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# A LIFE CYCLE ASSESSMENT FOR EVALUATING ENVIRONMENTAL IMPACTS OF INTER-REGIONAL HIGH-SPEED MASS TRANSIT PROJECTS

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**Abstract:** Most of the existing Life Cycle Assessment (LCA) research in the field of transport is ex-post evaluation. This paper proposes an LCA method in the planning phase for evaluating life cycle carbon dioxide (LC-$CO_2$) emission from the provision of modal railway systems. As a case study, the Superconducting MAGnetically LEVitated (MAGLEV) transport system is examined. The LC-$CO_2$ emission factors with standard infrastructure are introduced in the inventory analysis for the LC-$CO_2$ emission. The change in LC-$CO_2$ emission by shifting from the existing inter-regional transport mode (ordinary railways, airplanes and motor vehicles) to the MAGLEV are analyzed by the Extended Life Cycle Environmental Load (ELCEL) concept. An environmental efficiency index considering speed and capacity is also defined and the alternative transport system evaluations are conducted.

**Key Words**: Life cycle assessment (LCA), Environmental load, Transport infrastructure provision

## 1. INTRODUCTION

Due to increasing concerns about global and local environmental problems, improvement of railway systems is preferred for their lower environmental load in operational conditions. However, there are few examples in which their effects were quantitatively inspected. Even though such effects were proven, the basis and method of estimation were rarely clarified.

This study aims at developing a method which quantitatively evaluates carbon dioxide ($CO_2$) emission generated by railway system projects on the basis of Life Cycle Assessment (LCA). The method is applied to the "Chuo-Linear-Shinkansen project" in Japan, the Superconducting MAGnetically LEVitated (MAGLEV) transport system planned between Tokyo and Osaka within one hour at a maximum operating speed of 500km/h. $CO_2$ emission related to the construction of railway infrastructure and the production of vehicles are calculated. The change in $CO_2$ emission caused by a shift from other transport modes, and a comparison between the Superconducting MAGLEV system and alternative transport systems, are analyzed. Also, an environmental efficiency index considering service level of each transport mode is defined and applied to the comparison of alternative transport modes.

## 2. METHODOLOGY OF LIFE CYCLE ASSESMENT IN THE FIELD OF TRANSPORT

### 2.1 Life Cycle Assessment (LCA)

LCA is a method to quantitatively assess the impact of environmental load from a product or service throughout its total life cycle. LCA is standardized by the ISO 14040 series guidelines as illustrated in Figure 1 and has been broadly used as the method to assess the environmental friendliness of a product or service, and as the tool to show corporate social responsibility toward environmental awareness and action (Imura, et al, 2001).
Many applications of LCA to the transport sector have been conducted (Kato, 2001, 2004). LCA research about the Shinkansen was examined by Railway Technical Research Institute (2002) and by Inamura et al (2002). This research has focused not on future analysis but on ex-post evaluation. There are several problems to be solved for the prior evaluation as described later. However, it is important for the provision of environmentally friendly transport systems to develop and apply the prior evaluation by LCA, and this study intends to demonstrate this method.

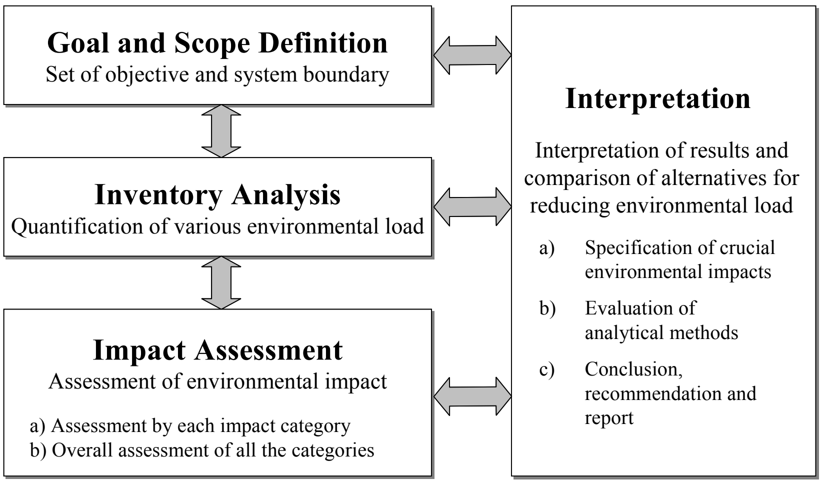



Figure 1. The Process of LCA Standardized by ISO 14040's

### 2.2 Life Cycle Inventory Using "Standard Infrastructure Models"

For Inventory Analysis (qualification of each environmental load emission), all the inputs and outputs of each life cycle phase of an object have to be investigated. These aggregations were examined in the existing LCA research. However, there are few detailed data with the design of the Chuo-Linear-Shinkansen project, where even specific routes have not yet been determined.

