PROC. OF JSCE
No. 343, March 1984

COMPUTER EVALUATION OF DRIVER-SIGN RECOGNITION

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1. INTRODUCTION

The safety of road traffic is improved by simultaneously conducting a broad complex of measures. A considerable portion of them are connected with improvement of traffic-control devices, which are basically visual communication techniques. These devices are the means by which the road user is advised of the detailed requirements or conditions affecting road use at specific places and times in order that proper action may be taken or delay avoided. Therefore, the traffic sign system should be evaluated according to the driver's visual capabilities and limitations for the different conditions of traffic.

However, evaluation and development of the sign system of a road require more detailed and specified information which cannot be provided through field observations. Solving this problem cannot be done without a tool with which the relation between the characteristics of traffic signs and the driver's visual behaviour and limitations can be analyzed as a system. Simulation programs can be used for design, procedural analysis, and performance assessment [Tritsker, 1974], and the technique of dynamic simulation on a digital computer can be well utilized in the analysis of such problems too complicated for field observations and analytical treatment.

This study describes the building and results of a digital computer simulation model which replicates the dynamic events of the signs' recognition by drivers, subject to their visual field limitations and eye-movement patterns, in different traffic conditions [Mōri, 1977]. This simulation model is a mathematical abstraction of several descriptive system characteristics including the roadway, the driver, the signs and the traffic conditions. The operations involved in this process include the introduction of different vehicles and signs into the system according to given rules of behaviour for sign-driver combinations. Through the evaluation of a traffic sign system, and using the efficiency-level index (ELI), modifications can be applied in order to increase its efficiency.

2. EFFICIENCY-LEVEL INDEX OF SIGN SYSTEMS

The efficiency-level index of sign systems was developed, from the sign-recognition point of view, in a previous study [Mōri, 1981] as a *comparative* index ranging between 0.0 and 1.0 as its lowest and highest values. It considers the two cases of overlooking (non-recognition: NR) and seeing (partial and total recognition: PR & TR) of traffic signs.

Many drivers completely absorbed in operating their vehicles simply do not notice road signs. This case is considered as *non-recognition*, in which the driver does not see the road sign at all. The case of *partial recognition* is when the driver glances at the sign gut for a time less than the time necessary to read and recognize its message. In this case the driver may recognize only the existance of the sign itself, but not its message. The ideal case of *total recognition* comes when the actual time of seeing the road sign reaches the time necessary to read and recognize it.

The eye-movement technique was used to measure the time necessary to see, read and recognize each type of road sign, and also the actual time the drivers spend reading these signs under different traffic conditions. In this technique, an eye-mark recorder was used with a camera operated at a speed of 18 frames per second, that gives an accuracy of 0.056 second for the eye's fixation duration. Comparing both actual time, AT, and necessary time, NT, gives the recognition levels and rates, as follows:

NR: $AT=0.0$
PR: $0.0<AT<NT$
TR: $AT \geqq NT$

The experimental work was conducted in the

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two directions of a 6.8 km road which contains 158 regulating and guiding signs. Subjects were 3 males age, 19, 25 and 30. All had valid driving licenses and a safe driving record with good vision.

The relative frequencies of drivers' fixation duration on traffic signs have been found to yield generally to the gamma distribution, with two parameters: the shape parameter k and the scaling parameter ν. The error evaluation function was initially calculated by using the least square method, next, an ileration procedure was conducting by applying Powell's method [Pwell, 1963, 1964]. This method is used generally for minimization of a function, without calculating derivatives, by changing one parameter at a time. Here, the method was applied to minimize the sum of the squared errors between both the experimental and estimated distributions, and at the same time to obtain the values of the shifted system parameters, k' & v'. Applying this method and obtaining minimization results illustrates the validity of the assumed distribution and also characterizes the shifted model. The two shifted parameters can be concluded from the gamma parameters by using the following two regression equations.

$$k'=0.9173k+0.3459$$

$$v'=1.0023v+0.0327$$

The proposed efficiency-level index is considers the two cases: over-looking (non-recognition: NR) and seeing (partial and total recognition: $PR+TR$) of road signs. For the former, since higher rates of NR mean lower efficiency, a sub-index I_1 is posited by using the relative rates of NR, as shown in the next equation.

