A COMPUTER-AIDED PLANNING SYSTEM FOR ROAD NETWORKS IN A METROPOLITAN AREA

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INTRODUCTION

In the Keihanshin Metropolitan area, one of the three biggest metropolitan areas in Japan, many big projects such as the New International Airport, Culture and Science Town and Akashi Bridge are now being undertaken. Corresponding to these projects, new road networks are under construction for the improvement of transport networks in this region. However, the progress of economic activity and the increase of car ownership is causing serious social problems, such as traffic congestion and air pollution by exhaust gases from cars.

This study aims to develop a computer-aided planning system for analysing and evaluating the effects of road network plans and related transport policies in metropolitan areas. This paper focuses mainly on a road network simulation system which is a key part of the computer-aided planning system, and the Keihanshin Metropolitan Area is taken as a study area.

The road network simulation system has the following characteristics:

1. The simulation system consists of two parts, one for the road networks in a whole metropolitan area and the other in urban areas included in the metropolitan area, representing a hierarchy of road networks.
2. The two parts of the road network simulation system have their own road network data-bases and the two data-bases are interrelated by the sharing of some road links.
3. Traffic flows on road networks are estimated, taking into account road congestion and road tolls. Traffic flows estimated in urban areas are based on an estimation of traffic flows in the metroplitan area.
4. The effects of road network plans and related policies are evaluated not only from the viewpoints of road users, but also from that of local residents, especially concerning aspects of the environment.
5. The information required and produced during the planning process is presented in an efficient and effective visual form by using computer graphics.

The simulation system developed here is applied to two case studies in the whole metropolitan area and an urban area respectively. In the metropolitan area, the effects of future road network plans are evaluated, and in the urban area traffic measures for reducing NOx emissions by cars are evaluated.

1. ROAD NETWORK SIMULATION SYSTEM

1.1 Outline of the Simulation System

The simulation system developed in this study consists of two parts, one for a whole metropolitan area and the other for urban areas as shown in Figure 1.

The simulation system in the metroplitan area is the following:

1. The road network data–base in the metropolitan area is used.
2. The trip matrix by vehicle type is assigned on the road networks taking into account road congestion and road tolls.
3. On the basis of estimated traffic flows, evaluation indices of road users such as congestion ratio and travel time are calculated.
4. The NOx emissions of each link are calculated for evaluation index on the basis of the estimated traffic flows.

The simulation system in the urban area is the following:

1. The road network data–base in urban area is used.
2. Among the trip matrix in the urban area, internal–external and through traffic flows of the urban area are obtained from traffic flows estimated in the simulation in the metropolitan area.
3. The trip matrix is assigned on the road networks in the same way as in the metropolitan area.