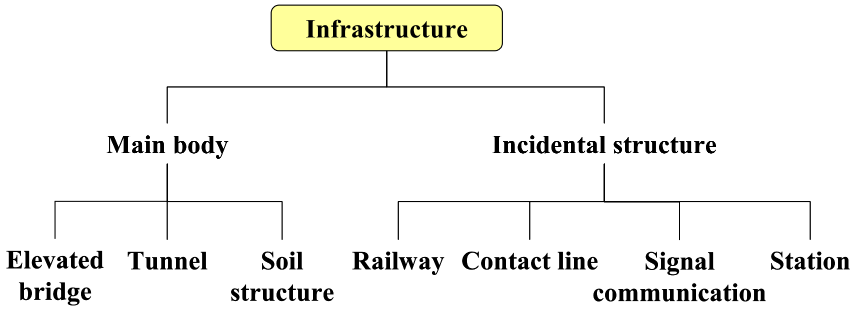



Figure 2. The Decomposition of Infrastructure of the Superconducting MAGLEV

Then, this study applies the "Hybrid LCA method". First, transport infrastructure is decomposed into many basic parts as shown in Figure 2. On the other hand, the standard infrastructure models are defined to each basic part from which it is possible to evaluate the life cycle environmental load. This approach is general for the application of LCA in the field of construction (Imura, et al, 2001). As for the railway system, the life cycle $CO_2$ emission factors of each decomposed part have already been provided by ITPS and Japan Railway Construction Public Corporation (2002, 2003). These emission factors are calculated from the combination of embodied $CO_2$ emission estimated by input/output analysis with basic materials and energies (such as steel, concrete and oil) and the accumulation of basic materials and energies inputted in the total life cycle process.

### 2.3 Setting System Boundaries

Within the environmental assessment of railway systems, both the construction of infrastructure and the production of trains have to be examined because they generate environmental load throughout their lifecycle. Since both of them should not be assessed separately due to the reason why this way does not consider the interaction, they need to be

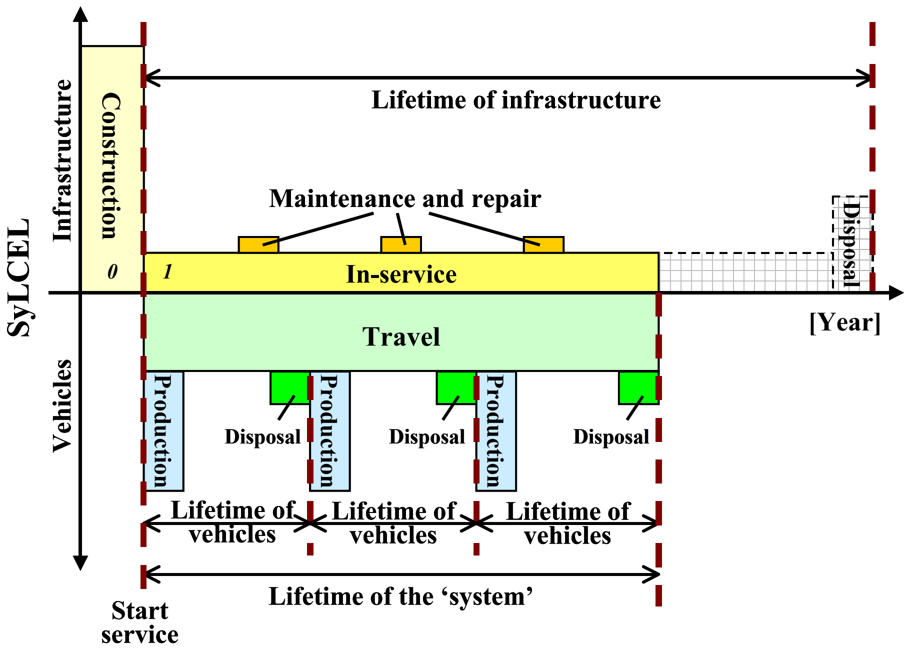



Figure 3. The Life Cycle Environmental Load Emission Superconducting MAGLEV System

assessed in a comprehensive manner as described in Figure 3. In this study, the environmental load evaluated by this holistic approach is defined as System Life Cycle Environmental Load (SyLCEL).

Furthermore, the assessment of the infrastructure system, unlike that of individual manufacturing products, may require extending the system boundary to the level that can account for spillover effects. In the case of transport infrastructure provision, the direct changes in modal share and traffic assignment need to be considered. Moreover, it indirectly leads to the change of the regional traffic situation, life-style of local residents and land use. As a result, environmental load from the regional human activities is supposed to be changed. In a big project as the Superconducting MAGLEV, the spillover effect may stretch across the nation.

In order to grasp this spillover effect theoretically and comprehensively, the application of the methodologies, such as input-output analysis and the computable general equilibrium (CGE) model, is useful. However, it is not possible to apply these methodologies in the practical assessment of one railway project because of constraints on model and data acquisition. Provided that the application of these methodologies would be possible, it is unlikely to consider a variety of alternatives that take account of the change of routes or construction methods. It is also most likely that the more the system boundary is extended, the less the accuracy of the assessment would be. Consequently, this makes the aggregation of each part of railway infrastructure less beneficial.

