B-55 Studies on evaluation of transport systems on environmental efficiency and promotion of transport systems suitable for the traffic demand (Abstract of the Final Report)

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1.Introduction

Carbon dioxide (CO_2) emission in transport sector occupies about 20% in Japan national CO_2 emission and shows a great increase, while other sectors are stable or slightly increasing. In developing countries such as countries in Fareast and/or South-east Asia, the CO_2 emission in transport sector is rapidly increasing because the motorization is making more progress. In order to reduce CO_2 emission to meet the Kyoto Protocol, it is indispensable to reduce the emission from the use of motor vehicles, which occupies about 80% to 90% in transport sector. For this purpose, high efficient vehicle technologies and/or public transportation technologies are needed to apply inside and outside of Japan so as to meet local traffic demand.

2.Research Objective

This research project consists of four parts. The first one is "Studies on evaluation of environmental efficiency of vehicles and promotion of measures to meet the traffic demand". In this part, transport systems are evaluated using life cycle assessment from the viewpoint of fuel life cycle, that is, well-to-tank and also life cycle of a product. The relationship between local characteristics and energy consumption for the transport of passengers and freights are investigated and economic measures will be assessed.

The second part is "Study on the measures to decrease the gross energy consumed in the transportation sector". This part mainly aims at developing test procedures for new vehicle like hybrid vehicles (HEVs), which will be just in the step to become widespread, as a leader of high efficient and low pollutant vehicles.

The third one is "A study on the reduction of the environmental impacts due to transportation by introducing new-type low fuel consumption buses". In order to cope with the global warming concerned with motor vehicles effectively in a short term, it is an important task to induce passengers from private cars to public transportation. Buses are considered to be one of the most appropriate ways to meet transport demand of passengers and freights without special infrastructures. It is necessary to consider a suitable new power system for transit buses and to estimate the CO_2 reduction effects by introducing the new type buses into urban traffics.

The last one is "The application of the environmental friendly transport system to the Asian countries". The demand for introducing environmental friendly transport systems to Asian countries will be investigated. Regarding the Beijing in China as an example, the transportation requirement in near future will be analyzed and its potential of CO_2 reduction and energy saving will be examined.

3.Research Method and Result at each part

3.1. Evaluation of environmental efficiency of vehicles and promotion of measures to meet traffic demand

In order to evaluate life cycle environmental burdens both directly and indirectly related to vehicles, the relationship between available primary energy and its path of energy flow until they are fueled to vehicles are investigated by literature search. At the same time, a model was made to evaluate well to wheel analysis of vehicles and make handling the data of energy conversion process included in each path of energy flow easily, which strongly depend upon the assumed technologies and social or geographical factors and therefore the data for the process are wide-ranged. By utilizing this model, a Japanese, North American and European well to wheel analysis was made. Calculated results indicate that (a) high efficiency of pure hydrogen fuel cell vehicles (FCV) and fuel cell hybrid vehicles (FCHEV) could be expected, (b) conventional fuel have got high efficiency at well to tank stage, whereas well to wheel efficiency of internal combustion engine vehicles would drop down because of their low tank to wheel efficiency, and (c) although it depend upon efficiency of fuel processors (FP), FCV or FCHEV of gasoline FP vehicles could be expected to have the highest efficiency among all. Because of the availability of data, the developed model can now only evaluate energy efficiency and greenhouse gas (GHG) emissions. However, since the model can be extended and applied to air pollutants such as NOx and PM, the model can be expected to evaluate comprehensive well to wheel analysis.

Secondary, as a preparation to estimate the effect of measures which are different corresponding to the regional characters, the trip energy which reflects regional characters was calculated. It was revealed that the modal share of pedestrian and bicycle is large and trip energy is small in the high density area. Through reviews and interviews on the integration of land use and transport, it was confirmed that environmentally sustainable transport would not necessarily be bound for homogeneous city area and that the effective integration of land use and transport should be considered so as to reflect regional characters in the multi spatial scales. From the viewpoint of the accessibility to parking and bus/tram-stop which is one of the important factors of the modal choice, it was shown quantitatively that population living in the area from which people could walk easily to the stop would increase by improving the location of the stop on the street. Continuously, the shapes of public transportation systems which meet the transportation demands in Beijing, where number of vehicle holding is drastically increasing according to China's significant economic growth, and their applicability are examined.