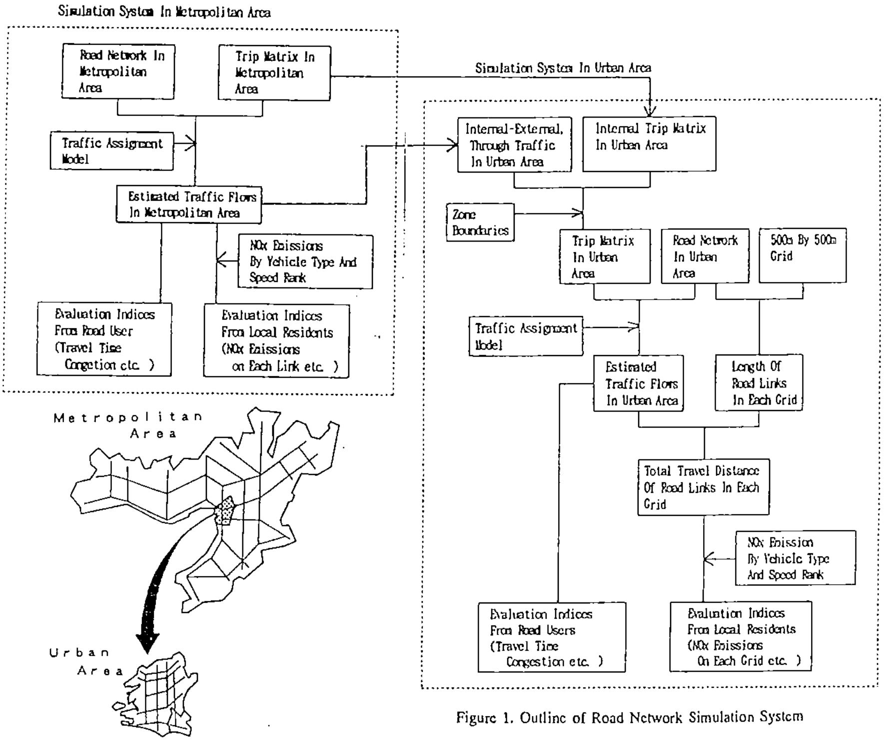


Figure 1. Outline of Road Network Simulation System

4. Estimated traffic flows on the road networks are converted into ones in 500m by 500m grids, considering which road links each grid includes.
5. NOx emissions in each grid are calculated on the basis of traffic flows in the grid, and indices from road users are also calculated.

1.2 Outline of the Study Area

The Keihanshin Metropolitan Area shown in Figure 2 is taken as a study area for the metropolitan area. In this figure, boundaries of administrative districts are drawn with expressways and national trunk road networks. The Keihanshin Metropolitan Area, which is the second largest metropolitan area in Japan, has a population of 17.67 million and an area of 10,742 km^2.

In this region there are three core cities, Osaka, Kobe and Kyoto. Osaka city, the largest of the three, is taken as a study area for the urban area. Osaka city has a population of 2.65 million and 211 km^2 area.

2. Development of the Simulation System

2.1 Road Networks for Traffic Simulation

The road networks for traffic simulation in the Keihanshin Metropolitan Area are made according to the following criteria.
a. All expressways and national trunk roads.
b. Main local roads on which the observed traffic volume is over 10,000 vehicles per day.
c. Other roads which are necessary to make up the total road network in the study area.
d. Ferry routes in the bay area.

In the Osaka City Area, the road networks for simulation were also made according to criteria similar to the metropolitan area, but more minor roads are included than in the latter.

Each link of the networks has the following attributes.
a. Road class (Expressway, national trunk road, local road and others)
b. Traffic regulation(One-way restriction, speed limit etc)
c. Distance, width and the number of lanes of each road link.
d. Road tolls on expressway.
e. Length of ferry route, travel time and capacity.

Figure 3 shows the road networks built for simulation in the Keihanshin Metropolitan Area. The road networks consist of 1,461 nodes and 2,388 links, and the length of the network is 9,321 km in total. Figure 4 shows the road networks for simulation in the Osaka City Area. The road networks consist of 1,484 nodes and 2,116 links and the length of the networks is 820.7km.