Therefore, this study employs an extended system boundary of the railway system that is limited to its SyLCEL and the direct change of the share of alternative transport modes, as illustrated in Figure 4. The life cycle environmental load obtained by this system boundary is defined as "Extended Life Cycle Environmental Load" (ELCEL), which was proposed by

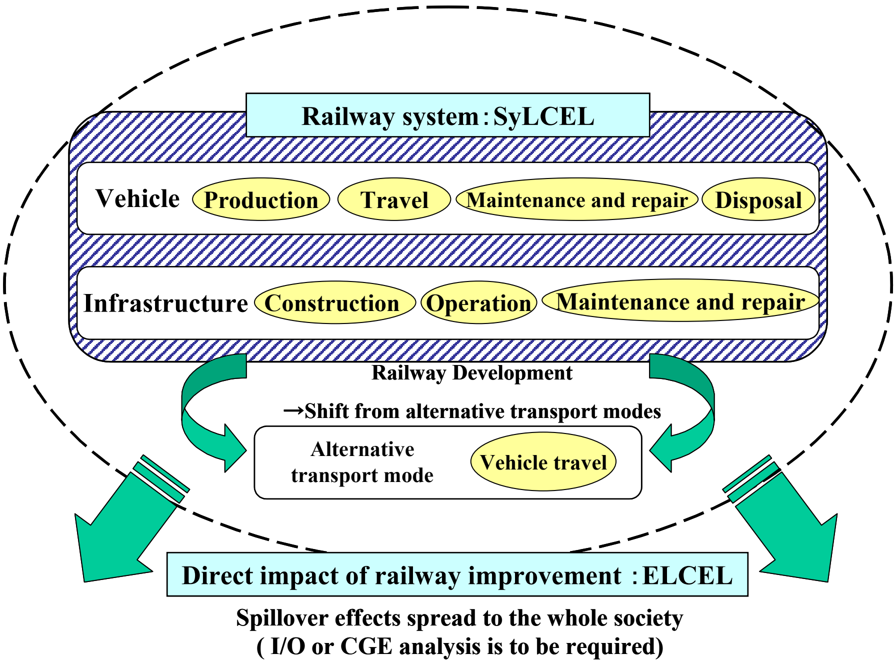



Figure 4. The Change of Environmental Load with the Provision of the Superconducting MAGLEV System

Kato (2001). ELCEL of the railway system is illustrated as Figure 4. In this case, the changes in modal share and the traffic situation need to be considered.

### 2.4 The Environmental Efficiency of Railway System

In the final stage of ISO-LCA, or Interpretation stage, the results from Inventory Analysis and Impact Assessment are explored and compared, depending on the designed alternatives. The ISO-LCA recommends the assessment "per functional unit" because simply comparing absolute values results in only the assessment from the viewpoint of the environment. In this context, the concept of the environmental efficiency has been recently adopted as an index for the Interpretation stage. In the case of industrial products, the environmental efficiency index is generally denoted by the Equation (1).

$$\begin{aligned} EnvironmentalEfficiency &= \frac{Performance\ of manufacturing\ goods}{Lifetime\ environmental\ load} \\ &= \frac{Duration \times Function}{Lifetime\ environmental\ load} \end{aligned} \qquad \text{.......(1)}$$

Equation (1) can not be recognized as the negative variable in which reducing environmental load is the only way to solve environmental issues but as the positive variable in which technological progress is proactively embraced. Referring to this definition of an environmental efficiency index, Tsujimura (2001) applies transport capacity and the amount of time required to a performance index as an environmental efficiency index for Shinkansen vehicles, as described by Equation (2).

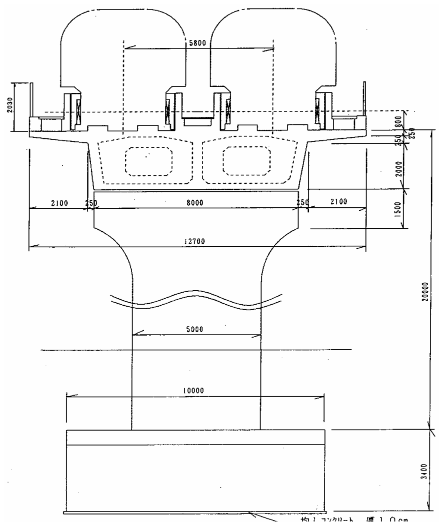
$$\begin{matrix} Environmental\ efficiency \\ of\ trains \end{matrix} = \frac{\dfrac{Seats \times Life\ travel\ distance}{Amount\ of\ time\ required}}{Lifetime\ environmental\ load} \qquad \text{.......(2)}$$

In the case of the railway system, transport volume needs to be used rather than transport capacity as the functional unit of an environmental efficiency index. For this reason, environmental efficiency of a railway system is defined as Equation (3).

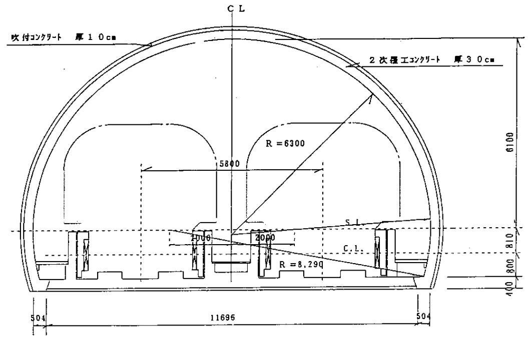
$$\begin{matrix} Environmental\ efficiency \\ of\ railway\ system \end{matrix} = \frac{\dfrac{Aberage\ number\ of\ person\ carried \times Life\ travel\ distance}{Amount\ of\ time\ required}}{Lifetime\ environmental\ load} \qquad \text{.......(3)}$$

Transforming the numerator, or the performance of the railway system, the equation would be further converted as Equation (4). It is interpreted that the performance is proportional to transport volume and speed.