$$I_1=1-NR$$

The latter (seeing the road signs) has a shifted gamma distribution, with the two parameters k' and v'. For the shifted-shape parameter k' which locates the distribution's peak, large values result in the distribution taking the shape of a right-skewed curve. This skewness locates the distribution's peak in the long-duration zone. Thus, the maximum value of k' for all the necessary time distributions, which was found to be $k'=6.22$, was considered to denote the corresponding highest sub-index of this parameter, $I_{k'}$, value of 1.0. Smaller or greater values of k' will result in reducing the system's efficiency to the lowest sub-index, $I_{k'}=0.0$, which corresponds to $k'=0.0$ as the minimum value and $k'=11.8$ as the maximum obtained value of the shifted parameter for all distributions.

On the other hand, the shifted-scaling parameter v', which affect the distribution's peak value, is estimated according to the necessary time, NT, distribution. The value of $v'=0.82$, which results in the highest frequency for the necessary time, is considered to give the highest sub-index $I_{v'}=1.0$. Smaller values of v' give lower peaks, and larger values result in higher peaks, but in the short-duration zone. Therefore, both reduce the sub-index $I_{v'}$ gradually to zero value at $v'=0.0$ or $v'=3.8$ which is the greatest value of v'.

Sub-index I_2 (seeing the traffic signs) is calculated to be the average of $I_{k'}$ and $I_{v'}$.

$$I_2=\frac{1}{2}(I_{k'}+I_{v'})$$

where,

$$\begin{aligned} I_{k'}&=0.16k' && 0.0\leqq k'\leqq 6.22\\ &=2.1122-(0.179k') && 6.22<k'\leqq 11.8\\ &=0.0 && k'>11.8 \end{aligned}$$

and,

$$\begin{aligned} I_{v'}&=1.22v' && 0.0\leqq v'\leqq 0.82\\ &=1.275-(0.335v') && 0.82<v'\leqq 3.8\\ &=0.0 && v'>3.8 \end{aligned}$$

Multiplication of the two sub-indeces I_1 and I_2 results in the efficiency-level index ELI.

$$ELI=I_1\times I_2$$

Table 1 summarizes the results of this method to obtain the efficiency-level index according to the functional sign classification in general conditions of traffic.

3. FEATURES AND ELEMENTS OF THE PROPOSED MODEL

The vision simulation model has been developed and validated as a general model incorporating the signs' height and position, the driver's visual characteristics and limitations, the structure of preceding large-sized or passenger vehicles, and traffic data for an urban road. This model can be used to study the effect of different variables involved in the problem of getting information from traffic signs. It has been structured so that any special feature can be included with minor modifications to the program logic.

The model was structured to examine the efficiency of a traffic sign system, considering the effect of sign characteristics and traffic conditions, especially when following large-sized vehicles. The other main conditions of traffic were considered also in the model, in addition to various characteristics of traffic signs and road geometry.

The model was coded in *FORTRAN IV* and was run on an *ACOS 77 NEAC SYSTEM* × 900 computer of Osaka University. The computer coding included several subroutines under control of the main program. The main program of

Table 1 Estimation of ELI of Function of Signs.

Classification of Signs	Number of Sighs	NT (sec.)	NR	k'	v'	ELI
Regulating Signs (R)						
Speed Limit (R1)	32	0.343	0.289	2.543 8	0.524 6	0.62
No-Parking (R2)	55	0.271	0.698	2.762 1	0.982 6	0.26
Turning Arrows Supported beside Signals (R3)	22	0.363	0.371	3.102 9	0.728 0	0.70
Guiding Signs (G)						
White Signs Supported on Pedestrian Bridges (G1)	17	0.436	0.404	2.024 7	0.414 6	0.63
Signs Supported beside Signals	14	0.383	0.395	4.239 4	0.908 1	0.42
Signs Supported on Roadside (G3)	5	0.308	0.395	4.239 4	0.908 1	0.42
Large Overhead Blue Signs (G4)	14	0.784	0.229	2.240 2	0.274 1	1.00
National Route Number Signs (G5)	5	0.370	0.643	10.675 3	3.808 4	0.00

this model functions as a monitor for the overall simulation system. A number of subroutines were developed to enable the computer to branch through the required logic patterns necessary in this simulation program. The most important elements are explained in the following paragraphs

elements are explained in the following paragraphs.

