The Traffic-Control System on the Hanshin Expressway

TSUYOSHI YOSHINO
Hanshin Expressway Public Corporation
1-3, 4-chome, Kyutaro-Machi, Chuo-ku
Osaka, 541, Japan

TSUNA SASAKI
Faculty of Science and Engineering
Kinki University
Higashi-Osaka
Osaka, 577, Japan

TOSHIHARU HASEGAWA
Faculty of Engineering
Kyoto University
Kyoto, 606-01, Japan

In 1970, the Hanshin Expressway Public Corporation started operating an automated traffic control system to maximize the total traffic flowing into its expressway network. The corporation has been improving the system ever since. The system relies on two control methods. The first is to limit the cars coming onto the expressway at each entrance ramp to avoid congestion in any section. The system calculates the maximum allowable inflows by solving a linear programming problem once in every five minutes using data from detectors installed along the expressway and at all ramps. The second method is to give drivers the most recent and accurate traffic information about the expressway and its vicinity, including expected travel times and accidents, through various information channels so that they can decide what routes to take. This system is greatly appreciated by the corporation because it is extremely cost effective and also by drivers, who now consider it an indispensable service.

The Hanshin Expressway Public Corporation, Osaka, Japan, started with only a 2.3 kilometer stretch as the first urban toll expressway in Osaka City in June 1964. In October 1966, the corporation opened its expressway in Kobe City, the first link in its large-scale urban expressway network serving the Hanshin (Osaka-
The Hanshin Expressway

Kobe) area, the second most populated area in Japan. It now operates an expressway network of 200 kilometers. The average number of cars flowing onto the expressway in 1992 was more than 828,000 a day, up from 5,000 in 1966. Recently, the number of cars entering the expressway each day has sometimes exceeded 1,000,000. Figure 1 shows the present Hanshin Expressway and planned extensions.

The corporation recognized the importance of traffic control on the expressway network and set up a special committee on traffic control in 1966. After two years of study, the committee presented its recommendations. The corporation adopted them and started implementation in 1969. The committee consisted of experts in such fields as traffic engineering, computers, communication engineering, and economics and was chaired by Professor Eiji Kometani of Kyoto University, now a professor emeritus.

Figure 1: The network of the Hanshin Expressway covers the western part of the main island of the Japanese Islands with a total length of 200 kilometers. Solid lines show the portions of the expressway in operation and dotted lines show the network under construction.

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The committee recommended an automated traffic control system for the expressway to maximize the total number of cars entering the expressway and to avoid congestion at any point on the expressway, that is, to maximize the corporation's income from the expressway.

The corporation completed the first stage of the system in March 1970. Since then, it has been improving the traffic control system as it has expanded the expressway network and as new technology has become available. The technical committee for traffic control systems on the Hanshin Expressway, chaired by Professor Tsuna Sasaki of Kinki University, has taken over the work of the special committee.

**The Hanshin Expressway Network: How Does It Serve the People?**

As the network of the Hanshin Expressway has grown, the number of cars using it has steadily increased and, consequently, so has the degree of traffic congestion and the number of accidents (Figures 2 to 4). We defined a congestion index as the length of traffic jams multiplied by their duration in period. We consider a section of the expressway to be congested when the time occupancy of the sampling point of the section exceeds a certain threshold and at the same time the traffic volume there becomes less than a certain value. We estimate the length of the congestion by counting the number of consecutive sections that are congested, and the congestion's duration is the time from its start to its dissolution.

Although the total area of the Hanshin Expressway is rather small compared with the total area of the intercity expressways,

![Graph showing the length of the Hanshin Expressway from 1964 to 1994.](image)

*Figure 2: The length of the Hanshin Expressway has been expanding steadily. The jump in 1969 is for Osaka World Exposition and the jump in 1994 is for the opening of the Kansai International Airport.*
Figure 3: The number of inflow cars, the number of accidents, and the number of breakdowns in each fiscal year are shown. The number of breakdowns means the number of cases of malfunction among cars on the expressway.