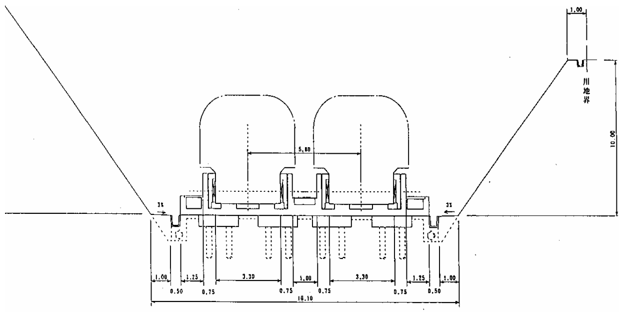
$$\begin{aligned} Performance &= \frac{[person / train \times service] \times [train \times km]}{[h / service]} \\ &= \frac{[person \times km]}{[h]} \\ &= [person] \times [km / h] \qquad (transportvolume \times velocity) \end{aligned} \qquad \text{.......(4)}$$



(a) Elevated bridge (Rigid Frame)



(b) Tunnel (Mountain Tunnel)



(c) Soil Structure (Cutting)

Figure 5. Some Examples of Standard Main Bodies

Table 1. Life Cycle $CO_2$ Emission Factors of Standard Main Bodies (Lifetime: 60 years)

| Type of structure | Construction | Maintenance and Repair |
|---|---|---|
| Elevated Bridge (Rigid frame) [t-C/km] | 3,680 | 120 |
| Tunnel (Mountain Tunnel) [t-C/km] | 5,310 | 210 |
| Soil Structure (Cutting) [t-C/km] | 1,940 | 90 |

## 3. STANDARD STRUCTURE MODELS AND ITS EMISSION FACTORS

This study covers only $CO_2$ as one example of environmental load. Impact Assessment of the standardized processes of LCA is not examined in this study. Life Cycle $CO_2$ emission (LC-$CO_2$) is used as a representative evaluation index.

### 3.1 Main Body of Infrastructure

Standard sections are abstracted from the MAGLEV test line in Yamanashi Prefecture as illustrated in Figure 5. Although the specific amount of materials and machineries for Inventory Analysis is not obvious, it can be assumed that the same construction method is executed at the construction and maintenance stage due to the fact that the infrastructure of the Superconducting MAGLEV is almost the same size as that of the Shinkansen. Therefore, the estimation of environmental load at the construction phase is examined in proportion to the size of the section of Shinkansen, referring to the results estimated by ITPS and Japan Railway Construction Public Corporation (2002). Similarly, the estimation of environmental load at the maintenance stage is explored on the basis of the findings of RTRI (2002) that the environmental load at the maintenance phase accounts for 3 to 7 % of that at the construction phase. Table 1 shows the results of LC-$CO_2$ emission factor according to each standardized infrastructure part.

### 3.2 Attached Structure

The same method as the main body of infrastructure can not be applied to attached structures due to the reason that many of the parts are peculiar to Superconducting MAGLEV.

**(a) Railway-track**

Railway-track of Superconducting MAGLEV is composed of U-shaped structure and ground coil attached to its sidewall. Since the amount of coil inputted is enormous, it is supposed that the amount of $CO_2$ emission at the production phase is not negligible. Its weight and material, however, have not been disclosed. This study estimates embodied $CO_2$ from railway construction as 190 [t-C/km], referring to the published data of copper coil available from the Miyazaki test line. Also, this study ignores the $CO_2$ emission from railway-track at the maintenance phase, for embodied $CO_2$ emission from the Superconducting MAGLEV is thought of as much lower than that from Shinkansen. It is because the inherent characteristic of Superconducting MAGLEV, or levitating travel, leads to much less frequency of rail replacement than the Shinkansen.

**(b) Overhead Wire, Signal System**

Overhead wires and poles do not exist because electric current is applied to the ground coil in the case of Superconducting MAGLEV. Instead, it is necessary to facilitate the cables intended to supply current into the ground coil. As for the signal system, the setting of some cables is actually prepared. This study, however, ignores the effects attributable to the signal system since practical examples of other railway systems show the insignificance of this matter.

**(c) Stations**

Nothing has been determined with regard to the specification of stations. In the case of the Yamanashi test line, platform doors are set up at berths. On this basis, it is presumed that the overall structure of actual line would be similar to that of the Yamanashi test line. Taking account of the similarity and a wide variety of additional facilities, the embodied $CO_2$ emission of the station of the Superconducting MAGLEV is set as 2,430[t-C/station], 10% greater than that of the Shinkansen.

