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Evaluation on Introducting of Light Rail Transit Systems in Japan by AHP

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Abstract : Urban transportaion systems of Light Rail Transit (LRT) are trying to introduce in several regions fitted with characteristics on each region in Japan. For examples, Light Rail Vehicles (LRV) were introduced for the sake of easiness of getting on/off of passengers in Kumamoto, and are intended to adopt by Hiroshima. On the otherhand, recently, improvements of tram systems for a sort of LRT were executed in front of Toyohashi station. This paper describes the merits and demerits of these LRT systems for urban use and evaluates properly for more practical uses.

Introduction

Recently, it is remarkably populated to introduce Light Rail Vehicles (LRVs) in urban cities mainly in Europe. In Japan, some movemens to introduce LRVs are rising partly and it was introduced in some cities (Kumamoto and Hiroshima). But, in Europe these systems are not only introduced LRVs but also developing to combine with urban plannnings and in the center of the city realized coexistences between LRVs and pedestrians and in suburban areas realized high speed running with exclusive guideways that we say Light Rail Transit (LRT) systems. In contrast to these circumstances , in Japan , it has just reached to introduce only LRVs. In the near future, it will appear to make LRT systems combined with urban plannnings in Japan too. But, in the present stage it must be ristricted to introduce only LRVs for several urban problems. In this case, though it is expected to be convenient for general passengers because of receiving modern technologies for examples loor floor structures in the vehicles , low noise and high accel/decelerations performances , and of fashionable vehicle designs , for the operators it must decide to introduce LRVs in the view of payabilities because of rises in vehicle prices.

In this paper, we evaluate merits and demerits of these LRVs in the technical view points ,and propose synthetic evaluation method that makes clear the positioning of LRVs in the urban transportation systems.

1. Qualitative evaluation of LRVs as urban transportation systems

In this chapter the characteristics of LRVs are evaluated qualitatively.

1.1 Merits of introducing LRVs

LRVs have several characteristics and are managed to be convenient for passengers consequently. Figure 1 shows some merits with correspondence to characteristics.

Low floor structure	— Easiness of getting on/off —	Human friendly, Speed up
Adopting IGBT elements	— Low noise —	Environment friendly
New novel design	— Image up —	Increasing passengers

Fig.1 Characteristics and merits of LRVs

1.2 Demerits of introducing LRVs

On the other hand, it may cause inexperienced situations that don't have experienced in the ordinary trams to introduce LRVs. Some subjects associated with LRVs are described in Figure 2.

Cost of vehicles — In the case of small numbers of LRVs , cost will be comparatively high.

Maintenance — Little experiences may require high technologies because of complicated bogie mechanisms and motor installed methods.

Fig.2 Characteristics and subjects of LRVs

As to the maintenance , it will be no problems for no- maintenance structures on LRVs usually, but in the case of general inspections for disassebling elements , may cause some subjects that we don't have been experienced former. But, it will happen no problems because of high technical performances of Japanese operators and of cooperations with manufacturing makers.

2. Quantitative evaluation of LRVs as urban transportation systems

It is cleared that LRV systems have a little subjects in vehicle costs for Japanese operators that are needed to secure the payabilities although have many merits for passengers. But, it can be realized as the total transportation systems for LRV systems if merits are prior to subjects. Therefore, it is expected to popularize if LRV systems can show how degrees they can decrease their costs , they can operate with payabilities for operators quantitatively.

This paper evaluates these merits and subjects quantitatively, and describes the examples of synthetic quantitative evaluation methods.

2.1 Evaluation of LRVs on environment (gas, noise, electromagnetic field)

2.1.1 Comparison of automobiles

It is essential to compare urban transportation systems with other transportation systems for examples automobiles and buses. In this case, the amount of exhaust gas converted to primary energy of crude oil is able to become one of the most important index for the environmental evaluation. .

2.1.2 Comparison of other urban transportation systems

It is assumed that noise and vibration of LRVs and tram systems are lower than any other urban transportation systems because of low speed. Figure 3 shows the example of measured noise outside vehicle of several transportation systems.