2.2 Trip Matrix Data

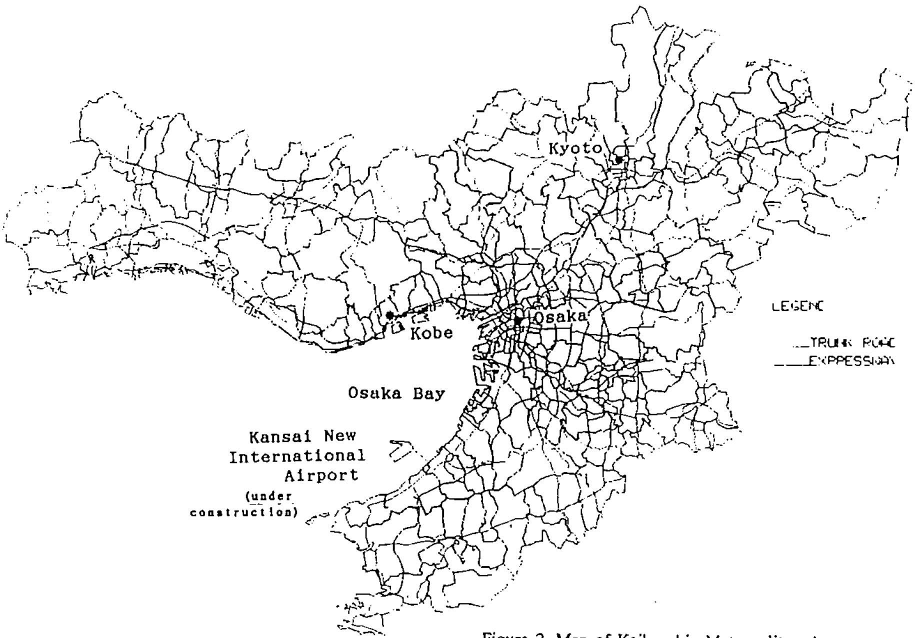


Figure 2. Map of Keihanshin Metropolitan Area

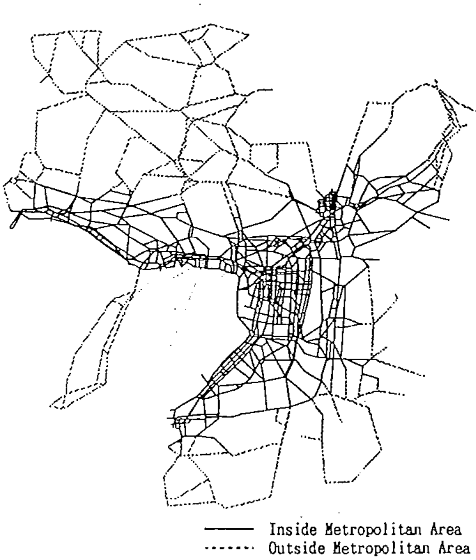


Figure 3. Road Networks
in Keihanshin Metropolitan Area

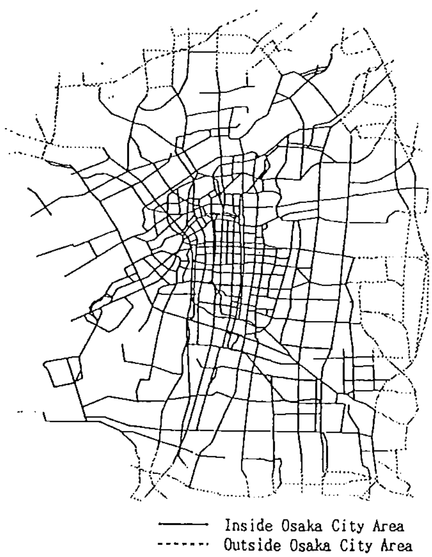


Figure 4. Road Networks in Osaka City

Future trip matrix data used here is that of the year 2000, which was estimated based on a Person Trip Survey conducted in 1980 by the Ministry of Construction and others. Estimated car traffic demand in 2000 will reach 34.38 million trip ends per day in total, and this means 1.46 times the traffic demand in 1980. In this study, the trip matrix in 1990 (base year) is calculated based on the growth rate of traffic demand in each zone from 1980 to 2000. Figure 5 shows the number of trip ends in each zone by the height of bar charts drawn in perspective. It can be found that most of the trip ends are concentrated in the central area of Osaka City.

Traffic assignments are carried out between 416 zones in the Keihanshin Metropolitan Area(259 zones are inside the area), and between 250 zones in the Osaka City Area(215 zones are inside the city area).

2.3 Traffic Assignment Model

A conventional capacity restraint model is employed as the traffic assignment model, and in this study an incremental assignment technique is applied to realize this assignment. In order to show how both road congestion and tolls have an influence on route choice by car drivers, the travel resistance is calculated by the following equation.

Equilibrium assignment is estimated on the basis of the travel resistance.

$$R=T+aC$$

where R: travel resistance　　T: travel time

a: the value of time　　C: tolls on expressway

Speed-Flow curves shown in Figure 6 which reflect road congestion on traffic flows are used. The curves for different classes of road (eg.expressway, trunk road) are prepared.

The value of time is estimated by the following equation (developed by Aoyama and Nishioka(1980)):

$$a=0.0324X-8.707$$

where X: Gross National Product per person

2.4 NOx Emissions Estimation Model

NOx emissions of road links are calculated by emissions per vehicle, link flows and link distance as the following equation.

$$N_j=\sum_k E_{ks}\times Q_{kj}\times D_j$$

where N_j: NOx emissions of link j

E_{ks}:NOx emission per vehicle by vehicle type k and speed rank s

Q_{kj}: Traffic flow on link j by vehicle type k

D_j: Distance of link j

In the simulation system for the urban area, NOx emissions are calculated on each 500m grid. In this study, the diffusion of NOx through the atmosphere is not considered.

