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Effects of introduction of a water-bus system and transport policies on road traffic and the environment in urban areas

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Abstract

In Japan's medium/small-size cities where public transportation services are not sufficient, dependence on privately owned cars is relatively large, contributing to the chronic traffic congestion on the roads. As the global environmental problems have become increasingly serious in recent years, calls are rapidly growing for a reduction in the amount of harmful exhaust gases from automobiles. Against this background, this study aims to examine the use of a water transportation system as a way of alleviating traffic congestion in urban areas and reducing the environmental load. Such urban transport policies as staggered-time commuting by office workers and a park-and-ride system are also studied, and the effects of these measures are analyzed. As a result, when combined with staggered-time commuting and park-and-ride systems, the water-bus is very likely to make a significant improvement in the current traffic situation. We can also expect financial benefits from the shortened travel time and a reduction in environmental burdens.

1 Introduction

In Japan's medium/small-size cities where public transportation services are not sufficient, dependence on privately owned cars is relatively large, contributing to the chronic traffic congestion on the roads. As the global environmental problems have become increasingly serious in recent years, calls are rapidly growing for a reduction in the amount of harmful exhaust gases from automobiles. One very effective way to deal with this problem is to keep energy efficiency from falling by alleviating the congestion of automobile traffic in urban areas. From a standpoint of improving the earth's environmental quality, social demand for lessening the congestion of automobile traffic is sharply on the rise (e.g. Pearce[1]).

Against this background, this study examines the use of a water transportation system as a way of alleviating traffic congestion in urban areas and reducing the environmental load. Such urban transport policies as staggered-time commuting by office workers and a park-and-ride system are also studied, and the effects of these measures are analyzed. For cities with a highly developed river network, the introduction of a new water transportation system can be expected to improve the efficiency of transportation by reducing heavy road traffic as it provides an alternative means of transportation. At the same time, a reduction in the amount of car exhaust can also help reduce the environmental load (e.g. Ferguson[2]).

Many studies have been made on transportation and environmental problems. Studies on urban transportation and energy include the following: a US study on transportation policy streamlining and the characteristics and effects of ordinances on traffic volume reduction, targeting not only traffic reduction but the improvement of air quality (e.g. Matsuda[3]); research on the macro analysis of the efficiency and strength of traffic energy consumption by linking urban functions and transportation (e.g.Hayashi[4]); a study on calculating the amount of energy consumption by various urban transportation means in Japan (e.g. Kawabata[5]).

Other studies about the effects on environment and energy consumption of changes in urban traffic and implementation of transportation measures include the following: analysis of the relationship between energy consumption and changes in traffic volume and means (e.g. Frost[6], Banister[7]), and a study on the reduction of air pollution by collecting charges from cars moving into urban areas (e.g. Odani[8]).

In contrast to these past studies, the authors of this paper focus on the effects of the use of a water transportation system and some urban transport policies such as staggered-time commuting by office workers and a park-and-ride system. These measures are evaluated for their effectiveness by calculating reductions in road traffic travel time, travel cost, and the amount of CO_2 discharge from automobiles.

2 Research approach

Fig.1 shows the analysis method we used in this research. In this paper, the water transportation system mentioned is a water-bus, and the effects of its introduction into the transportation system are measured in terms of a reduction in automobile traffic. First, current automobile OD traffic volume between zones is measured based on the road traffic data compiled by the Ministry of Construction. Next, by distributing this OD traffic volume over the road network of the target city, we estimate route traffic volume. We also make a choice model of transportation modes based on the results of the survey about the use of water-buses. This model can be used to estimate just how much of traffic will be transferred from automobiles to water-buses. At the same time, we try to calculate the amount of such transfer after the implementation of staggered-time commuting by office workers and a park-and-ride operation. Further the automobile OD traffic volume after the introduction of the water-buses is distributed throughout the road network of the target city and then the route traffic volume with these water-buses is estimated. Finally, by comparing route traffic now and after the introduction of the water-buses, we can quantitatively evaluate the effects of the water-buses and the urban transport policies from two points of view--change in automobile traffic and the effects of such change on our environment.