Figure 4: The degree of congestion on the expressway in each fiscal year is shown. The congestion index is defined as the length of the traffic congestion multiplied by its duration in a period.

street, and avenues in the Osaka-Kobe area, the Hanshin Expressway plays an extremely important role there. For instance, according to a 1992 road survey carried out by the City of Osaka, the total area of roads in Osaka City is 38.35 km² and the total area of the Hanshin Expressway in Osaka City is 1.51 km², that is, 3.9 percent

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of the total. On the other hand, the total vehicle-kilometers (km) traveled in Osaka City is 20,870,000 while the total vehicle-km traveled on the Hanshin Expressway is 6,770,000. This means that the Hanshin Expressway network handles 32.4 percent of the entire vehicle-km with only 3.9 percent of the road area. The urban expressway is very efficient but the smooth flow of the traffic in the city depends on the smooth flow of traffic on the urban expressway network.

The average number of cars per unit of arable land in Japan is much more than that in the US. Almost all cities and towns in Japan suffer from severe traffic congestion. Because land is scarce, it is estimated that the capacity of the road networks will never catch up with demand. It will always be necessary to find ways to maximize utilization of the road networks, even in the far distant future.

The Traffic-Control System on the Hanshin Expressway

Most efforts to cope with traffic difficulties have been made in response to existing traffic problems. The Hanshin Expressway Public Corporation designed and constructed its traffic-control system to cope with expected or estimated problems. There was no traffic congestion on the expressway when the corporation initiated the design of the traffic-control system. Because they started designing the system in the very early construction stage of the expressway, the designers had tremendous freedom in its design. At the same time, they needed wide and profound knowledge and foresight.

The fundamental objective of the traffic-control system on the Hanshin Expressway is to afford expressway users smooth and sufficient flow as much of the time as possible, without causing significant trouble to the adjacent road networks. The point is to avoid congestion on the road network. Congestion is caused by accidents, maintenance work, disabled cars, and miscellaneous other reasons. One type of congestion is called natural congestion. Natural congestion is caused by saturated traffic flow rather than by traffic accidents, construction, or some other distinct reason. This type of congestion is the most common (Figure 5).

Traffic-control methods can be divided into direct and indirect. The direct method is to control the number of vehicles coming onto the expressway at each entrance ramp. This method has two phases. One phase of control is adopted to avoid natural congestion when the traffic flows on and around the expressway are in a steady state. The other phase is for emergency control to eliminate the effects of an accident as quickly as possible.

This first phase can be broken down into two subphases. The first subphase is the control of incoming traffic using a linear programming model to maximize the total number of vehicles entering the system while preventing traffic congestion in any section of the expressway and avoiding bad effects on the surrounding road networks. The system solves a set of linear programming problems once in every five minutes using data derived in real time from detectors measuring traffic volume, time occupancy, and speed. This is called LP Control.

Basically, detectors have been installed every 500 meters along the expressway.
Figure 5: Causes of congestion in fiscal year 1989 are shown. Breakdowns means the number of cases of malfunction among cars on the expressway.

and at all of the entrance and exit ramps. At the same time, the system takes into account various traffic parameters derived from off-line analyses. When traffic volumes on each on-ramp exceed certain predetermined values, and fluctuations in the traffic flow parameters are within predetermined ranges, LP control goes into effect. The mathematical formulation of this traffic control is shown in the appendix [Sasaki and Myojin 1968].

When fluctuations exceed the thresholds, the system employs the second subphase, sequential control. Sequential control is used when congestion is expected soon in one or more sections or when one or more sections are already congested and LP control is no longer effective. As is well known, once a section of a road becomes congested, its capacity decreases tremendously. The Hanshin Expressway tries to avoid congestion in any section of the network and to dissolve any congestion that does occur as quickly as possible. When necessary, it closes entrance ramps successively depending on the extent of the troubled section of the expressway. We derive the criteria to decide when and how many ramps should be closed or limited using various off-line but fairly up-to-date analyses and simulations. Using these criteria, the computer system indicates when and where the sequential control should be used.

The ramp-metering technique should be the best available technique for achieving the first phase control on the expressway. To our great regret, however, the expressway has not adopted ramp metering because we have not reached accord among the government agencies concerned. Therefore, this phase is only coarsely im-
implemented by controlling the number of open toll booths at entrance ramps in response to advice given by the control system.

The second phase of the traffic control concerns incidents. When a traffic accident or disabled vehicle blocks the flow of traffic on a section of the expressway, traffic capacity can decrease tremendously and the flow of cars can be impaired. In such cases, the inflow of cars upstream of the troubled section should be limited to minimize impairment at the troubled section. When necessary, vehicles approaching the troubled section are forced to exit the expressway at the off-ramps upstream of the troubled section. This is called emergency control, and it is a combination of sequential control and forced-exit control.