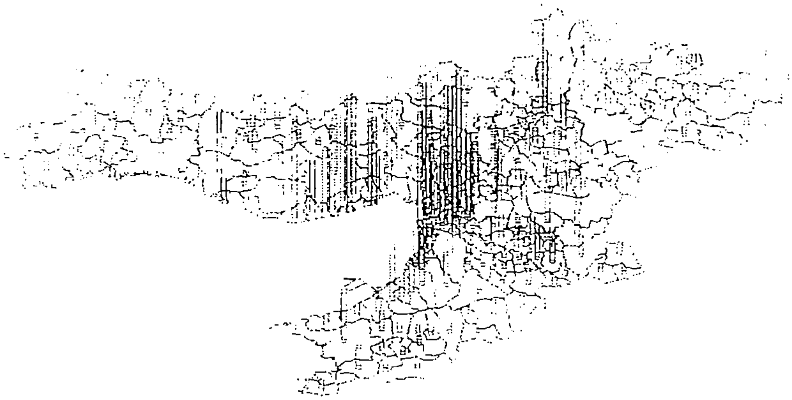


Figure 5. The Number of Trip Ends in Each Zone

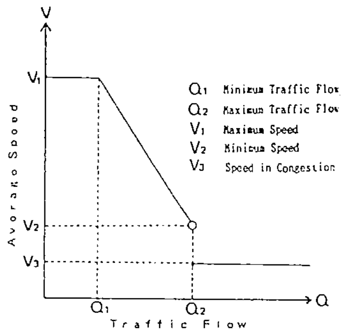


Figure 6. Relationship Between Traffic Flow and Average Speed

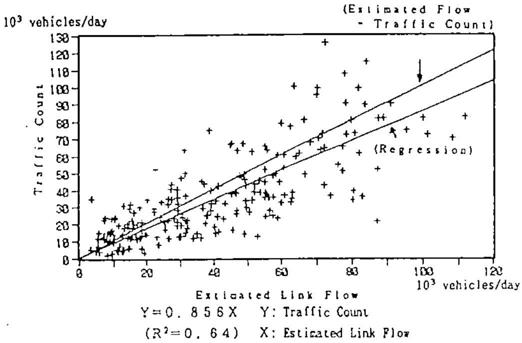


Figure 7. Comparison of the Estimated Link Flows withthe Traffic Counts

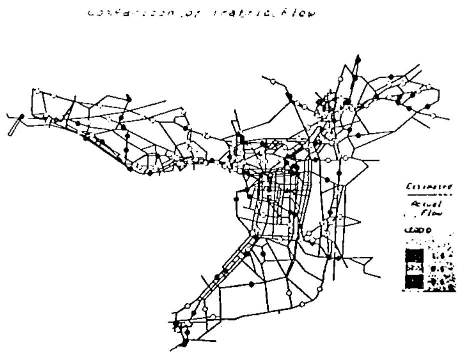


Figure 8. Relationship between the Estimated Link Flows and the Traffic Counts

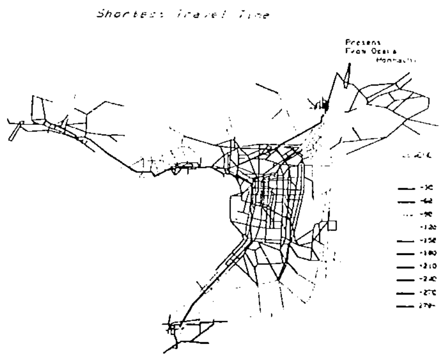


Figure 9. Estimated Shortest Travel Time from Central Area of Osaka to Each Road Link

3. Calibration of the Traffic Assignment Model

For validation of the traffic assignment model the estimated link flows are compared with the traffic counts. Traffic count data used for the validation are 24 hours traffic count data (surveyed by the Ministry of Construction in 1988) in points corresponding to the points on the road networks in both metropolitan and urban areas. The assignment model was calibrated until the differences between the estimated link flows and traffic counts were acceptable.

Figures 7 and 8 show the comparison of the traffic counts with the estimated link flows on road networks in metropolitan area, which were obtained after the calibration.

Figure 7 shows the ratio of the estimated link flows against the traffic counts (Estimation/Observation) on 287 points of the networks. In this figure, the ratio is classified into three ranks and each rank is represented by different colours. Displays like this figure are very useful to the model calibration because the points where differences between the estimated and observed flows are large can be distinguished easily.

