Life Cycle Inventory Analysis of Transportation System Using Input-Output Framework(産業連関表を用いた交通システムのライフサイクルアセスメント)

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学位の種類	博士　（学術）
学位記番号	学術博（情）博第6号
学位授与年月日	平成12年3月23日
学位授与の要件	学位規則第4条第1項該当
研究科，専攻	東北大学大学院情報科学研究科　（博士課程）人間社会情報科学専攻
学位論文題目	Life Cycle Inventory Analysis of Transportation System Using Input-Output Framework 「産業連関システムに基づく交通システムのライフサイクルアセスメント」
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論 文 内 容 要 旨

Abstract

The research adopted the concept of Life Cycle Assessment (LCA) in estimating the amount of environmental releases related to the transport system. The limitation of the conventional methodology of LCA is that it cannot include all the indirect effects, caused by the repercussion of the economy, which are not negligible. The hybrid Input-Output model was proposed as the inventory model to overcome this constraint. To extend the inventory model, the sensitivity analysis was proposed using the Input-Output Structural Decomposition Analysis (IO-SDA) approach. Different transport systems cannot be compared without careful considerations. The framework of the comparative analysis of different transport systems considering the system's function and system's scale was proposed. Finally, from the result of picked up case studies, the study recommended the transport policy to curb the amount of life cycle carbon emission from transport systems.

1. Introduction

This chapter pointed out the vital role of the impact from transport sector to the environment, the concept of sustainability transport and life cycle thinking. The carbon emission attributed to transportation sector is about one-third in most countries. The concept of sustainable transport is particularly conformable with the concept of LCA. Two important aspects needed to be considered in the LCA study were pointed out,

- To consider the project "from cradle to grave"
- To consider the indirect effect of ancillary input into the project

By setting the system boundary, the conventional process analysis approach fails to include the later aspect into the analysis. Therefore, in order to relax this constraint, Input-Output model was proposed in this study. The possibility to develop the sensitivity analysis under Input-Output framework using Input-Output Structural Decomposition Analysis (IO-SDA) as well as the necessary considerations for the comparative analysis of different transport systems were discussed. The research was organized in total six chapters. Chapter 1 gives general introduction to the research problem, objectives and framework of the study. Chapter 2 summarizes the related pervious literatures of Life Cycle Assessment and Input-Output Analysis. In chapter 3, the life cycle emission inventory model for transport project is developed using input-output framework. The model is used to analyze a case study of Tohoku Expressway in Japan. As the bridge between an inventory and improvement assessment, the input-output structural decomposition model is developed in Chapter 4. For the case study, the model was used to analyze the effect of change in technology of general road construction works in Japan during 1975-1990. In chapter 5, a comparison of the intercity transportation in the context of carbon emission between the expressway system and high-speed railway system in Tohoku region of Japan was carried out. Finally, the conclusion and recommendations were made in Chapter 6. The research framework is shown in Fig 1.

2. Literature Review

The general environmental problems related to transport sectors were pointed out. The overview of the framework of LCA was summarized. There are three major components in the framework of LCA proposed by SETAC; Inventory Analysis, Impact Assessment, and Improvement Assessment. Three components are linked by the goal definition and scoping. LCA was invented on 1960s and is widely applied in the design, policy and regulatory decision making nowadays. A brief history of LCA was also presented. LCA studies related to transport sector were picked up and discussed, for example, Kobayashi (1997), Lave (1977), Livinson et al. (1996), Murry and Delucchi (1998). The limitation of the conventional process approach that used the linear sequence was discussed.

Finally, some literatures related to environmental input-output analysis were picked up and discussed. Professor Wassily Leontief invented the input-output model since 1930s. The conventional economic input-output models were primarily used to analyze the interdependence among industries. The extended input-output models were broadly applied for the environmental and energy-related analysis, for example, Leontief (1970; 1972) Gutmanis (1975), Rose (1977), Harendeen (1974), Bullard et al. (1975), Hayami et al (1993) Hetherington (1996), Kondo et al. (1996), Moriguchi (1996), Nishimura et al. (1997). The failure to include the indirect effects into the previous LCA studies related to transport was discussed.

