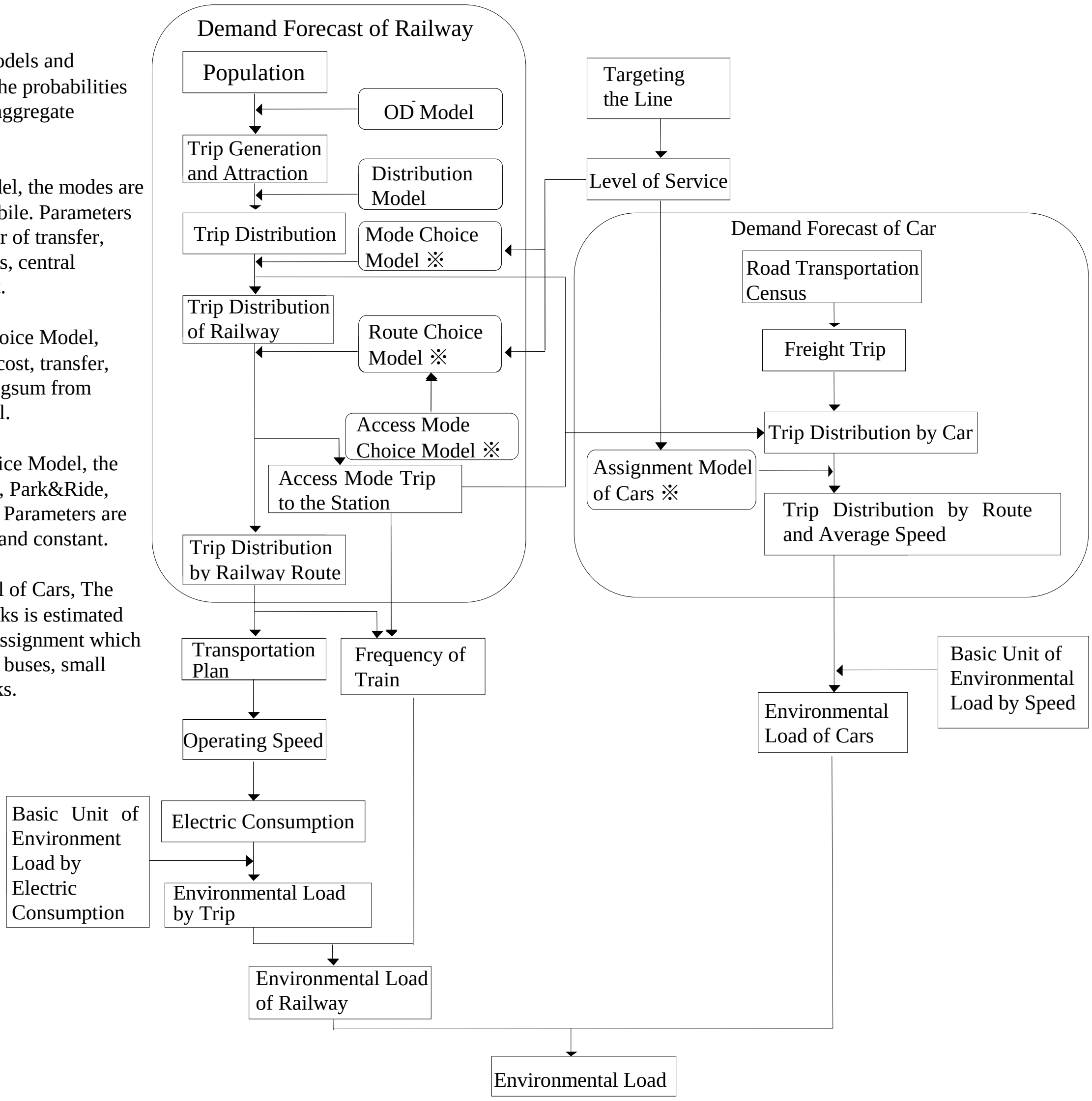


Figure 13 Flow of Calculation of Environmental Load in the Phase of Operation with Extended LCA

5. CASE STUDY

5.1 Calculation of Environmental Load in Each Structure

In this study, one newly constructed railway in the TOKYO area is targeted for case study. The line was constructed in the railway blank area and is transporting 90 thousand passengers a day. The contents of the case study are calculating the quantity of CO_2 emissions in each body (main structure, associated structure, and rolling stock) and in each phase (building-manufacturing, operation-maintenance, and disposal) (Table 3 and Figure 14).