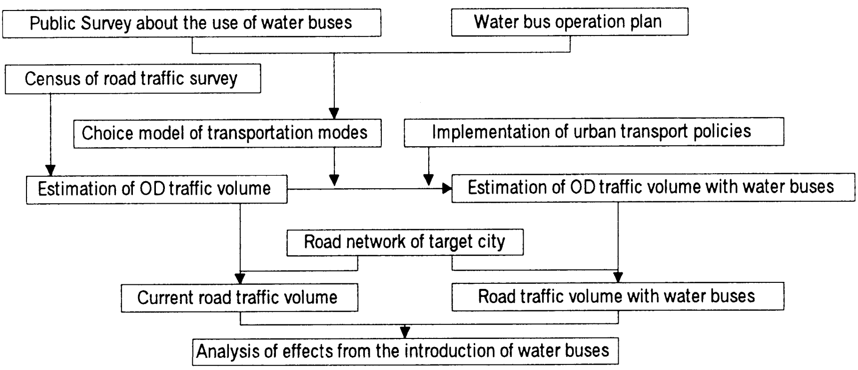

Fig.1 Introduction of a public water transportation system and urban transport policies-- analysis flow

3 Target city and current road traffic

3.1 Target city

Tokushima City serves as the target city for the use of water-buses in this research project. Located near the estuary of the Yoshino, one of the major rivers in Japan, the city has a highly developed network of waterways. Therefore, bridges are very important mean of transportation between the city center and places around the city and within the city itself. On the other hand, city traffic tends to clog around these bridges. Before the expansion of automobile traffic, however, transportation by boat used to be highly developed in this city. From the standpoint of both the current road network problems and this historical background, Tokushima City is clearly suited for the use of water-buses.
*The city has the population of about 265,000 and the area of 191 km^2.

3.2 Automobile traffic volume and problems of road traffic

In this research, we chose 1,384 links from among the routes inside the city and formed a network of these roads. With this network, we then estimated automobile traffic volume. To calculate the travel cost, traffic volume was measured by vehicle type in each link. Fig.2 shows changes in automobile traffic volume by travel purpose throughout the day. As it is clear from the graph, traffic peaks twice in a day, about 7 and 8 o'clock in the morning mainly for commuting to offices and about 17 and 18 o'clock in the evening mainly for returning from work. The challenge, therefore, is to disperse or reduce the amount of traffic during these peak hours.

The analysis of current automobile traffic on the road network shows as an important problem that the traffic congestion in the city occurs because of heavy automobile traffic flowing into and out of the city in the morning and in the evening using a few trunk roads linking the center of the city and its surrounding areas. By controlling the total automobile traffic into the city center from these surrounding areas, we can therefore alleviate traffic congestion on the main roads. Measures to bring about this improvement include staggered-time commuting by office workers and the park-and-ride system, i.e. driver's switch from their cars to public transportation when entering the city center.

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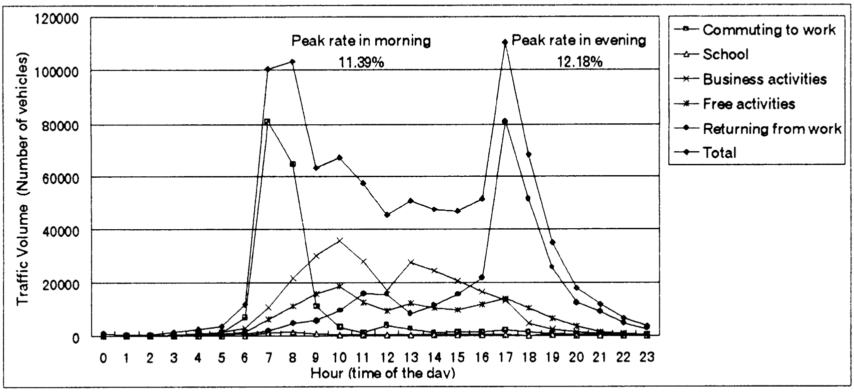

Fig.2 Changes in traffic volume by travel purpose throughout the day

4 Plan for a water transportation system

4.1 A public water transportation system

Today, water transportation began to attract a renewed attention as an effective means of alleviating chronic traffic congestion and reducing load on our environment. It is also considered effective in providing needed transportation in an emergency, as a recreation space along the river for the residents, and as an important sightseeing resource. With such growing interest, the River Bureau of the Ministry of Construction is studying measures centered on the effective utilization of rivers for transportation. The water-bus, the focus of this research, provides regular shuttle bus services in rivers or at sea.