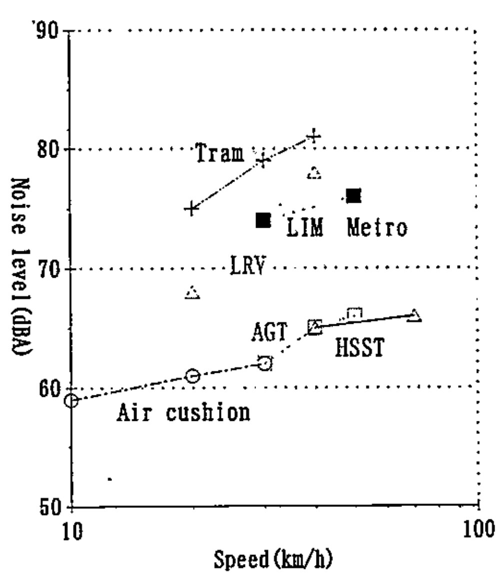

Fig.3 Examples of noise outside vehicle

Although it is advanced to be low noise for LRVs , it is not so low noise in the same speed regions in contrast to other new urban transportation systems. As to electromagnetic field in the vehicle it is not so high level for LRVs, but has different features in damping characteristics with distances that the level on around ceiling is higher than the floor in the vehicle because of installing electric devices on the ceiling.

Through these comparisons it can be quantitative evaluation and will clarify the positioning of LRVs on environment in urban transportation systems.

2.2 Evaluation of LRVs on energy

It is expected for LRV systems to be reduced a little more than any other same sorts of systems because of light weight and newest propulsion control method (induction motor plopulsion by VVVF inverter of IGBT elements). But, running energy consumptions on LRVs are much different by distances between stations , running speed , running pattern and regenerative power. Generally speaking, it tends to be larger for short trip systems for examples , short distances between stations , short coasting length and high speed to consume running energies. Accordingly, it is relatively high for conventional tram line that each station is settled at intervals of 400 ~ 500 meters to consume running energy.

For this reason, we must compare running energies with same conditions and after getting characteristics of energy consumption on LRVs , we require further examinations for saving energy method and high efficiency of control devices.

Figure 4 shows the example of running energy consumptions of main circuit on several transportation systems that run along the fixed patterns of high acceleration , long coasting length and high deceleration.

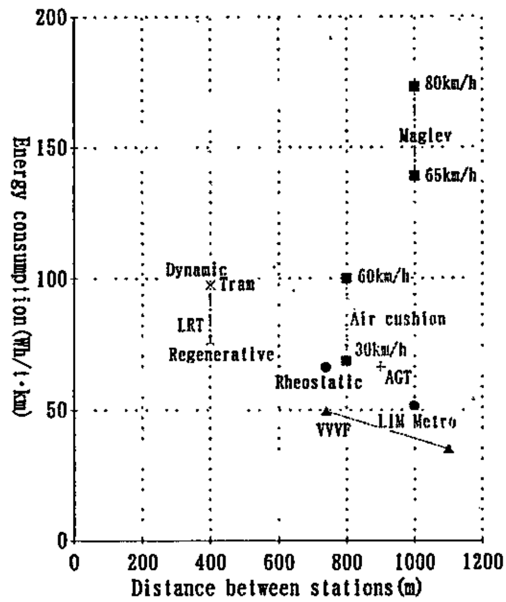

Fig.4 Running energy consumptions

By these results, it can be judged that energy savings for LRVs are well secured than tram systems , but are not necessarily favorable than any other systems because of differences of distances between stations.

2.3 Evaluation of LRVs in the viewpoint of transportation systems

It will contribute to the substantiality of urban transportation systems to evaluate LRVs properly that have several features in introducing urban cities. But, since evaluation items are extended over widely , it is difficult to evaluate uniquely for LRVs.

Though we have tried to evaluate LRVs uniquely by applied AHP (Analytic Hierarchy Process) , it could be found that different weighting by each point of view causes different results. Therefore, we will propose a sort of sensitivity analysis of AHP that it can allow how degree some technical indices for LRVs is wrong .

In calculating evaluation values , it was executed to compare with the same kinds of transportation systems of LRVs and conventional trams.

2.3.1 Hierarchy structures

We set up the hierarchy structures for evaluation of introducing LRVs like as figure 5.