In Figure 8 the vertical axis and horizontal axis represent observed and estimated flows respectively, and 200 points of the traffic counts and link flows within the metropolitan area are plotted. A linear regression equation was derived, and the regression curve between the two flows is drawn on the same graph. The regression coefficient(R square) is 0.64, which means that the traffic flows are well estimated.

The equation obtained above ,can be used for modifying the estimated base year(1990) traffic flows and also the estimated future(2000) traffic flows.

Figure 9 shows the shortest travel time from each link to the central part of Osaka City. In this figure, links on the network are coloured according to the travel time (time being measured in specific units), and the shortest travel routes from the central part of the city to three points in the metropolitan area are also displayed in thick lines. From this figure, estimated shortest travel time and routes are reasonable compared with actual travel time and route choice.

The same analyses on the estimated traffic flows and shortest travel time are also carried out on road network simulation in the urban area. Estimated traffic flows in the urban road networks are shown to be reasonable.

4. EVALUATION OF EFFECTS OF FUTURE ROAD NETWORK PLAN

4.1 Future Road Network and its Evaluation Method

In this section, the network simulation system developed in the previous section is applied to evaluate the effects of the future road networks in the Keihanshin Metropolitan Area. The future road networks are here defined as the road networks, the base year road networks to be added by the new roads which are expected to be completed by 2000, ten years after the base year.

Figure 10 shows the road networks under construction in the study area, including two main expressways planned as access routes to Kansai New International Airport,

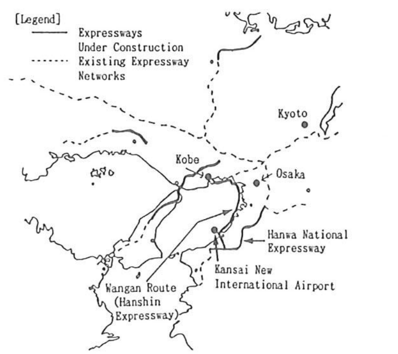


Figure 10. New Road Networks under Construction

Figure 13. Shortest Travel Time from Every Zone to Central Part of Osaka City (With-case)

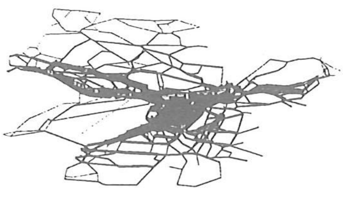


Figure 11. Estimated Future Traffic Flows in Keihanshin Metropolitan Area (with case)

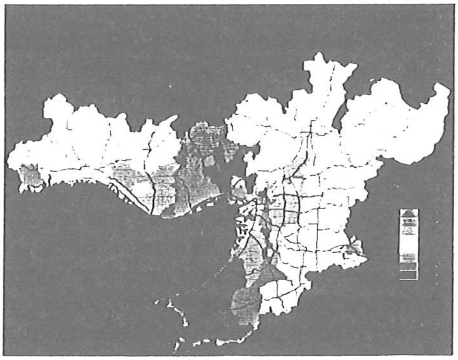


Figure 14. Comparison of Shortest Travel Time from Every Zone to Central Part of Osaka City ((With - Without) / Without)

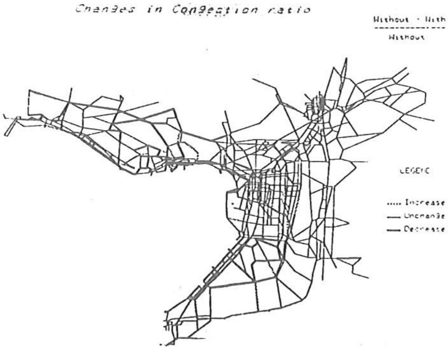


Figure 12. ComparisonofCongestion Ratio (With - Without)

Figure 15. Comparison of Average Travel Time per Trip Originating in Each Zone ((With - Without) / Without)

the Wangan Route(Hanshin Expressway) and the Hanwa National Expressway. The additional road networks consist of 131 nodes and 236 links.

The effects of the future road networks are evaluated by using with-and-without analysis. In this analysis, the with-case means that the future traffic matrix is assigned to the future road networks, and the without-case means that the future traffic matrix is assigned to the base year road networks.