3. Life Cycle Inventory Model of Transport Using Input-Output Framework

In this chapter, the life cycle inventory model was developed using Input-Output framework. The basic Input-Output model was declared first and the problem of using the conventional Input-Output model to estimate the amount of emission was discussed. The monetary unit is often used in Input-Output model. However, the estimation of the emission by the direct conversion the monetary term suffers from the non-uniform price of energy across sector. To eliminate this kind of error, the hybrid Input-Output model was utilized in this study. The model was applied to a case study of Tohoku expressway in Japan. The result showed that the indirect emission from the car production, expressway construction and expressway maintenance are quite large and not negligible. It was found that almost 90% of total emission comes from the fuel combustion in the operation stage while the emission from the production of vehicle and the emission from the facility construction accounted about 5% each. The emission caused by truck traffic on expressway is dominant due to high level of traffic on the expressway. The result of this chapter can be summarized in Table 1 and 2.

4. LCI Sensitivity Analysis Using Input-Output Structural Decomposition Analysis (IO-SDA)

Since the amount of life cycle emission can be varied by many factors, the development of sensitivity analysis is necessary. Using I-O framework allowed us to develop the sensitivity analysis in systematic way. In this chapter, the Structural Decomposition Analysis (SDA) under I-O framework was introduced. The model was applied to a case study to decompose the source of change in carbon emission intensity of various road construction works in Japan during 1975-1990. It was found that during the period of study the emission intensities decreased about 40% in all road construction categories. In this study, we classified the sources of change in emission into 2 major factors; 1) change in road construction technology 2) change in the manufacturing technology of the economy. We could be able to clarify the major source of emission intensity change in each construction category as shown in Fig.2.

5. Comparative Analysis of Life Cycle Emission of Transport Systems

This chapter provided the framework to for the comparison of environmental load in term of carbon emission of different transport systems. The comparison between an expressway system (Tohoku expressway) and a high-speed railway system (Tohoku Shinkansen) was picked up as a case study. The approach involves the system allocation and the system expansion concept. It is obvious that both systems are different in the system's function. The expressway serves both passenger and freight transport while the high speed railway serves only passenger transport. In this study, the different in the system function was considered as the allocation problem. Moreover, both systems are also different in the scale of traffic and construction. In this study, the system expansion concept was applied for different project's scale. Considering both systems, Tohoku Shinkansen would regained its benefit over its initial emission in 11 years after the opening to service (See Fig.3). The benefit in term of carbon emission saved if Tohoku expressway would had been substituted by the extension of Tohoku Shinkansen was also estimated (See Fig. 4).

6. Conclusions and Recommendations

The contributions of this research can be concluded as following.

1. It is the first time to obtained real data from the project to conduct the analysis of the emission from the total system of transport using EIO-LCA.

2. The comparative analysis between Inter-City Expressway and Shinkansen contributes as the fact finding in engineering aspect regarding the life cycle carbon emission from both systems.

3. It contributes the good reference for the better justification of both systems since the analysis of life cycle carbon emission from both huge projects is extremely a laborious work and is almost impossible to get this kind of information elsewhere

4. The study investigated in detail the emission from the construction of various transport facilities and could discover the structure as well as causes and effects of emission change of various road construction works in Japan during 1975-1990.
5. This study is the first attempt to apply IO-SDA approach for the LCA sensitivity analysis. The developed model would contribute as a new useful tool in the field of EIO-LCA and can serve as a bridge between the Inventory Analysis and Improvement Assessment.

It was clear that the most effective way to reduce the amount of emission related to expressway (road transportation) is to improve the fuel consumption efficiency. This can be done in several ways, for example, to improve the efficiency of the engine, reduce the weight of vehicle, to improve aerodynamics of vehicle, etc.. Since the technology of vehicle will be improved much in near future, the emission from the construction would become more important. The model developed here will be useful for assessment of the proposed construction technologies or environmental policies.

The promotion of bus transport seemed to be promising alternative. From Chapter 3, it was found that the life cycle emission of private car is about 6.5 times more than the life cycle emission from the bus. The effect depends on the percentage of mode shift. However, it seems that the mode share of bus service is quite very low (about 2% on expressway). The reason might be that Shinkansen is much more attractive than bus in terms of travel time, frequency, and fare. Moreover, considering in long run, Shinkansen system would produce less emission. Promoting the use of Shinkansen might be more feasible and more beneficial in terms of carbon emission saving.