However, in examining countermeasures to reduce carbon dioxide emission in order to comply with the Kyoto protocol and to mitigate local environmental degradation, an integrated evaluation system based on a certain standard is required. Based upon this concept, a quantitative evaluation system for the environmental influences of the countermeasures to change transport systems was developed. The main concept is "Extended Life Cycle Environmental Load (ELCEL)" which extended the evaluation range from the LCA to the ripple effects to the whole transportation system in order to estimate quantitatively the change and effect of environmental load accompanied with new construction of transportation facility. According to ELCEL concept, a methodology for evaluating transportation system is described. This research also introduces a the simplification technique of LCA using standard emission coefficient, considering that required specific data cannot be obtained in the construction phase of transport infrastructure. This methodology is applied to evaluate a) urban and b) intercity passenger transport as case studies.

a) Urban passenger transport:

This case study, comparing subway, light rail transit (exclusive/combined use orbit), bus, and car, shows that 1) it cannot be eliminated generating emissions with construction and maintenance, that is smaller than reduction of emissions accompanied with shifting to railway transport, 2) reduction of emissions with subway construction requires over about 30,000 [population/day and one way] demands, 3) it can reduce emissions only if sectional total transport demand is small and rate of conversion is large, 4) environmental load increases if the car speed falls largely with combined usage of orbit.

b) Intercity passenger transport

This case study, focusing on transport between Tokyo and Osaka, compares construction of magnetically levitated train named "Maglev Chuo Shinkansen" with other options such as Shinkansen, air transport, and highway (bus and car). It was shown that 1) environmental load with Shinkansen is rather small, and environmental load with "Maglev Chuo Shinkansen" is about three times more than that of Shinkansen, and environmental load with air transport is nine times more than that of Shinkansen, 2) life cycle environmental load accompanied with construction of "Maglev Chuo Shinkansen" might be three times more than that of Shinkansen, 3) and it does not exceed when its level considering improvement of convenience.

3.2. Development of test procedures for new vehicles

In Japan, most of HEVs on the market have no recharging function, and they will be very close to conventional internal combustion engine vehicles (ICEVs). These HEVs will be tested the similar way as conventional ICEVs, but have difficulties due to rechargeable energy storage system (battery). Certain quantity of battery energy will be consumed for propelling the vehicle, and contrary, certain quantity of energy from fuel will be spent for recharging the battery. So, change of state of charge (SOC) of the battery during test period affects the resultant fuel consumption data, and it is important to find the way to cancel this SOC change.

Effect of energy from or to on-board energy storage system makes it difficult to evaluate the fuel consumption of the HEVs, and effect of intelligent re-generative brake also makes it difficult to evaluate the actual regenerative energy by scheduled driving test on conventional 2WD chassis dynamometer system. Final target of this study is to find the uniform test procedure that is independent on system configuration of the test HEVs and/or driving schedule for testing.

Fuel consumption test similar to the conventional one for ICEVs was performed experimentally to clarify the accuracy degrading factors, using the HEVs on the market and CHassis DYnamometer (CH-DY)developed to evaluate electric vehicles. CH-DY is set 4WD mode to simulate regenerative brake behavior in on-road use and to enable the traction control function or ABS function of the tested vehicle.

Concerning the fuel consumption in gasoline only mode (FC_0), in mixed (gasoline and electric) mode (FCm) and SOC variation at the end of the mode test, we introduce eq. 1.

$$FCm = FC_0 + (V/\gamma)(\beta/\alpha)(\Delta SOC/L) \qquad (1)$$

where, α, β : vehicle efficiency in gasoline mode, electric mode , V : system voltage, γ : volume energy density of gasoline, L : distance traveled.

Assuming that several scheduled driving tests are conducted and data sets of fuel consumption vs. power consumption are obtained as the test results, points of the measured (power consumption, fuel consumption) will be distributed on the line defined by Eq. 1. Equation 1 shows that gradient of Eq. 1 is in proportion to β/α, namely to the ratio of electric mode efficiency and engine mode efficiency.

It also shows that y-axis-crossing value indicates resultant fuel consumption without RESS (rechargeable energy storage system, battery etc) effect.