These control phases are designed to limit the number of vehicles entering the expressway to minimize oversaturation on the through lanes of the expressway. We avoid congestion or queues on the through lanes of the expressway by forcing incoming vehicles to queue up at each entrance ramp. As is well known to traffic engineers, concentrated queues on through lanes are much more hazardous to the traffic flow of an entire city than many short queues at entrance ramps.

Because the traffic-control methods we recommended have not been implemented sufficiently, indirect methods of control have become quite important. The basic idea of the indirect method is to give drivers on and near the expressway or even at home or in their offices a chance to decide for themselves what to do when they have to travel. We make every effort to give them the most up-to-date and accurate traffic information, including estimated travel times, for the expressway and its connecting road networks through various information media, including variable sign boards, roadside radios, telephones, personal computer networks, and the fax network. Most traffic information given is revised every five minutes. An automatic incident detection and warning system, however, automatically detects with image processing techniques incidents such as traffic accidents on the lanes of the selected portion of the expressway and warns drivers approaching the trouble spot within one second.

We expect that the indirect method will lead traffic flow as a whole into a kind of optimal equilibrium state within a short while. As a matter of course, adjacent traffic control systems, such as the surface street traffic-control systems operated by the police departments of the neighboring prefectures and the system operated by intercity expressway networks, exchange information.

**How to Implement the Idea**

To implement our fundamental ideas for traffic control, we constructed a hardware system divided into three subsystems: terminal equipment for collecting and transferring information, an information processing system, and an information transmission system (Figure 6).

The equipment used for collecting information consists of vehicle detectors, mainly ultrasonic detectors; TV cameras to monitor traffic; automatic vehicle identifiers that read figures on the license plates of passing vehicles; emergency phones every 500 meters; and meteorological equipment to monitor visibility and some road
conditions. To provide information to drivers, we employ variable sign boards, roadside radio stations, information terminals at service areas, travel-time indicators, graphic information boards, automatic phone service, personal computer network service, and information systems for the toll booth attendants. This equipment is operated automatically and is normally unattended.

The information processing system consists of computer systems and man-machine interface equipment, including control consoles, graphic panels, TV monitors, and graphic displays. The computer system consists of nine super-minicomputer systems configured as a functionally distributed hierarchical system and three hot stand-by computers. Almost all the information-processing systems are concentrated in the Osaka control center to make hardware maintenance easier and to take advantage of high speed communication lines between the two control centers, one located in Osaka and the other in Kobe. In these control centers, we have installed various man-machine interface systems to help the controllers in decision making.

When traffic flow on the expressway network is in a steady state, these control centers can function without an attendant.

The computers perform every function concerning real-time traffic control and some of the off-line analyses functions, such as statistical analyses and data logging. They also run a simulation program...
to estimate travel times between some points on the expressway that have no automatic vehicle identifiers for measuring travel times. We have many other simulation programs running on separate computer systems to study the behavior of the expressway, for example, for simulating congestion. These programs simulate the macroscopic traffic flow on the expressway network. They are quite effective aids to decision making concerning the current operation and the future design of the expressway.

The terminal equipment and information-processing system are connected with metallic wire, wireless, and optical fiber channels. Optical fiber channels transmit most of the information in the control system. Information is conveyed through these channels by voice signal, data signal, and video signal.

The corporation has installed an automatic incident-detection system at one dangerous point on the expressway. It consists of four TV cameras some distance apart. From the images transmitted by these cameras, an image-processing system detects every vehicle going through this point with its speed and direction. The information-processing system can detect an incident involving a vehicle or vehicles and debris within one second and send a warning signal to vehicles upstream of that point and to the control center.

**How Does the Traffic-Control System Affect Drivers?**

The traffic-control system of the Hanshin Expressway affects drivers in two ways: it gives them information about the traffic situation on the expressway and the neighboring road networks, and it limits their access to the expressway at entrance ramps. The traffic information drivers are given includes (1) the location, length, and cause of congestion, and weather conditions, which are posted on variable-character information boards, graphic information boards, roadside radio programs, taped phone messages, and personal computer network; (2) the estimated travel time between various points, shown on travel-time indicators, and included in roadside radio, taped phone, and personal computer messages; and (3) notice of any automatically detected incident ahead transmitted by the incident warning system.