(1) Vehicular Speed

To assign the driver-sign characteristics randomly, vehicular speeds were dynamically simulated in the model's general case as generated variates for a random process to be limited between 20 and 50 km/h. When approaching each sign, the speed was considered constant due to the short distance during which the driver can see the traffic sign. This distance was also limited between maximum and minimum values of 120 and 20 m [Ishii, 1977].

The procedure for simulating normal variaties on a computer involves taking the sum of K uniformly distributed random variates r_1, r_2, $\cdots r_k$, where r_i is defined over the interval $0\leq$ ≤ 1 [Naylor, 1966]. This can be expressed by using the following computational form:

$$X=\sigma_x\left(\frac{12}{K}\right)^{0.5}\left(\sum_{i=1}^{k} r_i-\frac{k}{2}\right)+\mu_x$$

In this equation, x is the normally distributed random variate to be simulated with mean μ_x and standard deviation σ_x. Depending on the road traffic density TD, the mean and standard deviation can be concluded by using the following equations [Takata, 1965]:

$$\mu_x=59.2/(1+0.013TD)$$

$$\sigma_x=9.8/(1+0.017TD)$$

(2) Car-Following Principle

A specific car-following model for mixed traffic flow [Nakahira, 1976; Nitta, 1977; Mōri, 1978] was used on the basis that the flow characteristics of large-sized vehicles should be recognized in relation to other vehicles. The model considers the mixing ratio of large-sized vehicles as an index to express their influence on the traffic flow. By using the following equations of this model, the vehicular spacing was computed in order to obtain the effect of large-sized vehicles as sight obstructions.

$$S=S_i e^{V/V_m}$$

$$S_j=S_{jc}(P_l\gamma_l+P_c)$$

where

S = vehicular spacing;
S_j = jam spacing for mixed traffic flow;
S_{jc} = auto jam spacing;
V_m = critical speed, when the traffic volume is maximum;
V = following-car velocity;
P_l = percentage of large-sized vehicles;
γ_l = large-sized vehicle equivalency;
P_c = percentage of passenger vehicles.

At each generated speed, the calculated spacing between the preceding large-sized vehicle and the following vehicle was used to conclude the sight obstruction limits in respect to the driver's visual field. Large-sized vehicle equivalencies were assigned between 1.2 and 1.8 through a random generator which provides random numbers between 0.0 and 1.0. The dimensions of these vehicles were concluded to be within the standard recommendations [Hewes, 1977]. The value of the minimum spacing was taken to be the same as the auto jam spacing S_{jc}.

(3) Traffic Signs

Generation of traffic signs was randomly simulated according to a classification for sign position and height. The percentage of each type of traffic sign on the road was used for generating the traffic signs in a random process. Several groups for both overhead and roadside signs were also examined to obtain the effect of the signs' height and position on their rates of recognition and visible time.

4. MODEL COMPONENTS

(1) Main Program

The main program of this model functions as a monitor for the overall simulation system. The elements of the main program can be classified in the following manner:

① Initialize the non-visible and visible time, frequency and shifted parameters of the system.
② Provide initial seed values for all the rondom number generators.
③ Select the traffic condition.
④ Locate the preceding object, if any.
⑤ Increment the simulation time clock.
⑥ Locate sign-to-driver distance.
⑦ Select the road sign.
⑧ Perform computations involving the visual angles and driver's eye-movement pattern.
⑨ Provide information describing the driver's ability to see the traffic sign.
⑩ Prepare and provide output information for the required statistical analysis.
⑪ Calculate the signs' non-visible rate and visible time distribution and parameters.
⑫ Conclude the efficiency-level index of the road-sign system.

The overall logic of the simulation model's main program is presented schematically in **Fig. 1.**

(2) Subroutines

A number of subroutines were developed to enable the computer to branch through the required logic patterns necessary in this simulation program. The main subroutines are briefly described and inventoried below.