Linear regression method needs data sets of *FCm* and ΔSOC at various ΔSOC values. Figure 3.2.2 shows the result of base test performed by setting initial SOC to wide range, so that fuel consumption corresponding to various ΔSOC can be obtained. In Fig. 3.2.2 resultant fuel consumption has a tendency to be worse in both low and high ΔSOC situations. Over charged or over discharged initial SOC lead unexpected vehicle condition. So, test should be performed within proper initial SOC so that obtained data has enough linearity. But "proper initial SOC" or acceptable ΔSOC range will not clear without enough number of data or design information of test vehicle. This is the first problem to be solved.

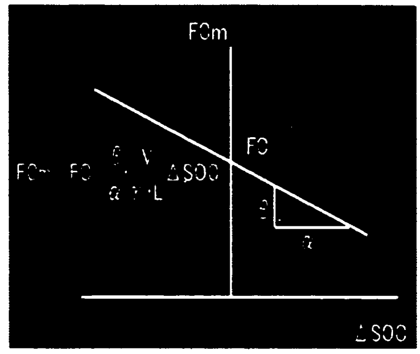

Fig.3.2.1 Effect of ΔSOC

Another main facts obtained in this study are as follows:

a. Ratio of fuel consumption to Δ SOC depends on the test mode. ΔSOC/km is better scale independent to test mode.
b. Result of cold start test in some driving schedule have notable error. Accuracy can be improved by dividing each time history data into several blocks corresponding to warm-up level and calucurating the average consumed fuel in each blocks.

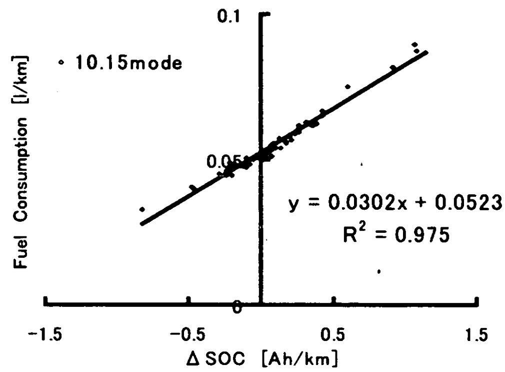

Fig.3.2.2 Linearity of fuel consumption data on ΔSOC

c. Some intellegent brake system needs test on chassis dynamometer for 4WDs.
d. In actual test, resultant data have to be obtained by small number of mode tests. The procedure to evaluate each data sets and the procedure to estimate the accuracy of obtained fuel consumption data are proposed.

3.3. Reduction of the Environmental Impacts due to Transportation by Introducing the New-type Low Fuel Consumption Buses

The "Dual-mode power system", that is the electromotive system supplied by a on-board generator or an external feeding line, have been supposed as for transit buses.

a) Advanced technologies, which could be applied to the "Dual-mode power system", were reviewed. As a result, VVVF-controlled AC motor, high power capacitor and advanced storage batteries etc have been picked up. And, driving conditions of transit bus were investigated by a traffic survey using a chartered bus. On basis of the latest technologies and the required performance for buses, a concept of the "Dual-mode powered bus" was designed shown as fig. 3.3.1.

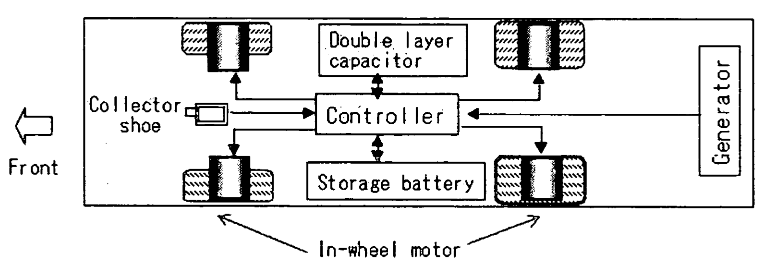

Fig. 3.3.1 Concept of "Dual-mode powered bus"

b) In order to consider proper methods for quantitative evaluation of the energy efficiencies and the regenerative effects, the dynamometer bench tests and the static charge-discharge tests were carried out. As a result, for example shown as fig. 3.3.2, it has been clarified that the conversion rate between electric and mechanical energy is 40% - 80% in urban bus trips.