In this hierarchy structures , it can be normalized to be numerical values for each evaluation items settled in the lowest layer through data or simulations.

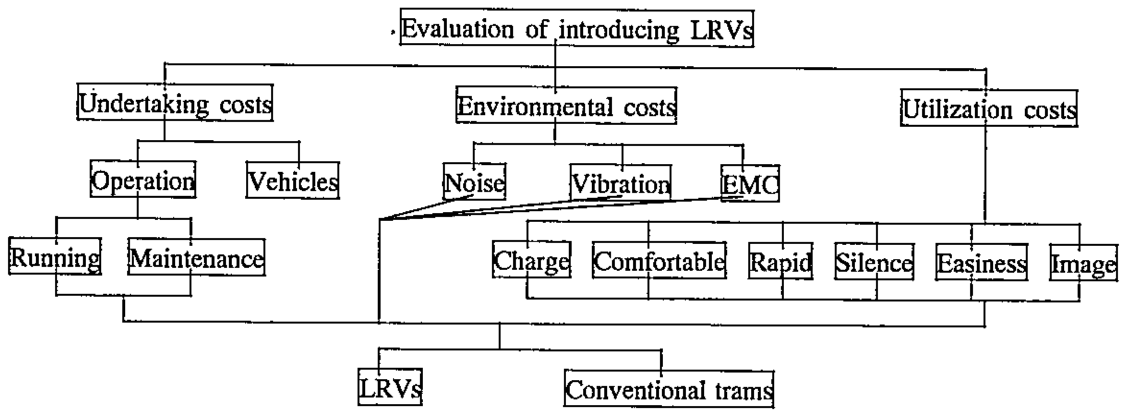

Fig. 5 Hierarchy for evaluation of introducing LRVs

2.3.2 Calculation method

Each evaluation value can be representative as the ratio LRVs to trams (assuming that the value of tram is 1 .)

For example, it can be estimated for the costs with running , maintenance and vehicle to operators like as equation (1). The vehicle costs of LRVs are estimated as $1+v_L$ as compared with 1 of trams.

	Vehicle (V)	Running(R)	Maintenance(M)	
LRVs	$1+v_L$	R_L	M_L	··· (1)
Trams	1.0	1.0	1.0	

For environmental costs, it can be evaluated in the same way. In this example we represent as follows.

	Noise(N)	Vibration(B)	EMC(E)	
LRVs	N_L	B_L	E_L	··· (2)
Trams	1.0	1.0	1.0	

For users' costs, it can be defined that rapidness is representative as the ratio of schedule speed , comfortableness is as it's of vibration level in the vehicle , silence is as it's of noise level , and easiness is estimated through simulations on getting on/off characteristics. Passenger fares that are supposed to be supplemented by operators themselves are setted $1+f_L$. Accordingly, users' costs are described like as equation (3).

	Fare(F)	Comfortable(C)	Rapid(T)	Silence(S)	Image(I)	Easiness(G)	
LRVs	$1+f_L$	C_L	1.0	S_L	I_L	G_L	··· (3)
Trams	1.0	1.0	1.0	1.0	1.0	1.0	

It can be shown for equations (1) ~ (3) to be evaluated by AHP like as equation (4). In this equation , the former is the value of LRVs while the latter is of trams.

Operators	$(o + k\cdot v_L , 1.0)$	
Environment	$(s , 1.0)$	··· (4)
Users	$(u + m\cdot f_L , 1.0)$	

Provided that $o, k\cdot v_L$, s, u, m, f_L are the calculation values gotten by AHP.

Through these results, it can be arranged as following.

① In the case of $o + k \cdot v_L < 1$,

It can be introduced for LRVs without any conditions because of profitableness to operators clearly.

② In the case of $o + k \cdot v_L > 1$,

We arrange as following.

(a) Burden on users.

In this case, if the quantities of profitableness on users are superior to those of disadvantages on operators, LRVs can be introduced.

$$u + m \cdot f_L \leqq 1$$

$$(o + k \cdot v_L) - 1 < 1 - (u + m \cdot f_L) \quad \cdots (5)$$

(b) Burden on public subsidies.