4.2 River network and water-bus network

We made the following plan for the operation of the water-bus, and carried out simulations for its introduction into the existing transportation system. In this plan, "bus stops" are set up near schools, commercial establishments, and public facilities along the rivers flowing through Tokushima City. These bus stops are also put up around the bridges on the main roads used by vehicles into the city from its surrounding areas. As Table 1 shows, all these bus stops are arranged in such a way as to ensure mutual connections. Fig. 3 is the map of these water-bus stops. The fare is set at 200 yen for each ride, and 7,800 yen for a 1-month pass used by commuters and students. These prices are the same for the current municipal bus services.

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Table 1 Operating routes

Routes	Bus stop numbers
Routes A	9-15-16-22-23-24
Routes B	5-18-17-16-15-9
Routes C	9-1-8-7-3-11-2-10-9
Routes D	7-6-5-14-13-12-7
Routes E	4-13-19-20-21

Note: These numbers indicate the bus stops as shown in Fig. 3.

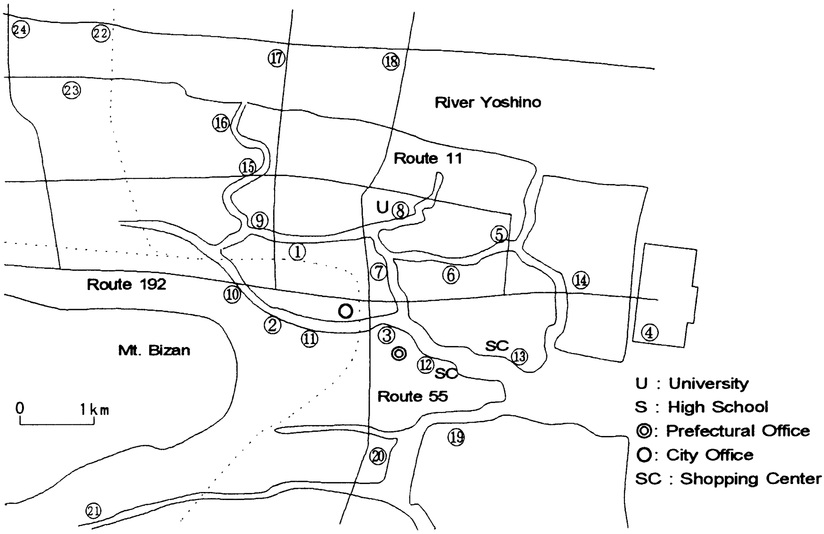

Fig.3 Water-bus stop arrangement

5 Transfer from automobiles to water-buses

5.1 Questionnaire survey on the use of water-buses

We surveyed Tokushima citizens about their intention to use the water-bus. The data thus obtained were used to produce a model for estimating the amount of a traffic shift from the existing means of transportation to the water-bus system. A total of 1,370 questionnaires were distributed in November and December 1994, of which 1,006 have been collected.