On the other hand, a simulation program to estimate the energy consumption of the dual-mode power system was composed. As a result, it is expected that the "Dual-mode power system bus" can achieve an excellent fuel consumption ratio (kilometer per liter) that is two times those of ordinary buses.

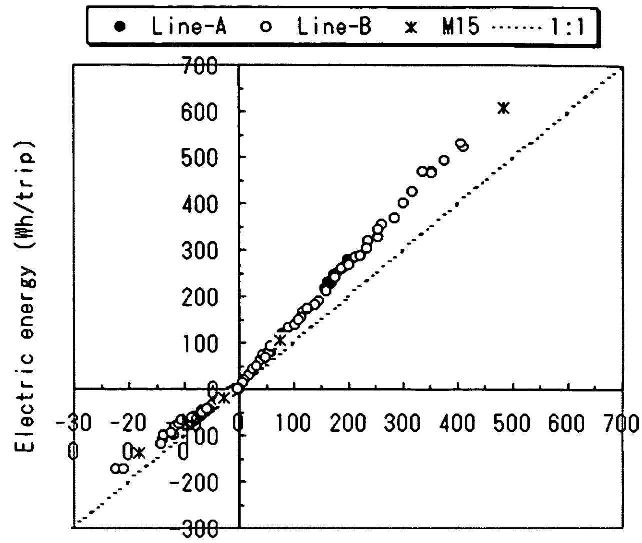

Fig. 3.3.2 Electric energy vs. mechanical energy of motor system in bus trips

c) Two models of bus-lines for the "Dual-mode bus" were supposed as shown fig. 3.3.3, and the CO_2 emission per one line was calculated in compared with conventional bus or LRT, and the CO_2 emission of the "Dual-mode bus" line was estimated as a half of it of conventional bus line. It have been predicted that the introduction of the "Dual-mode buses" to all applicable cites in Japan would reduce the 140 kt of CO_2 emission by inducing 20% of car passengers along lines to the "Dual-mode buses"(fig. 3.3.4).

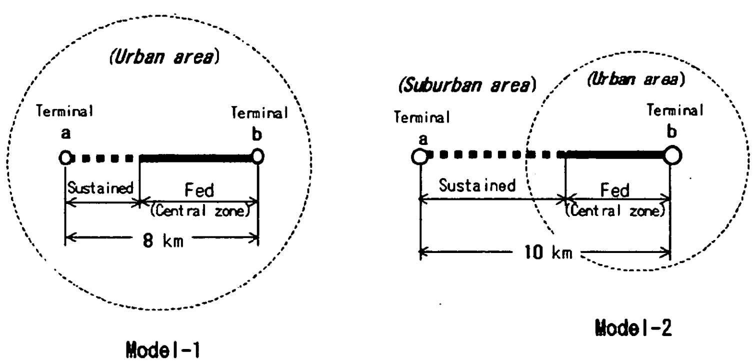

Fig.3.3.3 Model lines for "Dual-mode buses"

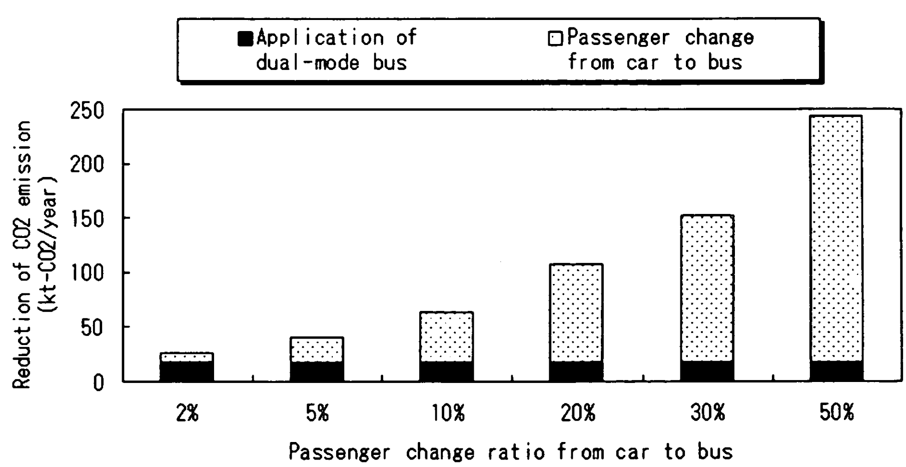

Fig.3.3.4 Reduction of CO2 emission by introducing "Dual-mode buses"