In this case, if the quantities of profitableness on environment are superior to those of disadvantages on operators, LRVs can be introduced.

$$s \leqq 1$$

$$(o + k \cdot v_L) - 1 < 1 - s \quad \cdots (6)$$

(c) Burden on users and public subsidies

In this case, if the quantities of profitableness on users and environment are superior to those of disadvantages on operators, LRVs can be introduced.

$$u + m \cdot f_L \leqq 1$$

$$s \leqq 1$$

$$(o + k \cdot v_L) - 1 < \{1 - (u + m \cdot f_L)\} + (1 - s) \quad \cdots (7)$$

2.3.3 Example of calculation results

Pair comparison matrices between users, sociality and operators each other are assumed as followong equation (8).

Operators

	V	R	M
V	1	4	4
R	1/4	1	1
M	1/4	1	1

Social

	N	B	E
N	1	2	8
B	1/2	1	4
E	1/8	1/4	1

Users

	F	C	S	I	G	T
F	1	4	2	4	2	1
C	1/4	1	1/2	1	1/2	1/4
S	1/2	2	1	2	1	1/2
I	1/4	1	1/2	1	1/2	1/4
G	1/2	2	1	2	1	1/2
T	1	4	2	4	2	1

$\cdots (8)$

As the results of these calculations , each cost for introducing LRVs is estimated as following.

Operators' cost : $0.960 + 0.667\,v_L$

Social cost : 0.981 $\cdots (9)$

Users' cost : $0.957 + 0.286\,f_L$

Moreover, after rearranging by substituting each values based on data or simulations into any other parameters, we can get the results as following .

$R_L = 0.757$, $M_L = 1$, $N_L = 0.963$, $V_L = 1.016$, $E_L = 1$, $C_L = 1$, $S_L = 1.054$, $I_L = 0.5$, $G_L = 0.896$

Thus, we can get the results as following figure 6.

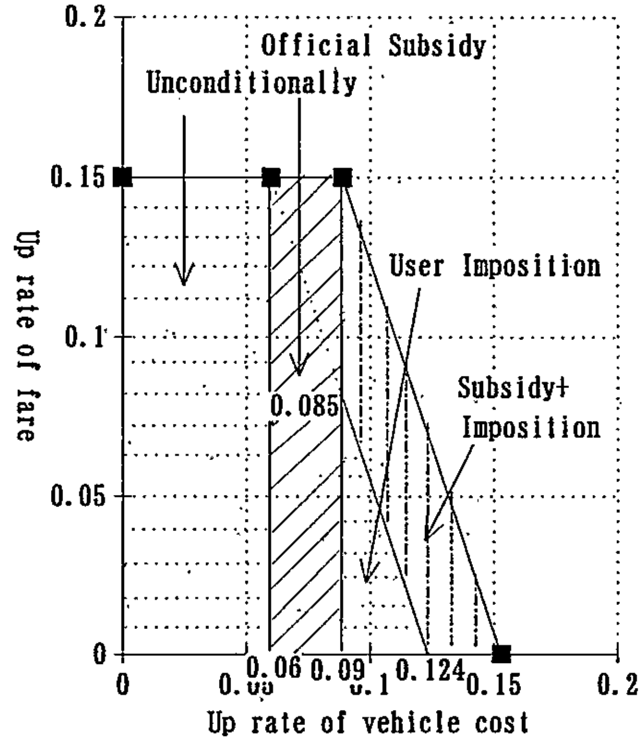

Fig. 6 Permitted cost up ratio of vehicle in introducing LRVs

According to these results, we can see that it is permitted for introducing LRVs to allow 6 % up of vehicle costs without subsidies and to allow 9 % up of those with subsidies. And considering the burdens of users , about 15 % up of vehicle costs will be permitted. But in this case, all of shortages must be supplied with subsidies because permitted up ratio of fares is 0 %.

3. Concluding

As mentioned above , it was introduced for LRVs to characterize and evaluate on environment and energy. And we proposed the attempts to evaluate the system priority decision method based on technical indices. Through this method synthetic evaluations including merits and subjects for LRVs can be realized and how means can be valid for introducing LRVs with quantitativeness. It is important for us to evaluate LRVs justly and to try to fill up urban transportation systems through these methods.