Figure 14 shows the accumulated CO_2 emission in the 50 years life time. 22 years after the inauguration, emission by the operation-maintenance exceeds that by the structure building.

Table 3 CO_2 Emission by Rail Structure (Life cycle time: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%	

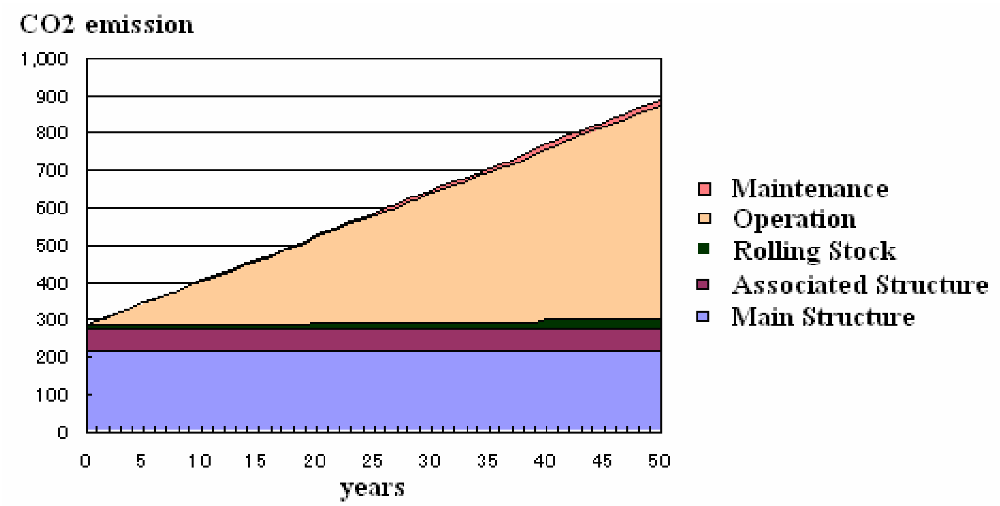


Figure 14 CO_2 Emission in the 50 Years Life Time

5.2 Case Study of Environmental Effects of Railway Project

This study implemented two case studies of environmental effects of railway projects with the views shown below:

- View 1: Contribution to the reduction of CO_2
- View 2: The best option of the transportation mode for the least environmental effect

5.2.1 View 1: Contribution to the reduction of CO_2

Case 1: Suburban newly constructed line

This line is the same as shown in 5.1. In the study, calculations of the emission from affected neighboring railways and automobile usage are added to the original calculation of the quantity of CO_2 emission in each body (main structure, associated structure, and rolling stock) and in each phase (building-manufacturing, operation-maintenance, and disposal).

As a result, new railway construction in the railway blank area introduces the diversion of passengers from automobiles and other far-away railways to the new line and totally contributes to the reduction of emission even with the emission from construction (Figure 15).