### 3.3 Production, Maintenance and Disposal Stages of Trains

As well as other parts of infrastructure, few detailed data with regard to trains are available in the actual state. According to Tsujimura (2001), the embodied $CO_2$ emission from Shinkansen vehicles at the production stage, the maintenance phase and the disposal phase are as 150[t-$CO_2$/train], 95[t-$CO_2$/train] and 0.62[t-$CO_2$/train], respectively. Besides, the costs of trains of the Shinkansen and the Superconducting MAGLEV are expected as 40 billion [yen/train(16cars)] and 12.8 billion [yen/train(16cars)], respectively. This study assumes that the amount of $CO_2$ emission is proportional to the cost of each train. The embodied $CO_2$

emission factors estimated from trains by each life stage are shown in Table 2.

Table 2. $CO_2$ Emission Factors of Trains by each Life Stage (Lifetime: 20 years)

| Life Cycle Stage | Production | Maintenance and repair | Disposal |
|---|---|---|---|
| $CO_2$ emission [t-C/train] | 2,100 | 1,300 | 8.7 |

### 3.4 Running Stage of Trains

Table 3 shows the values of $CO_2$ emission generated from travel between Tokyo and Osaka by each transport mode. According to the table, the ratio of Shinkansen, Superconducting MAGLEV to airplane is 1:3:9. The process of estimation is as follows.

Table 3. $CO_2$ Emission Factors in Running by each Transport Mode

| Transport mode | $CO_2$ emission [g-C/person·km] |
|---|---|
| Superconducting MAGLEV | 11.7 |
| Shinkansen | 3.9 |
| Ordinary Railway | 5.0 |
| Airplane | 34.0 |
| Passenger-car | 31.7 |

**(a) Superconducting MAGLEV**

Electric power consumption by the Superconducting MAGLEV is affected by various elements relating to vehicles and supply side of electricity, and the linear shape of routes to operational conditions. There are no other ways to estimate electric power consumption arising from the Superconducting MAGLEV except the experimental data obtained in test lines (RTRI, 2002). The electric power consumption would be 90[Wh/seat·km], given that the operating speed is approximately 500[km/h]. This study employs the estimated values and further estimates travel distance, capacity and carrying efficiency as 500[train·km/service], 1000[seats/train] and 80%, respectively.

**(b) Shinkansen Railway (Tokaido Shinkansen)**

The actual results have not been disclosed. According to the simulation of RTRI (2002), $CO_2$ emission of the Shinkansen series 700 traveling between Tokyo and Shin-Osaka is estimated as 6,310[t-C/train(16cars)]. On the basis of this estimated results, this study employs travel distance, capacity and carrying efficiency as 515[train·km/service], 1,323[seats/train(16cars)] and 65%, respectively.

**(c) Ordinary Railways**

The values in "the summary report of the survey on transport-related energy consumption in Japan" (2002) are adopted.

**(d) Airplanes**

According to the hearing investigation into the Japan Airlines Corporation, fuel consumption associated with the flying between Haneda (Tokyo) and Itami (Osaka) is reported as 10,130[liter/plane]. $CO_2$ emission associated with the flying is estimated as 29.2[g-C/person·km] based on the fact that flying distance, capacity per airplane and carrying efficiency are 447[km], 569[seats] and 90%, respectively.

According to the similar hearing investigation into the All Nippon Airways Corporation, fuel consumption resulted from the flying between Haneda and Itami is informed of as 11,095 to 11,198[liter/plane]. $CO_2$ emission can be estimated as 38.8[g-C/person·km], referring to the fact that flying distance, capacity per airplane and carrying efficiency are 476[km], 569[seats] and 65 - 70%, respectively.

In this study, a mean value of these two estimations is applied as $CO_2$ emission attributable to airplanes.

**(e) Passenger-car**
$CO_2$ emission of passenger cars at the travel phase is estimated as 44.4[g-C/car·km] in the case of running at 80[km/h] surveyed by the Bureau of Environment, Tokyo Metropolitan Government. The average number of passengers is assumed to be 1.4[passengers/car].

### 3.5 Operation

Electric power consumption relevant to stations accounts for the majority of $CO_2$ emission at the operation phase. According to ITPS and Japan Railway Construction Public Corporation (2003), the embodied $CO_2$ emission arising from a station on the Shinkansen during the operation phase is estimated as 245[t-C/station·year].

## 4. INVENTORY ANALYSIS OF THE SUPERCONDUCTING MAGLEV PROJECT AND ITS INTERPRETATION

LCA is applied for the Superconducting MAGLEV project by LC-$CO_2$ emission factors of standard models calculated in the chapter 3.

### 4.1 Assumptions

Table 4. Assumptions of Route Length and the Number of Station

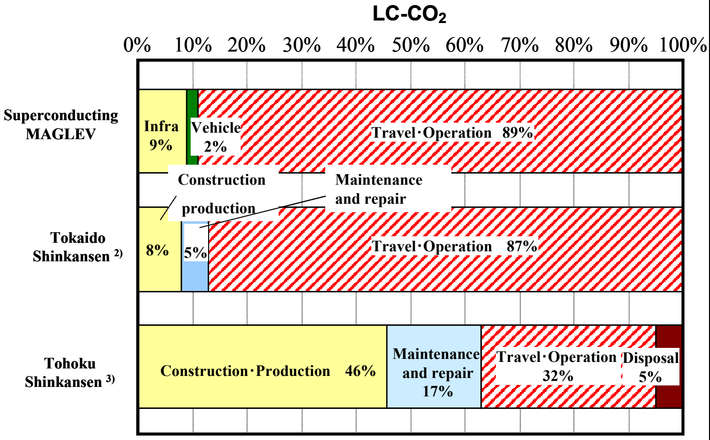
| Elevated bridge | Tunnel | Soil structure | Total | Station |
|---|---|---|---|---|
| 120km | 300km | 80km | 500km | 9 |

The route length of each structural classification and the number of stations are assumed as shown in Table 4 due to the lack of detailed planning data.