Table 1
Emission Factors Calculated from the Model

Item	Direct	Direct + Indirect	Unit
Expressway Construction			
Bridge	0.207	1.200	ton-C/million yen
Pavement	0.267	0.877	ton-C/million yen
Tunnel & Earthwork	0.257	0.901	ton-C/million yen
Other works	0.204	0.915	ton-C/million yen
Expressway Maintenance	0.195	0.922	ton-C/million yen
Vehicle Production			
Passenger Car	0.023	1.042	ton-C/vehicle
Truck	0.029	1.552	ton-C/vehicle
Bus	0.077	4.179	ton-C/vehicle
Fuel		1.047	kg-C / kg-C
Gasoline	0.643		kg-C / liter
Deisel	0.721		kg-C / liter

Table 2
Carbon Emission from Tohoku Expressway by Stage

	Direct	Direct +Indirect	Share
Production of vehicle	47	2,200	5.0%
Passenger Car	33	1,500	
Bus	1	55	
Truck	13	7,200	
Expressway construction	12	2,200	4.8%
Earthwork	2	500	
Pavement	2	200	
Tunnel	1	180	
Bridge	1	470	
Other works	6	850	
Expressway maintenance	52	250	0.5%
Vehicle operation	39,000	41,000	89.6%
Passenger Car	9,400	9,800	
Bus	990	1,040	
Truck	28,000	30,000	
Total	39,000	45,000	100.0%

Note : Rounded values (Unit = 1,000 ton-C)