5.2 Model

Based on the analysis results of this survey, we produced choice models of transportation modes for commuters going to work and students going to school, and for others engaged in other activities. Equations (1) and (2) below express these models by purpose. For commuters and students, their model is logit, but a linear model is used for those engaged in other activities, as a logit model did not work well.

a) For commuting to work and going to school

$$P_1 = 1/\left[\exp\left\{2.1631 - 0.000169(c_2 - c_1) - 0.823(t_2 - t_1)\right\} + 1\right] \; ; \; R^2 = 0.778 \quad (1)$$

b) For free activities

$$P_1 = 0.2769 + 0.000387(c_2 - c_1) \; ; \; R^2 = 0.919 \quad (2)$$

Where, P : Possibility for using water-bus
(Small numbers 1 and 2 mean water-bus and automobile, respectively)
c : Transportation cost (ditto)
t : Transportation time (ditto)

5.3 Estimated traffic shift from automobile to water-bus

We calculated the amount of a traffic shift from automobiles to the water-bus service using the above equations (1) and (2). As the results (Table 2) show, the total amount of a traffic shift is not very large, probably attributable to the fact that the number of people who can use the water-bus service is small because the service network is limited in size.

Table 2 Estimated amount of a traffic shift from automobiles to water-buses

Reduction (vehicles)	6 o'clock	7 o'clock	8 o'clock	Total
Commuting, School X1	10	505	345	860
For other activities X2	28	160	257	445
Total reduction X=X1+X2	38	665	602	1,305
OD total Y	5,961	48,572	46,032	100,565
OD reduction ratio (X/Y) (%)	0.64%	1.37%	1.31%	1.30%

It has been pointed out that about 10 percent reduction in traffic volume will significantly improve the automobile traffic condition inside the city, but the figures we came up with are not enough to contribute to such an improvement.

6 Effects of the water-bus and urban transport policies

6.1 Indicators of the effects

To analyze and evaluate the effects of this water-bus system on road traffic and environment, we used the following three indicators: total travel time, total travel cost, and carbon dioxide (CO_2) discharge. The total travel time can be calculated by the following equation (3).

$$TT = \sum_i (T_i \times Q_i) \tag{3}$$

Where TT: Total travel time
T_i : Link i travel time
Q_i : Traffic volume along link i

To calculate the total travel cost, we first obtain the fuel consumption from the speed-fuel consumption curve (e.g. Ministry of Construction[9]). We can then calculate the total travel cost by multiplying this fuel consumption with the unit fuel cost (e.g. GEIC[10]). In the same manner, the CO_2 discharge can be calculated first by obtaining the fuel consumption from the above curve, and then multiplying it with the unit CO_2 discharge. With these indicators, we measure the effects on the traffic condition of the water-bus plus the staggered-time commuting and park-and-ride system.

6.2 Measuring the effects of the water-bus and staggered-time commuting

We simulate a case in which both the water-bus and this staggered-time commuting are used at the same time. Because of this staggered-time commuting (including students going to school), we assume that 10 percent of OD traffic volume from 7-9 in the morning will shift to the hour between 9-10. Likewise, 10 percent of OD traffic volume from 17-19 in the evening (traffic rush hours as people go home) is to shift to the hour between 19-20.

Table 3 shows changes in the total travel time, total travel cost, and CO_2 discharge as a result of the concurrent implementation of the water-bus system and staggered-time commuting. As you can see, all these indicators show a noticeable decrease in traffic volume during these controlled hours (7-9 in the morning, 17-19 in the evening). There was however a slight increase in these indicators during 9-10 in the morning and during 19-20 in the evening, but as Fig. 2 shows, traffic volume is in fact too small during these hours to make much difference to begin with. As has been indicated, the introduction of this staggered-time commuting helps disperse traffic during peak hours, alleviating the chronic traffic congestion in Tokushima City to a large degree.

Table 3 Effects of the water-bus and staggered-time commuting

Time of the day	Total travel time (vehicles*hour/day)	Travel cost (1,000yen/day)	CO_2 discharge (kgC/day)
7:00 – 8:00	6,853	973	6,636
8:00 – 9:00	4,650	735	5,135
9:00 – 10:00	-8,399	-1,544	-11,124
17:00 – 18:00	5,481	728	4,975
18:00 – 19:00	4,467	628	4,271
19:00 – 20:00	-5,205	-759	-5,124
Day total	8,165	907	5,819

6.3 Measuring the effects of the water-bus and park-and-ride system

We simulate a case in which large parking lots are created along these main roads where drivers can switch from their cars to the water-bus (park-and-ride) for transportation into the city. In this case, we assume that during the busy commuting hours (including students going to school), 30 percent of the traffic from areas north of the Yoshino, 40 percent from the west, and 30 percent from the south will switch to the water-bus service at these parking lots. Table 4 shows the number of vehicles parked at these parking areas (meaning a reduction in the number of cars going to the city) during the morning rush hours in this park-and-ride system.