4.2 Evaluation from the Viewpoint of Traffic Flow

Figure 11 shows the results of traffic assignment on the road networks in the Keihanshin Metropolitan Area in the with-case (in the case of with future road networks). In this figure, the band-width on each road link represents the estimated traffic volume in perspective.

Figure 12 shows the percentage decrease in the congestion ratio on each road link of the with-case compared with the without-case. ((Without-With)/Without). The congesion ratio is defined as traffic volume divided by road capacity. Differences of 10% or less are ignored here, and lines coloured in blue show a decrease and dotted lines coloured in red show an increase.

This figure shows that congestion on road links in the bay area, especially parallel to the Wangan Route and the Hanwa Expressway, decreases. The congestion ratio increases on the routes to access the Wangan Route. This means that traffic flows are shifted from city areas to the Wangan Route along the bay area.

4.3 Evaluation from Viewpoint of Shortest Travel Time

Figure 13 shows the contour of the shortest travel time to the central part of Osaka City in the with-case. Zones are coloured according to the travel time (time being measured in specific units). The shortest travel time is based on the congestion of each road link using the estimated traffic flow.

Figure 14 shows the percentage decrease in the shortest travel time of the with-case compared with the without-case ((Without-With)/ Without). Zones are also coloured in red with several levels of shading according to the percentage decrease. The shortest travel times decrease in most zones of the study area, and especially along the Osaka Bay area.

4.4 Evaluation from Viewpoint of Average Travel Time per Trip

Average travel time per trip originating in each zone, in both the with- and without-case, is calculated by the following equation.

$$Ti=\sum_j (t_{ij}\times OD_{ij})/\sum_j OD_{ij}$$

where T_i : Average travel time of trip originating in zone i

t_{ij} : Travel time from zone i to j

OD_{ij} : Number of trips from zone i to j

Figure 15 shows the percentage decrease in the average travel time of the without-case against the with-case ((Without- With)/Without) in a similar way as Figure 14. From this figure, it can be seen that the average travel time decreases in the districts mainly along the bay area, but the decreases are smaller and more limited than in Figure 16.

5. EVALUATION OF EFFECTS OF TRAFFIC MEASURES FOR DECREASING NOx EMISSIONS IN THE URBAN AREA

5.1 Traffic Measures

The simulation system for the urban area is applied to evaluate the effects of traffic measures on the decrease in NOx emissions in the Osaka City Area. In this study, the reduction of car traffic is implemented in the simulation as a traffic measure, and NOx emissions are estimated in each 500m grid. The whole city area of Osaka is divided into two districts, the central city district and the outer city district as shown in Figure 16. Traffic reduction in central city district varies from 0%, 5% and 10%, and that in the outer city district varies from 10%, 20%. Traffic measures are made as combinations of car traffic reduction in those two districts, and 6 cases in total are examined as shown in Table 1.

5.2 Total NOx Emissions

Figure 17 shows the decrease in total NOx emissions in the whole city area in each case compared with the present situation. This shows that an additional 10% traffic reduction in the central city district results in a 1.7% decrease in total NOx emissions throughout the city, and an additional 5% traffic reduction in the outer city district results in a 4.4% decrease in total NOx emissions. This means that car traffic reduction in the outer city district has five times the effect in decreasing NOx emissions in the whole city area as dose that in the central city area.

5.3 Distribution of NOx Emissions

Figure 18 shows NOx emissions for each grid. Grids are coloured in red with several levels of shading according to NOx emissions. Grids with high emissions concentrate along the circular urban expressway in the central city district, and there are also grids with high emissions along the main routes to neighbouring cities and in the bay area.

Figure 19 shows the grids in two selected cases where NOx emissions decrease by 10% or 20% compared with the present situation. Figure a) shows the case of a 20% traffic reduction in the central city district and Figure b) shows the case of an additional 10% traffic reduction in the outer city district. Areas where NOx emissions are decreased by traffic reduction in the central city district are found in limited areas such as the north west parts of the central city area. As Figure b) shows, additional

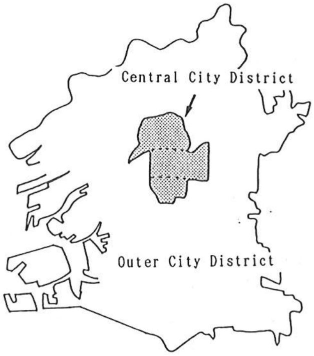


Figure 16. Districts for Reducing Car Traffic

Table 1 Cases of Analysis

% of Reduction in Car Traffic		CENTRAL CITY DISTRICT 10 %	CENTRAL CITY DISTRICT 20 %
OUTER CITY DISTRICT	0 %	Case 1	Case 2
	5 %	Case 3	Case 4
	10 %	Case 5	Case 6