The most crucial values estimated are the number of passengers of the Superconducting MAGLEV, and the amount of shift from alternative transport modes. In this study, the medium-estimated values of transport demand in 2020 forecasted in the basic scheme of the Central Linear Shinkansen (Tokida, et al, 2002) can be used. These are shown in Table 5. These values are assumed not to change even after the placement of the Superconducting MAGLEV. Then, 10[services/hour] at maximum and 850[cars] (=53[trains]) will be needed.

### 4.2 Estimated Results of LC-$CO_2$

SyLC-$CO_2$ ($CO_2$ emission evaluated by the boundary of SyLCEL) of the Superconducting MAGLEV system is estimated as 24.6[Mt-C/60yrs], given that the life time of the system is 60 years. The detail values estimated are illustrated in Figure 6. LC-$CO_2$ exhausted at the travel phase accounts for approximately 88%, which is large and indicates the similar trend as the case of Tokaido Shinkansen estimated by RTRI (2002). However, despite the fact that the route extension of the Superconducting MAGLEV is almost equivalent to that of the Tokaido Shinkansen and that the transport capacity of the Superconducting MAGLEV is




| LC-$CO_2$ | | The values set in estimation | |
|---|---|---|---|
| [Mt-C/60yrs] | [g-C/person-km] | Route length [km] | The number of persons carried [100 million person· km/year] |
| 24.6 | 13 | 500 | 306 |
| 12.8 | 5.4 | 515 | 400 |
| 11.4 | 16 | 497 | 122 |

Figure 6. Comparison of SyLC-$CO_2$ between Superconducting MAGLEV and Shinkansen

forecasted as approximately three fourths those of the Tokaido Shinkansen, the SyLC-$CO_2$ of the Superconducting MAGLEV is estimated twice as large as that of the Tokaido Shinkansen. Even in case where the transport capacity is viewed as the passengers·km unit, the SyLC-$CO_2$ of the Superconducting MAGLEV is around 2.5 times larger than that of the Tokaido Shinkansen because of the significant contribution of the $CO_2$ emission at the travel phase. For this reason, how to reduce the emission at the travel phase can be regarded as the critical point for designing an environmentally-friendly system. The alleviation of air resistance is considered as the major factor which will contribute to reducing the emission.

Meanwhile, within infrastructure, the LC-$CO_2$ emission originated from tunnels, that have the large $CO_2$ emission factor and account for 60% of total length, constitutes approximately 69% of the total amount of the emission arising from the infrastructure. This is caused by a large usage of concrete.

### 4.3 Estimation Results of the Change in ELC-$CO_2$

In order to estimate the ELC-$CO_2$ with the Superconducting MAGLEV, it is necessary to estimate the change of $CO_2$ emission with the travel of alternative transport modes. Of the total transportation demand for the Superconducting MAGLEV, two-third is a shift from the existing Tokaido Shinkansen and one-sixth is a shift from other transport modes, based on the results of future demand forecasts. Of the other transport modes, the ratio of airplanes, automobiles, and ordinary railways is set as 1:1:1, referring to the forecast by Tokida et al (2002). The estimated results of ELC-$CO_2$ are as shown in Figure 7. The case where the Superconducting MAGLEV is developed leads to a remarkable increase of $CO_2$ emission which largely exceeds a decrease of $CO_2$ emission at the running stage associated with the shift from alternative transport modes. The gap between the case with the Superconducting MAGLEV and that without it is approximately 0.21[Mt-C/year], or the increase of the case with the Superconducting MAGLEV by 125% in comparison with the case without it.

### 4.4 Comparison with Airplanes

The increase of travel demand by 1.32 times, as shown in Table 5, stimulated by the