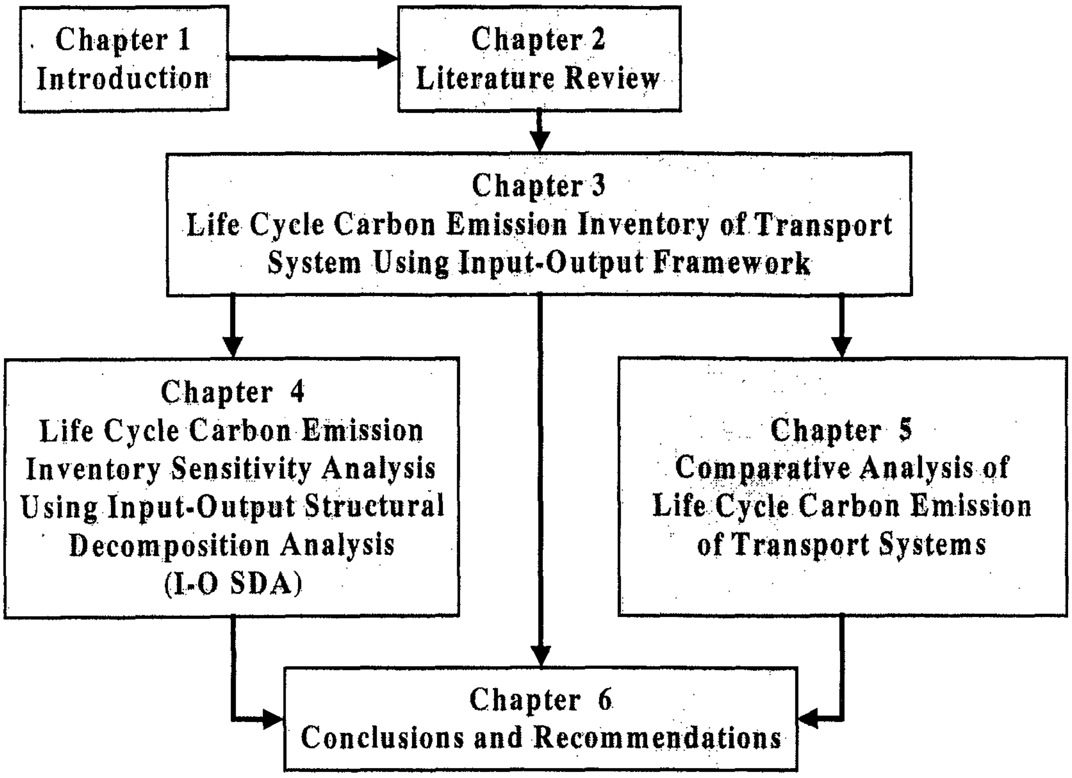

Fig. 1 Research Framework

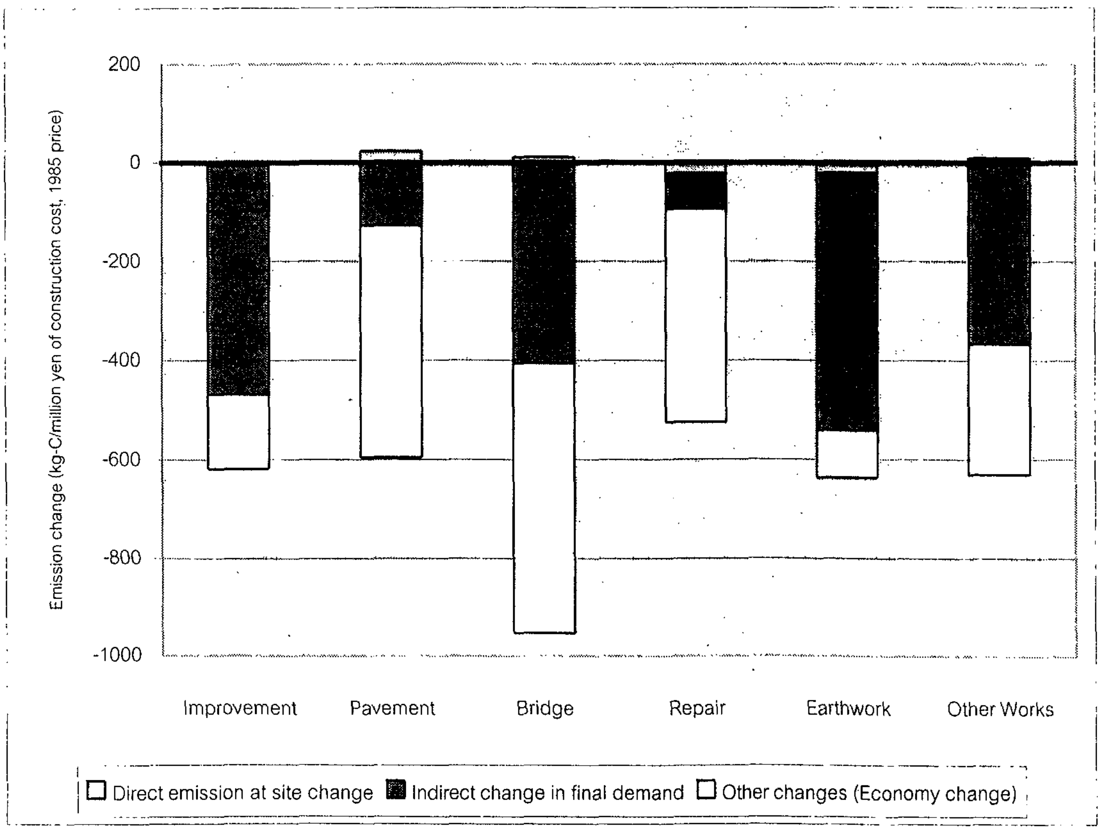

Fig. 2 Decomposition of the Emission Change