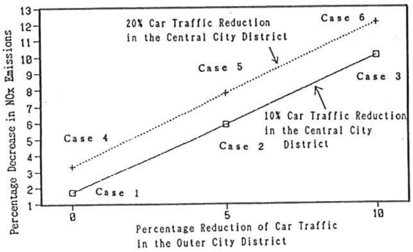


Figure 17. Percentage Decrease in NOx Emissions in each case Compared with Present Situation

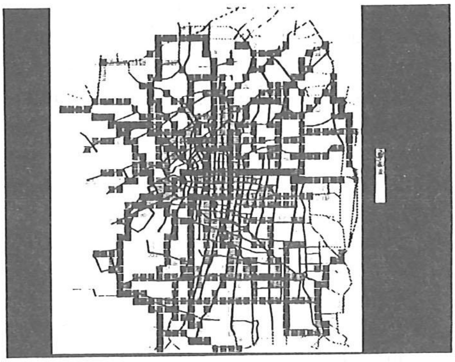
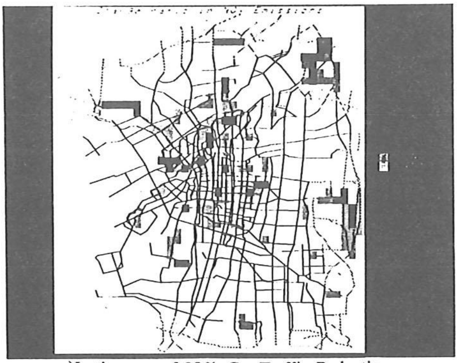
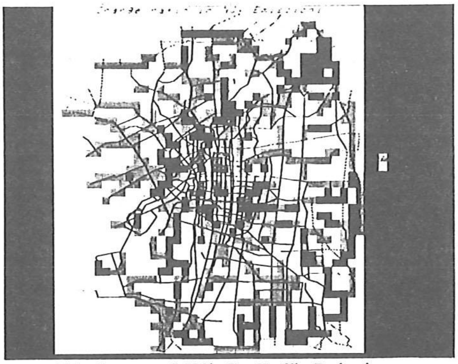


Figure 18. NOx Emissions of each Grid in Present Situation



a)In the case of 20% Car Traffic Reduction in the Central City District (Case 2)



b)In the case of 20% Car Traffic Reduction in Central City District and 10% reduction in the Outer City District (case 6)

Figure 19. Percentage Decrease in NOx Emissions of Each Grid

10% traffic reduction in the outer city district results in a NOx decrease in wider areas mainly in southern and eastern parts along the city boundaries.

CONCLUSION

In this paper, a road network simulation system, which is a key part of a computer-aided planning system, was developed for evaluating the effects of road network plans and related transport policies in the Keihanshin Metropolitan Area.

The major findings of this study are the following:

1. Traffic flows are estimated well in both the metropolitan area and the urban area, taking into account such travel resistance as road congestion and tolls in both areas.
2. There is an interrelationship between road network data-bases in the metropolitan area and the urban area, and traffic flows estimated in the urban area are based on an estimation of traffic flows in the metropolitan area.
3. Results are obtained by evaluating not only the whole area, but also local districts, and the results for each link, grid or zone can be made clear.
4. In addition to evaluation from the viewpoint of road users, NOx emissions are calculated for an evaluation index of local residents on the basis of estimated traffic flows.
5. Representing the output of traffic assignment graphically, including intermediate results obtained during the analysis, makes it easy to calibrate an assignment model.

In further research, the following subjects are hoped to be considered:

1. A data-base management system should be introduced for handling a large set of road networks and information produced during the planning process.
2. For improving the accuracy of the simulation system, the trip matrix should be replaced by the newest one in the traffic prediction model, and diffusion of NOx emmisions through the atmosphere has to be incorporated in the NOx estimation model.
3. It is necessary for the possibility to be examined of using visual presentation, based on network planning, for the purpose of facilitating community involvement in the planning process.

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