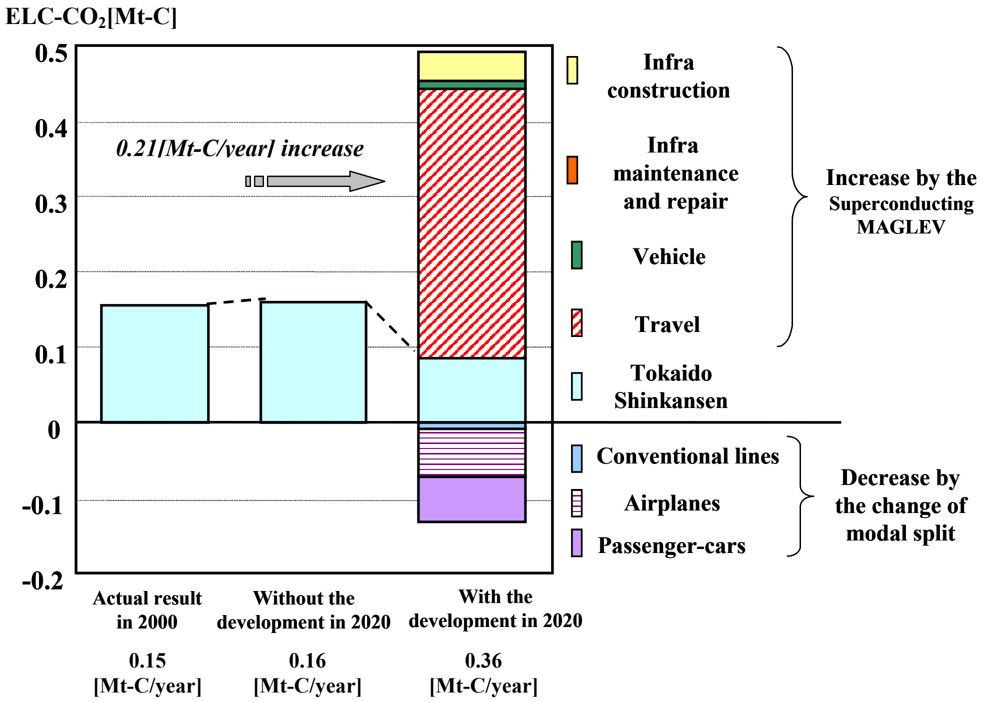



Figure 7. The Change of ELC-$CO_2$ before and after the Introduction of the Superconducting MAGLEV

Table 5. Estimated Transport Demand of Superconducting MAGLEV
(Tokida, et al, 2002, Assumption: Economic growth rate in Japan is 1% per annum)

| 2002 Actual figure | 2020 Without MAGLEV | | 2020 With MAGLEV | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tokaido Shinkansen (100million persons-km) | Tokaido Shinkansen (100million persons-km) | Index (Compared with year 2000) | Tokaido Shinkansen (100million persons-km) | Superconducting MAGLEV (100million persons-km) | Shift from Tokaido Shinkansen (100million persons-km) | Shift from other modes (100million persons-km) | Induced demand (100million persons-km | Total (100million persons-km) | Index (Compared with year 2000) |
| 397 | 410 | 1.03 | 218 | 306 | 202 | 56 | 48 | 524 | 1.32 |

introduction of the Superconducting MAGLEV can also be made possible by the improvement of the level of service of existing transport modes. Provided that the convenience of airplanes is dramatically increased and the airplanes bear the same demand, growth, the overall ELC-$CO_2$ increases by 1.5 times greater than that in which the Superconducting MAGLEV is developed as illustrated in Figure 8.

As for airplanes flying between Haneda and Itami, no examples of LCA have been found, and consequently the detailed data of the construction of the airport and production of the bodies of airplanes are not available. In line with this, this study simply estimates the environmental efficiency by use of the life-cycle emission factor of the environmental load estimated by RTRI (2002) through the method of input-output analysis, or 175[t-$CO_2$/million passengers·km] (system boundary: construction and maintenance of airports, production and repair of airframe, aviation), and the actual record of airplanes put into services, or 41[flight/day].

In addition, this estimation does not consider the increase of ELC-$CO_2$ with the extension of airports and the increase of equipment, whereby leading to a further increase of ELC-$CO_2$. However, there remains a question for recognizing this alternative to be compared because it

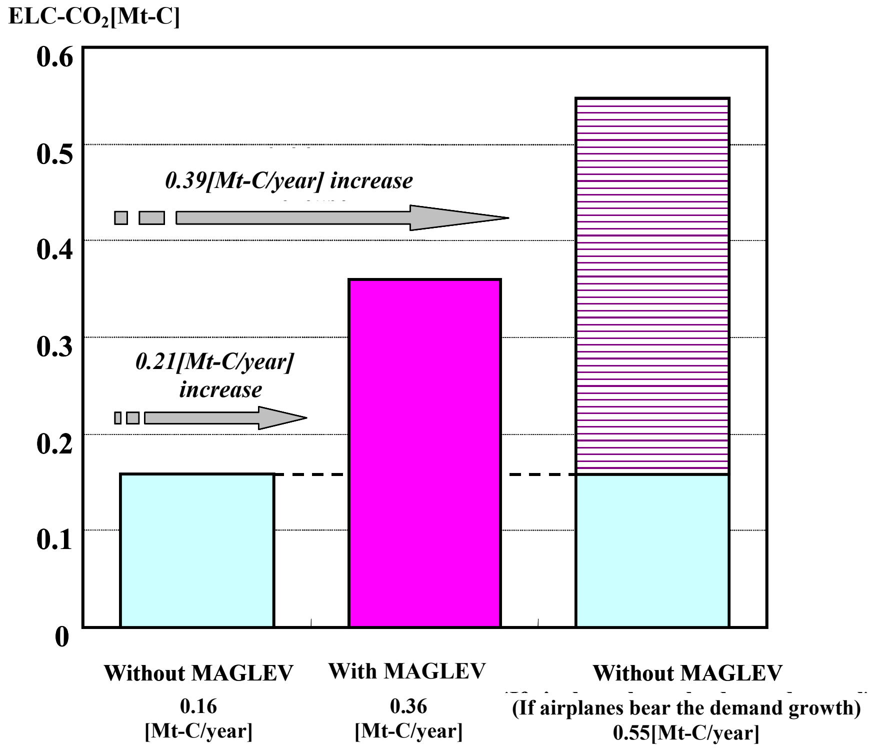



Figure 8. The Change of ELC-$CO_2$ when the Growth of Transport Demand is borne by Airplanes