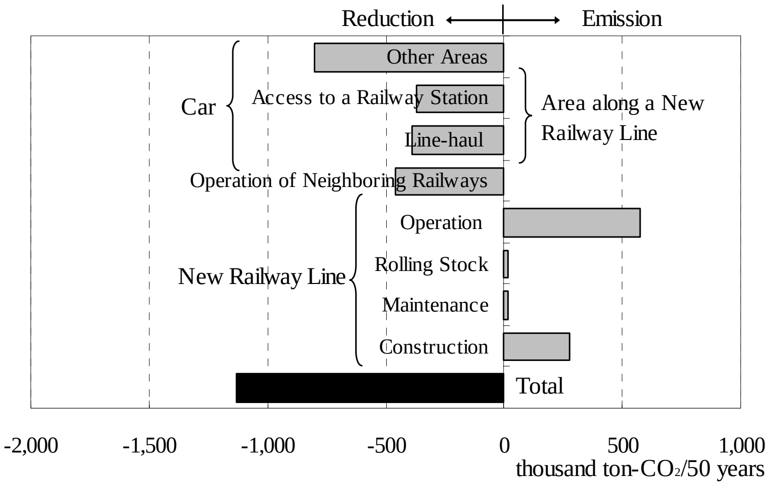


Figure 15 The Result of an Analysis of View 1(Case 1)

Case 2: Parallel to the existing line

On the other hand, construction of the line parallel to the existing line has a competing relation each other and has a different result. The average speed of new line is lower than parallel railway, the new line has a purpose of releasing the congestion of the existing line and transferring occurs between the two lines. Transferring from automobile is less and the reduction of emission is not enough to cover the emission from construction (Figure 16).

Emission from operation of neighbored railway is increasing. The reason is that new line induced the diverting of passengers from denser lines to other lines and frequencies of those railways were adjusted.

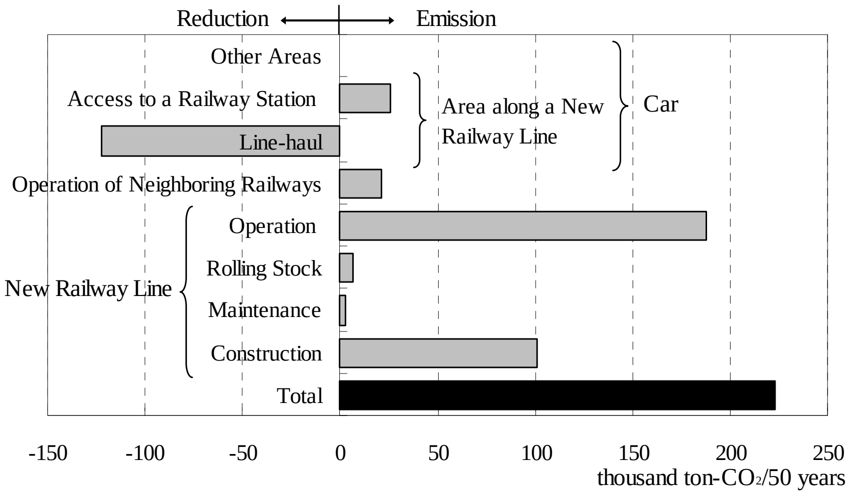


Figure 16 The Result of an Analysis of View 1(Case 2)

5.2.2 View 2: The best option of the transportation mode for the least environmental effect

This case study is the comparison of environmental effect between railway transport and BRT. Railway is the newly constructed line connecting the city center of Tokyo and suburban area and is transporting 270 thousand passengers a day. BRT is an imaginary mode for the study and has the same capacity as the railway. In this study, environmental load from BRT infrastructure is assumed as the same as the rail. So the comparison of emission is only in the operation-maintenance phase (Figure 17).

Emission from operation of buses is estimated as below:

- Set the frequency of buses
- Calculate the environmental burden per one bus trip by the average speed of bus movement curve
- Multiply the number of bus trip

The number of bus trip is set by the maximum traffic volume in each bus operation type which is decided from the OD matrix by the train operation types. In this case, capacity of a bus is set as 40 and average occupation ratio is set as 20%.

According to the result of the calculation of CO2 emission by the LCA of the railway, the emission in the construction phase shares 28% in 30 years and 19% in 50 years. On the other hand, the emission in the operation phase is 70% in 30 years and 79% in 50 years (Figure 18). Of course the result in the operation Phase is that railway transport is much more environmentally–friendly compared to bus transport (Figure 19).