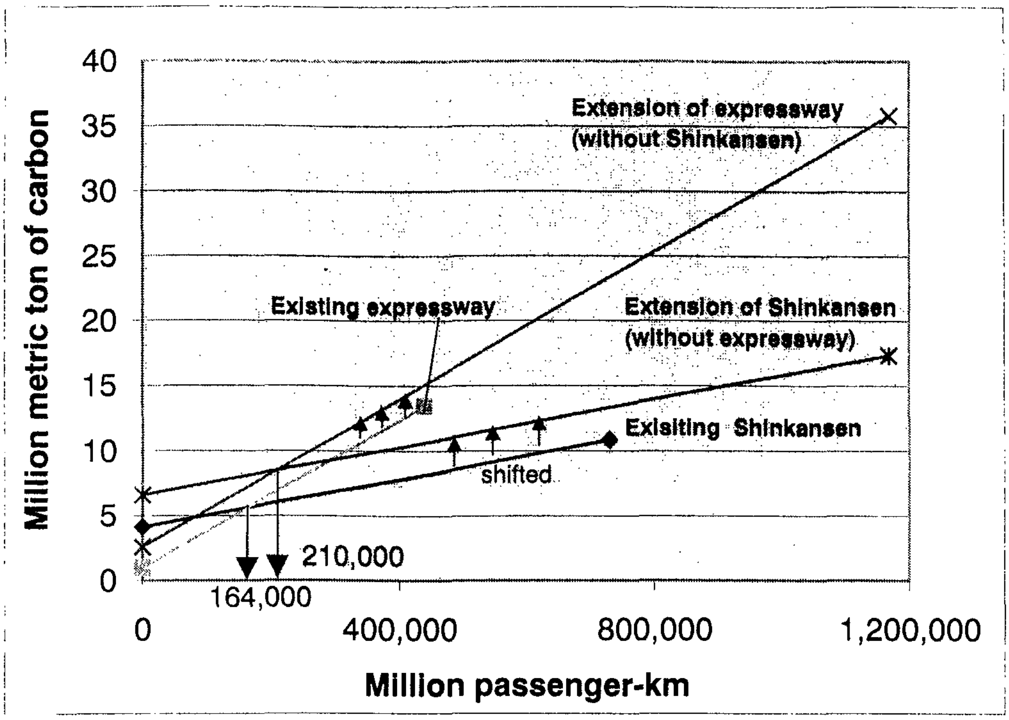

Fig.3 The Extension of the Scale of Expressway System and High-Speed Railway System