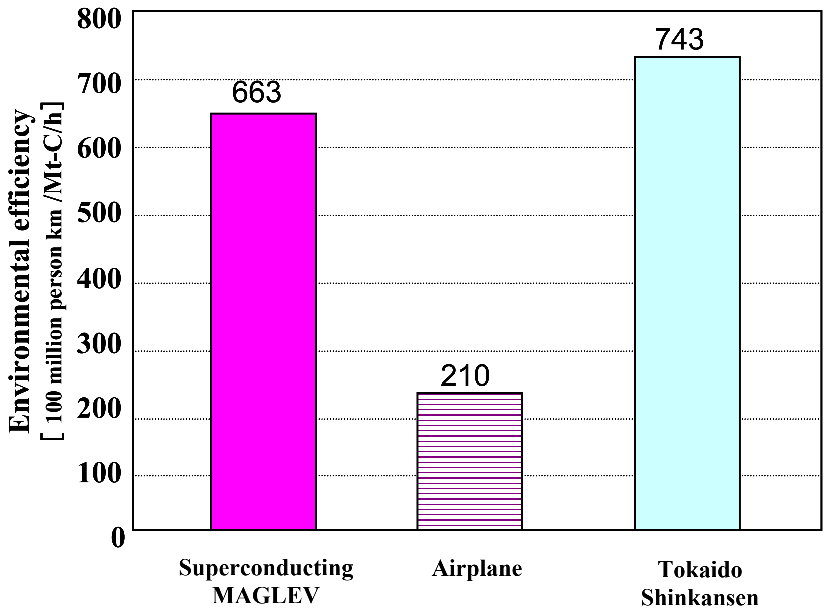
is highly unlikely to assume that this alternative is realized.

As described above, assuming the cases "what if the project is not undertaken" as alternatives is called the assessment under the "baseline". The change of environmental load due to the implementation of the project can be determined as the gap between the environmental load of the "baseline" and that in which intended activities are implemented. However, to be setting "baseline" and interpreting the results is sometimes arbitrary. This is one of the important discussions in LCA applied to the transport sector.

### 4.5 Environmental Efficiency of Alternative Transport Modes

In order to compare the results evaluated by each functional unit, the environmental efficiency index defined in Equation (3) is applied here. There are several alternative transport modes between Tokyo and Osaka. The Superconducting MAGLEV, the Tokaido Shinkansen and airplanes are covered. The assumption and results of each alternative mode are shown in Figure 9. ELC-$CO_2$ of the Superconducting MAGLEV is twice as great as that of the Tokaido Shinkansen. However, the environmental efficiency of the Superconducting MAGLEV is estimated as nine tenths of that of the Tokaido Shinkansen. As for airplanes, the amount of time required is equal to that of the Superconducting MAGLEV, and ELC-$CO_2$ of airplanes is greater than that of the Tokaido Shinkansen. Capacity is approximately one-third that of the Tokaido Shinkansen. It results in the lowest efficiency of airplanes in the alternative modes.

## 5. CONCLUSIONS




| | Superconducting MAGLEV | Airplane | Tokaido Shinkansen |
|---|---|---|---|
| The number of seats [persons] | 1,000 | 506 | 1,323 |
| Carrying efficiency [%] | 80 | 75 | 65 |
| Life travel distance [100 million km] | 20.4 | 8.7 | 27.7 |
| LC-$CO_2$ [Mt-C/60yrs] | 24.6 | 15.7 | 12.8 |
| Amount of time required [h] | 1.0 | 1.0 | 2.5 |

Figure 9. The Comparison of Environmental Efficiency by Alternative Transport Modes between Tokyo and Osaka

This paper proposes an LCA method in the planning phase for evaluating LC-$CO_2$ from the provision of modal railway systems. As a case study, the superconducting MAGLEV system is examined. SyLC-$CO_2$ of the Superconducting MAGLEV system is estimated as an example of inter-regional railway projects. The change in $CO_2$ emission by shifting from alternative existing transport modes is comprehensively evaluated by using the ELCEL concept. The main findings are as follows:

1) SyLC-$CO_2$ of the Superconducting MAGLEV accounts for approximately 24.6[Mt-C/60yrs]. This value is equivalent to that generated in the entire Aichi prefecture throughout one year.
2) Approximately 90% of the SyLC-$CO_2$ is generated at the running stage. For this, technological progress for low electricity-consuming trains is desirable.
3) A remarkable increase of $CO_2$ emission with the provision of the Superconducting MAGLEV largely exceeds a decrease of $CO_2$ emission with the shift from alternative transport modes.
4) The environmental efficiency which considers performance of the Superconducting MAGLEV, is almost at the same level as the Shinkansen.

For the future, the following issues should be considered: a) further investigation of the environmental efficiency indices; b) consideration of technological innovations during life time; c) investigation on estimation errors resulting from the application of the standardized model; and d) an inventory analysis of various environmental loads and its integrated evaluation.

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