In 1989, the Hanshin Expressway conducted a survey of users of the expressway through question sheets handed to drivers at some on-ramps to discover their attitudes towards the traffic-control system. The results of the survey mailed back to the corporation showed that

1. Almost all drivers pay attention to the information provided by the control system,
2. The travel-time information is valuable to them,
3. Roadside radio is also important,
4. They found the estimated travel time highly credible,
5. They are very tolerant of low travel speeds on the expressway,
6. About one third of the respondents do not like the inflow control at entrance ramps, and
7. Almost 90 percent of the users often change their routes in response to information provided by the traffic control system (Figures 7 to 9).

Drivers on the expressway are now
acclimated to the traffic-control systems after some years of learning that the information provided has high credibility. Figure 10 shows the ratios at which drivers detour according to the lengths and causes of the congestion they can expect if they stay on the expressway. If congestion is caused by an accident and its length is eight km, about 90 percent of the drivers shift to a surface street, while if the cause is natural congestion, the detour rate is only about 80 percent.

Drivers have come to recognize the traffic-control system of the Hanshin Expressway as an indispensable service, and so has the corporation.

What Are the Costs and Benefits?

The amount invested in the traffic-control system of the Hanshin Expressway, including the survey research between 1964 and 1981 was ¥7,500,000,000. The cost of maintaining the system in this period was ¥1,400,000,000, for a total cost of ¥8,900,000,000 (about US $84,800,000 at the March 1994 exchange rate). The total investment for the traffic-control system amounts to about one percent of the total toll revenue of the expressway.

The traffic-control system has many functions, such as surveillance of traffic flow, control of information systems, calculation of inflow control, collection of traffic data, logging, and analyses. Here we will estimate only the benefit of traffic surveillance. Without automatic measurement of traffic-flow parameters, the incremental
Figure 8: In 1989, we surveyed drivers to obtain their evaluation of the accuracy of estimated travel times given by the expressway and the traveling speed at which they feel that traffic is congested.

The benefits to users were also estimated by the Research Group of Traffic Engineering [1982]. They limited the benefit to the travel time saved by drivers using traffic information provided by the control system. According to surveys carried out when the traffic control was temporarily out of order for some reason, traffic control decreases the length of congested portions of the expressway by 30 percent and the duration by 20 percent. The Research Group of Traffic Engineering based these estimates on average lengths and durations of congestion with and without the control system.

The total amount of time saved by users from 1970 to 1981 is estimated as
Figure 9: The results of the 1989 survey of drivers on the expressway shows that almost two thirds of them admit the inflow control at entrance ramps is better than getting involved in congestion and that more than 90 percent of drivers would decide their routes in response to the information from the expressway.

17,850,000 hours. The average hourly benefit to the citizens of Osaka for the time saved totals about ¥27,300,000,000 (about US $260,000,000). The total benefit to users and to the corporation is estimated to be ¥33,600,000,000 (US $320,000,000).

We estimated these benefits conservatively, so the actual benefits of the traffic control system should be far more than the cost.

**Cooperation with Other Organizations**

Unlike almost all other public institutions in Japan, the related traffic-control systems in the Osaka-Kobe area cooperate exceptionally well. For instance, the police departments of the prefectural governments of Osaka and Hyogo (Kobe) have constructed traffic signals at the intersections near entrance and exit ramps to minimize undesirable effects on traffic flow on the expressway. The exchange of information between the institutions operating the traffic control systems of the intercity expressway and of the surface streets is also very good. Each institution transmits traffic information to related control systems once every five minutes and then to drivers via various channels.

Since March 1991, the police department of the Osaka Prefecture has been operating information boards giving estimated travel times at two points in the southern Osaka Prefecture. They show the estimated travel time from those points to the central busi-
ness district (CBD) of Osaka City via three alternative routes, a combination of their own travel-time estimates and those of the Hanshin Expressway. Iida et al. [1993] have been making repeated surveys to investigate the reactions of drivers. So far, more than 70 percent of the drivers who answered the questionnaire survey evaluate the accuracy of the estimates as better than "fairly good," and 50 percent of them often change their routes in response to the travel-time information shown.

In 1993, the police department of Osaka Prefecture also started a facsimile service for traffic information in the prefecture. By calling the traffic-control center via facsimile, anyone can obtain information on traffic congestion and its cause, road closures, estimated travel times between points, and so forth. People seem to find this a most useful service. Naturally, traffic information from the control center of the Hanshin Expressway is an important part of the information given.

