A Study on the Methodology for Evaluating the Environmental Load of Rail Infrastructure

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Abstract

This study aims to establish a methodology to evaluate the environmental impact through the whole life cycle of a railway as a preliminary survey of a railway project, with the application of the Life Cycle Assessment. It also considers the Extended Life Cycle Environmental Load (ELCEL), which includes the effects of the environmental load reduction by decreasing traffic of alternative modes such as automobile traffic. This method is available for the environmental evaluation of new railway projects in the planning phase.

Keywords: CO_2, Extended Life Cycle Environmental Load (ELCEL), Factor of Environmental Load, Planning Phase

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. However, until now rail transport has been generally discussed only in terms of its operating stage. As well, such discussions have been based primarily on the average value of greenhouse gas emitted during the operation of the transportation mode in a country [1].

For a more precise study of emission control in the development of new railways, this average value is not applicable because the amount of emission varies by transport conditions such as load factor, the length of the line haul, etc. And it is also important to note that not only emission from operation but also from 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 total emission reduction, and this also should be taken into account.

This study aims to establish a methodology to evaluate the environmental impact through the whole life cycle of a railway as a preliminary survey of a railway project. The methodology contains how to evaluate the total environmental load of railway project which emits carbon dioxide (CO_2) from the construction through disposal, with the application of the Life Cycle Assessment (LCA). It also takes into consideration the Extended Life Cycle Environmental Load (ELCEL) by Kato et al [2], which includes the effects of the environmental load reduction by decreasing alternatives to railway lines such as automobile traffic.

This study focuses on CO_2 as the major emission of greenhouse gases. The result of this study is to be applied as an index of effects brought by new railways to entire society.

2. Evaluation of Railway Project with LCA

2.1 Life cycle assessment (LCA)

LCA is a methodology to evaluate the environmental effects of products through the whole life cycle from the cradle to the grave. This study appropriates this LCA concept to measure the environmental impact of the lifespan of a railway project, including construction of infrastructure and rolling stock, maintenances, operations, and disposal (Fig.1).

LCA originally contains Inventory Analysis which evaluates amounts of various environmental impacts. However, in this study, we target the amount of CO_2 because it shares 95% of greenhouse gases.

2.2 Extended LCA (ELCEL)

Extended Life Cycle Environmental Load (ELCEL) is an extended concept of LCA. It is available to evaluate external impacts of new railways to other transportations. Due to this method, total reduction of emission by the decrease of the number of cars can also be counted (Fig.2).

2.3 Views of evaluation

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

- View 1: How much the new line contributes to less emission
- View 2: Which route of the new rail line has least impact
- View 3: Which transportation mode least emits

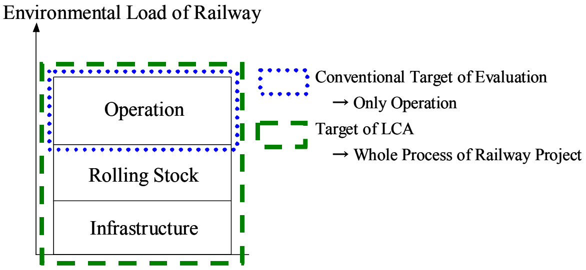

Fig.1: LCA on railway project

2.4 Scope of the study

2.4.1 Life span

Life span of targeted project is decided with the consideration of the lifetime of the structures and the project term. In this study, 30 years or 50 years is adopted. These numbers are commonly used in financial analyses in Japan and contain construction period.

2.4.2 Scope of analysis

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

2.4.3 Spatial extension

As the extension of LCA shown above, spatial scope of the study is also extended (Fig.3).

3. Method for Measurement of Environmental Load

This study measured the environmental load of railway construction with an environmental 'emission factor' in each phase from the collection of resources to disposal.