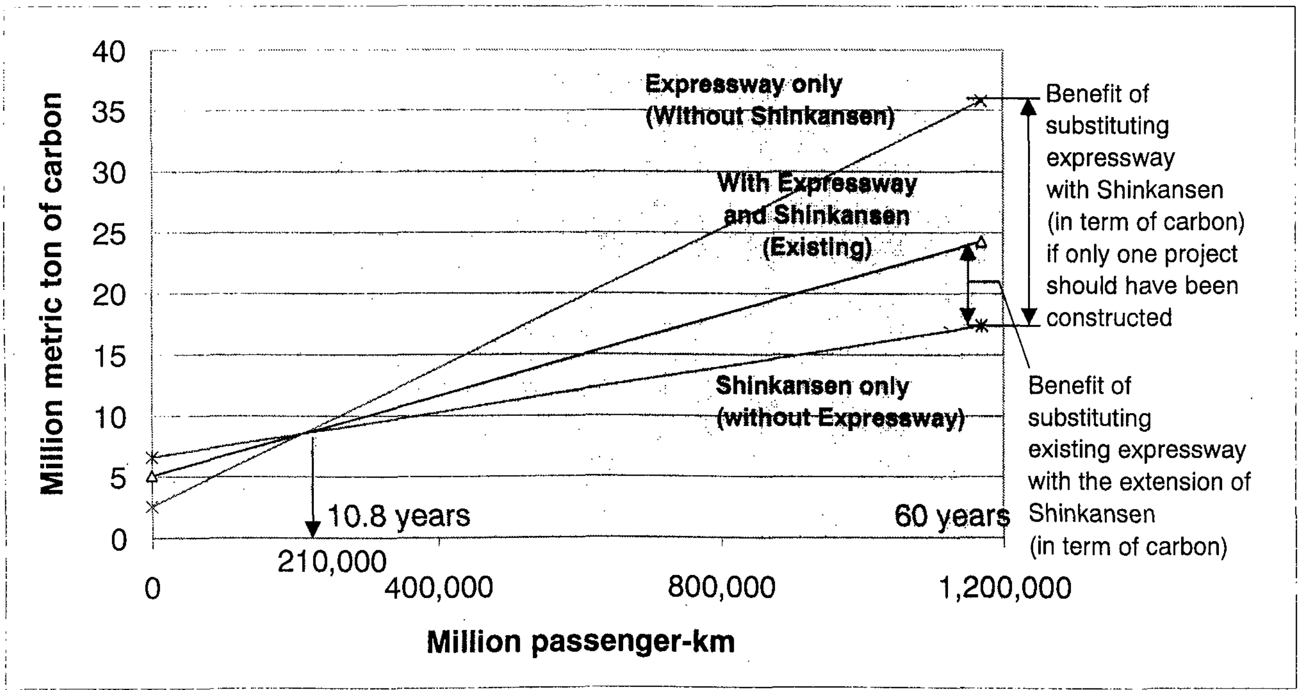

Fig. 4 The Benefit in Term of Carbon of Substituting Tohoku Expressway with Tohoku Shinkansen

論文審査の結果の要旨

交通システムは自動車や車両といった財およびその運用・走行のみならず、道路や鉄道、駅といった施設の建設、運用、維持、管理などを含む巨大かつ総合的なシステムである。現在、世界的に問題となっている炭酸ガスの増加による地球温暖化問題の鍵の一つを握っているのがこの交通システムである。従来からペットボトルや自動車といった財に関しては、その製造から廃棄までに排出されるガスを評価する、いわゆるライフサイクルインベントリー分析（ＬＣＩ）が数多くなされてきた。また交通分野においても自動車と鉄道の運用時におけるエネルギー効率の比較研究は多い。しかし、この巨大な交通システム全体の誕生から廃棄まで含むＬＣＩ研究は困難であるとされてきた。本研究はハイブリット型産業連関分析という新しい枠組みを導入して交通システム全体のＬＣＩ分析を提案したものである。また、生産構造の時系列変化による影響を構造分解分析により明らかにしている。更にモデルを東北自動車道と東北新幹線に適用して比較分析を行ったものであり、全６章からなる。

第１章は序論である。

第２章は従来研究のレビューである。過去のＬＣＩ研究の多くは財の製造、販売、使用、廃棄のプロセスを詳細に追跡するプロセス分析法によるものであった。プロセス分析法は製造段階におけるエネルギー投入等、環境に対する影響を詳細に追跡できる一方、取得されたデータに結果が大きく依存する、システムバウンダリーの設定が任意である等、多くの問題・限界があることを指摘している。

第３章では、ハイブリット型産業連関分析の枠組みを使ったＬＣＩ分析手法を提案、それを東北自動車道プロジェクトに適用し、その有用性を確認している。従来のエネルギー消費量予測において誤差発生の最大の要因は産業部門ごとのエネルギー購入価格の相違である。本研究ではこの影響を避けるため物理量単位を金銭単位取引と混在させたハイブリッドＩＯモデルによって解決している点が非常に高く評価される。また、405 産業部門という膨大なデータ処理によって東北自動車道がその建設開始時期から６０年間で発生する炭酸ガス量を詳細に推計したことは大きな成果である。

第４章では産業連関システムの構造分解分析による時系列産業構造変化、技術進歩の影響を分析している。高速道路の建設工事という複合的プロジェクトを建設業の投入構造変化（技術進歩）と他産業（鉄鋼業、セメント産業等）の構造変化と分離して環境影響を評価する試みはもちろん世界で初めてであり、社会的にも学術的にも大きな業績といえる。分析の結果、橋梁工事、舗装工事において大きな技術進歩があり、土工工事においては他産業（セメント、輸送産業）の技術進歩によって排出量が減少したことが明らかとなったのは実務的な大きな成果である。

第５章はＬＣＩ分析による東北自動車道と東北新幹線の環境影響分析である。高速道路は現状を前提とすれば建設後３０年の間は新幹線より炭酸ガス排出量が少ない。しかし、旅客交通量を等しいと仮定すれば、その期間は１１年に縮小する。この分析の結果は意外なものであり、非常に興味深い。第６章は結論である。

以上要するに本論文はハイブリット型産業連関分析という新しい枠組みを導入して交通システム全体のＬＣＩ分析を提案し、環境分析の分野に有用な知見を与えたものであり、土木計画学および経済学を含む情報科学の学際分野の発展に寄与するところが少なくない。

よって、本論文は博士（学術）の学位論文として合格と認める。