① NORMAL generates simulated normal varieties for the vehicular speed.
② OPEN estimates the sign's visible time

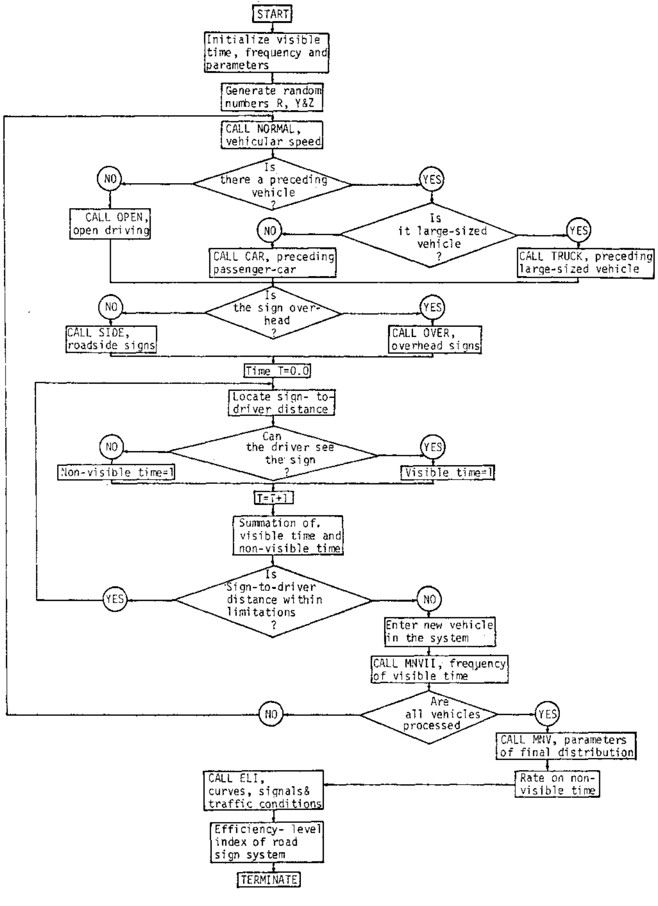

Fig. 1 Flow diagram of general simulation model.

frequency for the open driving case

③ CAR estimates the sign's visible time frequency for the preceding passenger-car case.

④ TRUCK generates randomly the equivalency of a large-sized vehicle and its dimensions.

⑤ OVER computes the vertical visual angles from the driver's eye to the overhead signs and also the angles of the sight obstruction due to the preceding large-sized vehicle.

⑥ SIDE computes the inclined visual angles from the driver's eye to the roadside signs and also the angles of the sight obstruction due to the preceding large-sized vehicle.

⑦ MNVII analyzes statistically the frequencies of the sign's visible rates, and also the rates of recognition for phase II of partial and total recognition.

⑧ SELI calculates the efficiency-level index, *ELI*, of the road-sign system as a combination for the different conditions of traffic according to their rates.

5. INPUT-OUTPUT INFORMATION

The input information required for this simulation model can be classified into the following general categories:

① Traffic characteristics
  a Vehicular speed
  b Traffic volume
  c Mixed ratio of large-sized vehicles
  d Dimensions of large-sized vehicles
  e Vehicular spacing
  f Open-driving rate
② Sign characteristics
  a Mixed ratio between overhead and roadside signs
  b Height of overhead signs
  c Height and lateral clearance of roadside signs
  d Number of signs at curves and with signals
③ Driver characteristics
  a Height of driver's eyes
  b Necessary time for traffic sign recognition
④ Program control data

The computer output is the product of an integration of the different variables affecting the driver's vision when getting information from traffic signs. In general, the putput information for each case includes the following:

① Number of times the sign cannot be seen by drivers due to traffic obstacles.

② Number of times the sign cannot be seen by driver due to other than traffic obstacles.

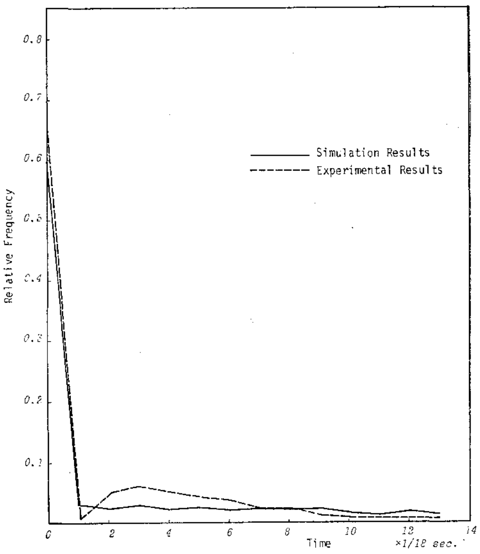

Fig. 2 Relative frequency of recognition distributions for simulation and experimental results.