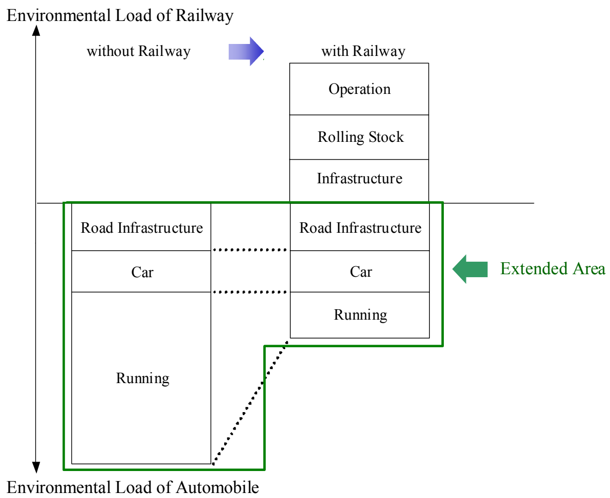

Fig.2: Extended LCA on railway project

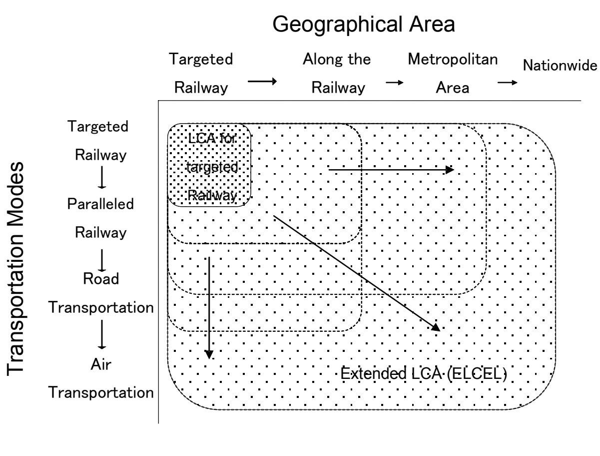

Fig.3: Scope of extended LCA (ELCEL)

3.1 Standardization of elements in 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 stage 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 Fig.4. 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.

3.2 Definition of 'environmental emission factor'

In this study, the aimed structures for evaluation consists on main structure, associated structure, and rolling stock. Furthermore these are divided into the phases: 'building-manufacturing phase', 'operation-maintenance phase', and 'disposal phase' (Table 1). Emission of CO_2 is calculated in each element in each phase, and accumulated into a structure with the concept of 'emission factor'.

Environmental 'emission factor' means the unit quantity of environmental load from something. For example, 'emission factor of CO_2' means the quantity of CO_2 emission from the unit quantity of the material or work. 'Emission factor of CO_2' was proposed by the Japan Society of Civil Engineers and other technical societies [3]. Multiplying emission factor with the quantity of consumed material is the quantity of CO_2 from the material. Accumulation of the multiples in the elements becomes the emission factor of each structure or rolling stock.

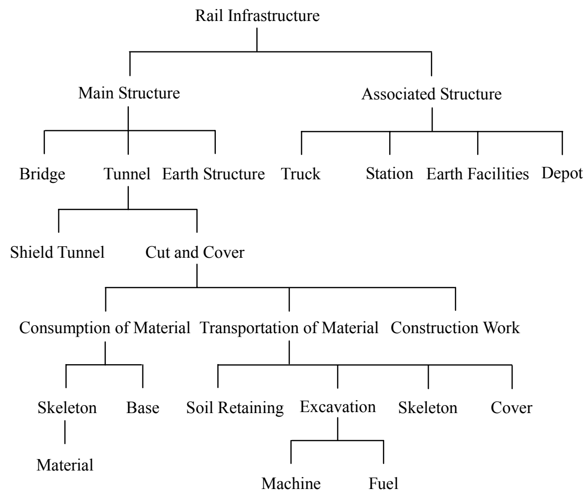

Fig.4: Divided elements
(Example of cut and cover tunnel)

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	Construction	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	Construction	Consumption of Material
			Transport of Material
			Construction
		Maintenance	
	Depot	Construction	Consumption of Material
			Transport of Material
			Construction
Rolling Stock	Rolling Stock	Manufacture	Consumption of Material
			Manufacturing, Assembly
		Maintenance	
		Operation	
		Disposal	

Table 2: CO_2 emission factors in each structure

Item		Emission Factor	Unit
Viaduct (H=8m, 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
Bridge (Reinforced Concrete Girder, L=20m)		3.10	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
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
Rail		14.4	ton-CO_2/ million・car・km
Overhung Electric Line		0.152	
Rolling Stock (Pantograph, Brake, Wheel, etc)		6.81	
Aluminum Body (20m×10car train)	Manufacturing	93.9	ton-CO_2 /car
	Disposal	0.662	ton-CO_2 /car
Stainless Body (20m×10 car train)	Manufacturing	66.8	ton-CO_2 /car
	Disposal	0.662	ton-CO_2 /car

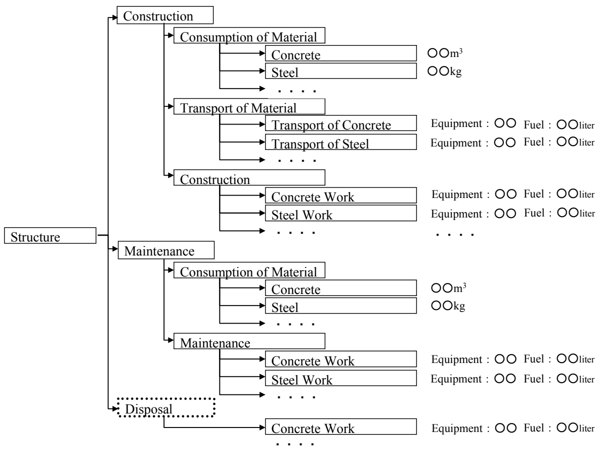

Fig.5: Elements for the environmental ‘emission factor’