**How Much Does This Control System Impact Other Systems?**

The traffic-control system of the Hanshin Expressway is the first automated traffic-control system in Japan, and it has been a model for everything from concept design to actual implementation for newer systems in Japan and in other countries. For instance, when Taiwan decided to implement its expressway traffic control, many of the Japanese committee members were invited to hold a seminar and to work as consultants [Taiwan Area National Freeway Bureau 1983].

Some of the subsystems of the traffic-control system, such as the automatic
roadside radio system and the travel-time estimation system have been adopted by the Osaka police department and by the Japan Highway Public Corporation and made a part of their traffic-control systems.

Conclusion

In September 1994, a new international airport opened on a man-made island in Osaka Bay. The police department of Osaka Prefecture, the Japan Highway Public Corporation, and the Hanshin Expressway Public Corporation are cooperating on operating the roads that serve the airport. Two Hanshin Expressway routes, one Japan Highway Public Corporation route and some arterial surface routes are coordinated. Although two railway companies are connecting the new airport to many cities in this area, the Hanshin Expressway network and its traffic control systems are expected to be very important.

The Hanshin Expressway Public Corporation will continue to cope with the difficulties and problems of one of the most advanced traffic-control systems in the world. One of the most important factors determining our success in designing, operating, and maintaining the traffic-control system is that we stressed selecting objectives and methods of control that relied on well-established theoretical concepts and that could be understood by expressway users. In comparison with the Metropolitan Expressway in Tokyo, Hanshin Expressway has much less congestion in spite of the fact that the average vehicle-kilometer for a day per unit length and the average trip length of vehicles on each expressway is almost same.

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APPENDIX: The Linear Programming Model to Control Inflow (LP Control)

LP control is formulated as follows:

Maximize

\[ Z = a_1u_{t,1} + a_2u_{t,2} + \cdots + a_ku_{t,k}, \]  
(1)

subject to

\[ X_1 = Q_{11}u_{t,1} + Q_{12}u_{t,2} + \cdots + Q_{1k}u_{t,k} \leq C_1, \]

\[ X_2 = Q_{21}u_{t,1} + Q_{22}u_{t,2} + \cdots + Q_{2k}u_{t,k} \leq C_2, \]

\[ \vdots \]

\[ X_m = Q_{m1}u_{t,1} + Q_{m2}u_{t,2} + \cdots + Q_{mk}u_{t,k} \leq C_m, \]  
(2)

and

\[ \text{subject to:} \]

\[ 0 \leq u_{t,i} \leq N_{t,i} + u_{i}^{d}, \quad i = 1, 2, \ldots, k, \]  
(3)

Where

\[ u_{t,i} \]  
the allowable inflow through the entrance ramp \( i \) (\( i = 1, 2, \ldots, k \)) between time \( t \) and \( t + dt \),

\[ N_{t,i} \]  
the number of vehicles waiting (queue length) at the entrance ramp \( i \) at time \( t \),

\[ u_{i}^{d} \]  
the estimated demand of inflow through ramp \( i \) (\( i = 1, 2, \ldots, k \)) between time \( t \) and \( t + dt \),

\[ dt \]  
control cycle, 5 minutes for the control system of the Hanshin Expressway.
$L_i = \text{the maximum number of vehicles allowed to wait at ramp } i,$

$X_{ih} = \text{the traffic volume estimated to flow at section } h \text{ of the expressway, } h = 1, 2, \ldots, m,$

$C_h = \text{traffic capacity of section } h,$

$a_i = \text{constant},$

$Q_{ih} = \text{constant},$

$k = \text{the number of entrance ramps under consideration},$

$m = \text{the number of sections}.$

$Q_{ih}$ is called the influence factor on entrance ramp $i$ on section $h$. It is the ratio of the traffic volume that will occur on section $h$ with the inflow of a single vehicle through entrance ramp $i$. This factor is estimated by surveying the trip path distribution of vehicles from each entrance ramp. A section of the expressway is defined as the expressway between successive ramps, and the traffic capacity of section $h$, $C_h$, or the maximum number of vehicles going through $h$ in a unit of time, may be determined by the bottleneck within section $h$.

If we set all $a_i$ in equation (1) to 1, we have a maximum of inflow traffic volume between $t$ and $t + dt$, and if we set $a_i$ as the mean trip length of vehicles flowing into the expressway through entrance ramp $i$, we have the maximum vehicle-kilometers in $dt$ [Sasaki and Myojin 1968]. When the demands entering from a ramp exceed a certain value, this LP problem may not have a feasible solution because of constraint (3). In this case, another control strategy is adopted.

**References**


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