3.4. The Application of the Environmental Friendly Transport System to the Asian Countries

According to the public transportation requirement in Beijing, a dual mode bus is firstly introduced in this study. Fig.3.4.1 is the running route and mode of that bus. It runs round trip between station A and station D. Between station B and C, which place has ultra low emission limit, the bus runs at pure electricity mode. At other areas, the bus runs at hybrid mode.

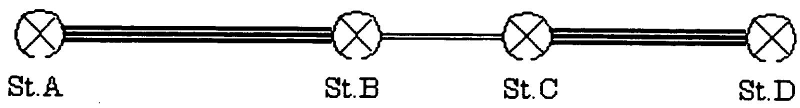

Fig. 3.4.1 Running route and bus mode (The lengths between each two stations are 6km, 5km and 6km, respectively.)

Table 3.4.1 lists the capacity and speed performance of that bus.
The proposed bus consists of a generator, fuel tank, two in-wheel motors and a set of batteries for the power source.

Table 3.4.1 Basic specification of the dual mode bus

Item	Parameter Value
Gross Vehicle Weight	9,450kg
No. of Passengers	60
Max. Speed	65km/h
Auxiliary Power	2kW
Electricity Range	5km

Table 3.4.2 lists the main kinds of energy flow among the power train components. Three kinds of energy flow are listed at both pure electricity mode and hybrid mode. In PEV mode, the battery is discharged and its SOC(State Of Charge) becomes lower. In HEV mode, the generator provides electrical energy both to the motors and battery, and the battery is charged to keep the SOC high level. Based on the power, energy requirement and energy flow modes, the main power train parameters(generator power, motor power and battery capacity) are listed in Table 3.4.3. The dual mode bus running control divides PEV mode control and HEV mode control. The battery charges and discharges alternatively and its SOC keeps continuous.

Table 3.4.2 Main kinds of energy flow of the dual mode bus

Mode	Sub Mode	Energy Out	Energy In
PEV	Idling	Battery	Auxiliary Parts
	Driving	Battery	Motor
	Regenerating	Motor	Battery
HEV	Low Speed Driving	Generator	Motor, Generator
	High Speed Driving	Generator, Battery	Motor
	Regenerating	Motor	Battery

Table. 3.4.3 Main parameters of the power train

Item	Max. Speed	Parameter Value
Motor	Type	in-wheel AC induction
	Max. Power	90kw×2
Generator	Power	50kw
Battery	Type	NiMH
	Capacity	100Ah
	Usable Energy	11kwh

Table 3.4.4 lists the simulation result with SOC varies between 0.6 and 0.8, and the energy regenerating ratio is set to 80%. From table 3.4.4, the average fuel consumption (L/100km) for the bus in the route in Fig.3.4.1 is:

Table 3.4.4 Fuel economy of the dual mode bus

Item		PEV	HEV
SOC	Start	0.8	0.6
	End	0.6	0.8
Fuel Consumption (L/100km)		0	40.3
Range (km)		5	12

$f_a = \frac{12*40.3}{12+5} = 28.4$ (L/100km)

The comparative fuel economy of that bus with a conventional diesel engine bus is: 28.4/37.7=75%. Where, 37.7(L/100km) is the simulated fuel consumption of that conventional bus.

According to the number of consumed crude oil in China, 0.21 billion tons in 2002, and if 75% fuel consumption is obtained for every motor vehicle, almost 50 million tons of oil could be reduced one year.

4.Discussion

The vehicle's performance evaluation system was developed, which deals with the production, supply, storage of energy and area characters such as traffic demand becomes possible. The factors on which test precision greatly depends were found in the measurement of the energy efficiency of HEVs. The dual mode bus system got the high efficiency of two times of the current bus system by experiments based on the actual travel activity data and also showed the applicability to Beijing, China. By integrating these results onto the model system based on the expanded life cycle evaluation in which infrastructure construction, induced demand and driving speed are taken into consideration, it is thought that the traffic system which fit to the region.