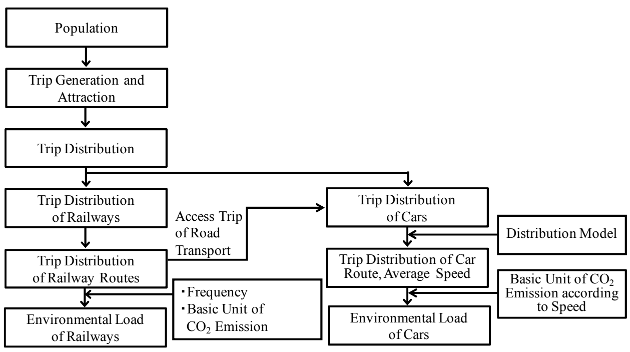

Fig.7: Estimation of environmental load in operation phase

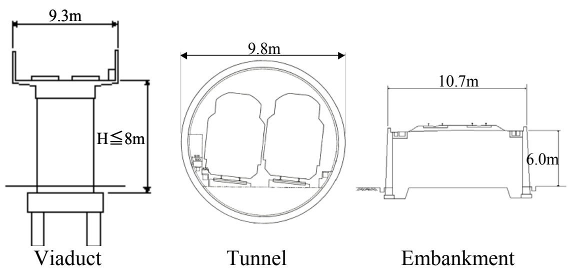

Fig.6: CO_2 Emission factors in each Structure

3.3 Environmental load from train and automobile

Environmental load from train and automobile is estimated by the environmental emission factor and the passenger shift by the with-without case study of the new railway.

The number of passenger shift is estimated by the number of passengers on each route and zoned station in the ‘railway route selection model’. Environmental load is estimated by multiplying the emission factor by the electricity which is calculated by the train number suitable for passengers and train acceleration.

Environmental load in the automobile operation 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’.

4. Case Studies

4.1 Environmental load of rail infrastructure

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 now transporting 90 thousand passengers a day. The case study contains the calculation of 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).

Fig.8 shows the accumulated CO_2 emission in the 50 years life time after construction. 22 years after the inauguration, emission by the operation-maintenance exceeds that by the initial construction. However emission by construction still shares 43% of total emission during 30 years and 32% during 50 years. It means that not only operation but also entire life cycle including construction of infrastructure must be taken into consideration.

4.2 Extended LCA of rail project with ELCEL

Chapter 4.1 shows a quantity of emission from a rail infrastructure. This chapter shows the entire impact of the same rail project on reduction of CO_2 emission with extended LCA concept (ELCEL).

This line was newly constructed in the railway blank area (same as the case of 4.1). This new line gives a large impact to neighboring road transportations and a lot of passengers shifted to the new rail. ELCEL evaluated total CO_2 emission along the corridor adding to the emission from the new line.

Fig.9 shows the 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.

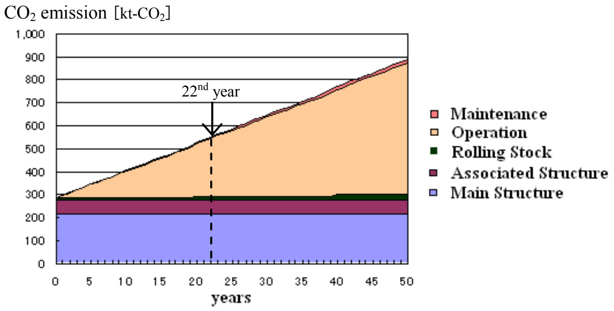

Fig.8: CO_2 emission during 50 years

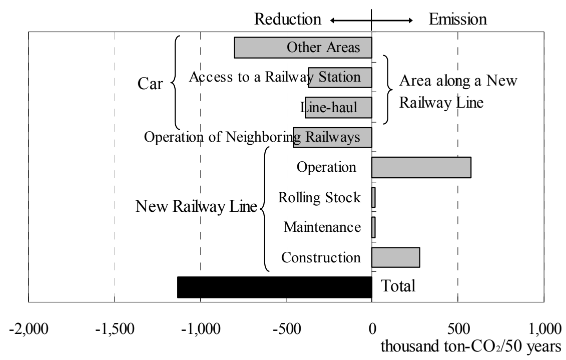

Fig.9: Extended LCA on newly constructed line

5. Conclusion

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

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 modified for many railway projects throughout the world especially developing countries where a lot of new rail projects are expected [4].

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

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