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Table 4 Estimated number of vehicles parked at parking areas in the park-and-ride system

Water bus stop	No. of vehicles parked			
	6-7 o'clock	7-8 o'clock	8-9 o'clock	3-hour total
18	29	622	677	1,328
17	29	622	677	1,328
22	44	578	438	1,060
24	80	514	330	924
23	71	1,080	642	1,793
21	70	950	725	1,745

Table 5 shows the total travel time, total travel cost, and CO_2 discharge as a result of the concurrent use of the water-bus system and the park-and-ride system. As these graphs show, the park-and-ride system is effective in controlling the amount of automobile traffic during the morning and evening rush hours. We can say that this measure can be expected to alleviate the chronic traffic jams in Tokushima City during peak hours.

Table 5 Effects of the water-bus and the park-and-ride system

Time of the day	Total travel time (vehicles*hour/day)	Travel cost (1,000yen/day)	CO_2 discharge (kgC/day)
6:00 - 7:00	142	29	201
7:00 - 8:00	2,376	302	2,013
8:00 - 9:00	1,200	179	1,213
17:00 - 18:00	1,182	163	1,100
18:00 - 19:00	971	149	993
19:00 - 20:00	488	66	427
Day total	7,015	1,034	6,986

6.4 Measuring the effects of a package of urban transport policies

Here, we simulate a case in which a package of the water-bus system and the staggered-time commuting and park-and-ride systems is implemented. Table 6 shows changes in the total travel time, total travel cost, and CO_2 discharge. As this table show, the combination of the staggered-time commuting and park-and-ride system together with the water-bus system

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is more effective in reducing the amount of traffic during rush hours than their separate implementation. As for the CO_2 discharge, these methods combined cut the amount of CO_2 discharge by 2,600 tons per year. We can say that the water-bus system and these urban transport policies combined will make a tangible improvement in alleviating chronic traffic congestion in Tokushima City and reducing the overall load on our environment.

Table 6 Effects of a package of urban transport policies

Time of the day	Total travel time (vehicles*hour/day)	Travel cost (1,000yen/day)	CO_2 discharge (kgC/day)
6:00 - 7:00	142	29	201
7:00 - 8:00	7,864	1,104	7,490
8:00 - 9:00	5,326	836	5,808
9:00 - 10:00	-8,399	-1,544	-11,124
17:00 - 18:00	5,481	782	5,345
18:00 - 19:00	5,136	724	4,910
19:00 - 20:00	-4,816	-703	-4,762
Day total	11,236	1,346	8,717

7 Conclusion

We have studied the introduction of a public water transportation system and implementation of such urban transport policies as staggered-time commuting and park-and-ride systems, and evaluated their effects on alleviating the chronic traffic congestion of Tokushima City and lessening the burden on our environment. As for the effectiveness of the water-bus system, the expected shift in the amount of traffic from automobiles to the water-bus is rather restricted within the city and the total amount of such transfer is not very large. When combined with other urban transport policies, namely staggered-time commuting and park-and-ride, the system is very likely to make a significant improvement in the current traffic situation. We can also expect financial benefits from the shortened travel time and a reduction in environmental burdens.

A network of rivers can also be an important sightseeing asset for the city as well as a place for the residents to relax. The introduction of a water transportation system can be expected to increase the value of this asset. Another advantage is that the water-bus can be operated in a less crowded space, offering speed and on-time services. Bulk transportation

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is also possible. Further, an expected increase in the number of tourists to this water-bus service will revitalize the activities within the city and bring about economic benefits. With all these likely advantages, the introduction of a public water transportation system such as the water-bus discussed in this report deserves serious consideration in the future as it revitalizes regional activities and improves the traffic situation in the city through a clever use of local geographical features.

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