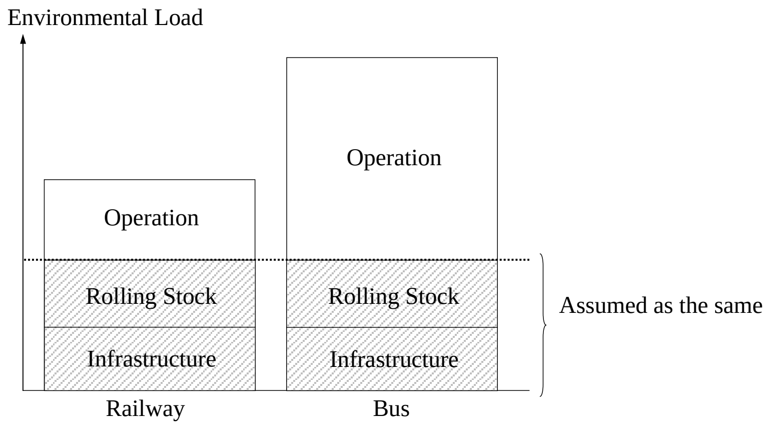


Figure 17 Target of Evaluation of Environmental Load

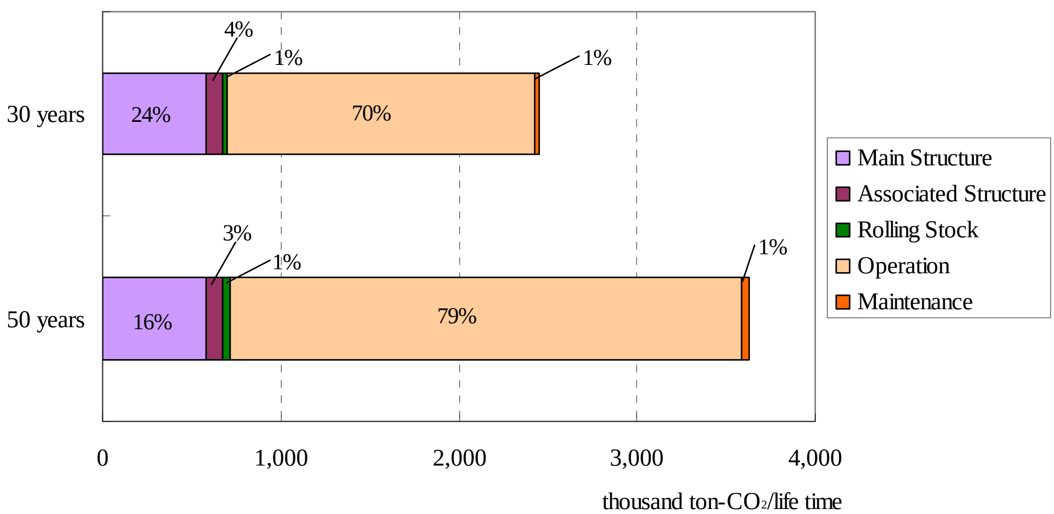


Figure 18 Output of LCA (Railway Only)

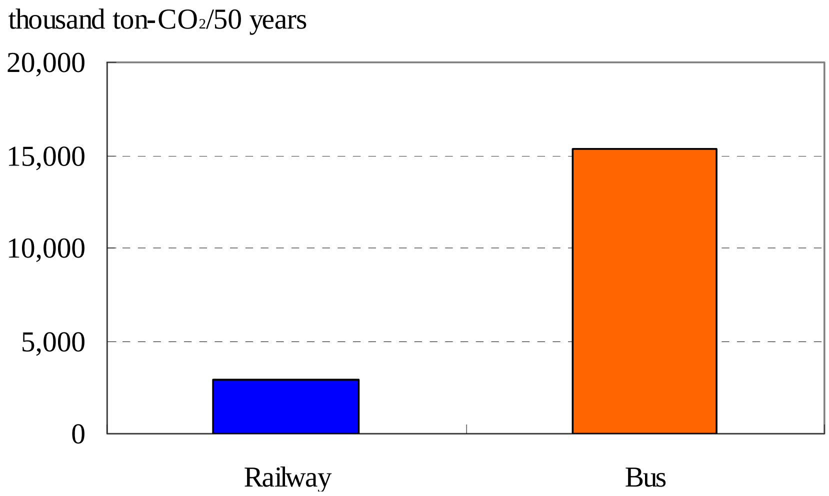


Figure 19 CO_2 Emission in the Operation Phase in the View2

6. CONCLUSION

This study proposes the method for evaluation of railway construction with the concept of LCA, which can contain the effect from the construction to the disposal. By this method, railway transport is proved to be generally an environmentally-friendly transportation mode.
However, it should be noted that the scale of the benefit is altered depend upon each case. It is easily assumed that if more passengers transferred from cars to the new railway, the project can be more environmentally-friendly.
This study shows this fact quantitatively, that is:

- Railway is environmentally-friendly enough to cover the emission from construction of itself.
- The newly constructed line in the railway blank area is more effective to reduce emission.
- The parallel line to the conventional one does not always have such an effect.

Of course, the new parallel line should be appreciated if the line has other benefits such as reduction of congestion and travel duration. Anyway, most significant fact in this study is to develop the method to evaluate the environmental impact of the infrastructural project quantitatively.
We consider that this method is available for the evaluation of all new railway projects. We are preparing a guidance manual of this method. Based on this manual, we are to study other types of railways including SHINKANSEN high speed rail. And we hope that this manual will be of valuable use for many railway projects throughout the world.

REFERENCES

SHIBAHARA,N., KATO,H. and KANO,K. (2003) An Evaluation Method of Environmental Performance on Railway Systems Applying the Standardized Life-Cycle Emission Factor, **Environmental Systems Research, Vol.31**, pp.167-172 (in Japanese)

KANO,K., ASAMI,H., TAKAHASHI,K. and KATO,H. (2004) Basic Units of LCA of Railway Projects, **Environmental Systems Research, Vol.32**, pp.203-208 (in Japanese)

MORITA,Y., HIGASHI,M. and YAMASAKI,T. (2008) A Study on Method of Measuring

Effect Railway Projects on the Environment, **J-RAIL2008**, pp.591-594 (in Japanese)

KATO,H., SHIBAHARA,N. and OSADA,M. (2005) A Life Cycle Assessment for Evaluating Environmental Impacts of Inter-regional High-speed Mass Transit Projects, **Journal of the Eastern Asia Society for Transportation Studies, Vol.6**, pp.3211-3224

KATO,H. and SHIBAHARA,N. (2006) A State of the Arts of Life Cycle Assessment Researches for City, Infrastructure and Transport Systems, **Proceedings of Infrastructure Planning, Vol.33(CD-ROM),** 4pages (in Japanese)

KATO,H. and SHIBAHARA,N. (2006) An Application of Life Cycle Assessment to Public Transport Projects – A Case of Superconducting MAGLEV System –, **Journal of Life Cycle Assessment, Vol.2 No.2**, pp.166-175 (in Japanese)

SHIBAHARA,N., KATO,H. and WATANABE,Y.(2006) Life Cycle Assessment of an Alternative Inter-regional High-speed Railway Projects by an Eco-Efficiency Index, **Proceedings of Infrastructure Planning, Vol.34(CD-ROM),** 4pages (in Japanese)

SHIBAHARA,N. and KATO,H. (2008) Ranking Method of Alternative Inter-regional Transport Systems by their Global Environmental Impacts, **Proceedings of Infrastructure Planning, Vol.37(CD-ROM),** 4pages (in Japanese)

INAMURA,H., M.PIANTANAKULCHAI. and TAKEYAMA,Y. (2002) Life Cycle Inventory Analysis of Transportation System – Comparative Study of Expressway and Shinkansen –, **Transport Policy Research Review, Vol.4 No.4 2002 Winter**, pp.11-22 (in Japanese)

Japan Society of Civil Engineers (1996) 4th Symposium of Global Environment

Architectural Institute of Japan (1999) Guidance for LCA in Buildings