③ Time-frequency distribution and parameters for the visible and recognition rates.

④ Efficiency-level index of the road sign system.

6. MODEL VALIDATION

Since the purpose of building a digital simulation model is to duplicate the real-world situation, the model performance must be verified. This was accomplished by comparing the signs' recognition distributions generated by the simulation model with those estimated from experimental observations.

The speed on the test road was limited at 40 km/h, while the average measured speed was 30 km/h, therefore, the simulated speeds were generated to be within a range of 20–50 km/h. Overhead and roadside signs were produced to correspond to their actual rates and positions. Overhead signs and had a height of 5.0 m, while the other group of roadside signs had a height of 2.5 m at a lateral distance of 4.0 m, since the vehicles were always moving in the curb lane.

In making this comparison to check the model's validity, the field data of the experimental investigation was used. The relative frequency distribution of the signs' recognition rates obtained from the experimental results is plotted in **Fig.** 2, together with the results of the simulation run of the same traffic condition for purposes of comparison. The results from the simulation model are in reasonable overall agreement with the experimental observations, especially for the non-recognition ($AT=0.0$) and total recognition ($AT \geqq NT$) rates. In this case $NT=0.421$ second, which is the necessary time for the total average signs.

Regarding the sign system's efficiency-level index for the general condition of traffic, the simulation results give an index of 0.17, while the experimental results give an index of 0.19. This also can be considered as another reasonable argument for the validity of the simulation model.

7. VEHICULAR SPEED AND EFFICIENCY-LEVEL INDEX OF SIGNS

The human element rather than design economy may determine the ceiling on design speed, since large percentages of accidents occur on straight sections of road under ideal driving conditions [Matson, 1955]. In determining this speed according to the human input system, one of the considerations should be directed for finding the suitable speed which allows drivers to utilize the road sign system more efficiently.

The generated variaties of the randomly simulated vehicular speeds were replaced in the model by constant values, ranging from 20 to 50 km/h, in order to obtain their effect on the efficiency-level index of the road sign system. As shown in **Fig. 3**, the ELI has higher values at the range of 25–45 km/h. Higher speeds result in reducing the time the sign can be seen in spite of the long resulting spacings between vehicles. On the other hand, lower speeds given shorter spacings which also reduce the signs' visible time. Consequently, ELI obtains smaller values in both cases. Considering the relative frequency of the various visible time durations, **Fig. 4** clarifies that the speed 40 km/h has the best distribution since it has few occurrences of short visible time duration. The test road's maximum speed is limited to 40 km/h, which is considered a suitable speed for such a road-sign system.

8. EFFICNCY-LEVEL INDEX OF SIGNS AND ACCIDENT PATTERNS

The determination of the cause of an accident is no simple matter; however, the most commonly designated cause of accidents is human error [Zeller, 1970]. Clearly the driver must do his part, but this is not by any means the whole problem. The need to reduce human error by easing the driving task can be accomplished through many different measures. One of them is to give drivers an efficient system for transmitting information, which depends mainly on traffic signs, even though there is no direct relationship between road accidents and drivers' failure to recognize these signs. In this part, and as an illustration of the model's application, the problem of how the accident rate depends on the efficiency-level index of signs is explored in order to obtain a proportional representation for both variables.

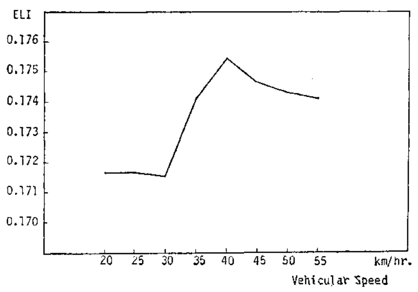

Fig. 3 Effect of vehicular speed on ELI.

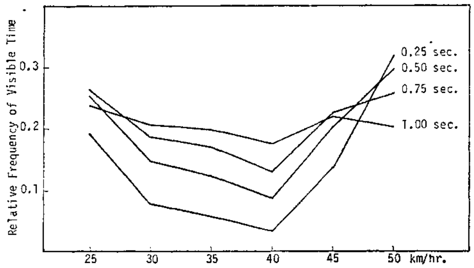

Fig 4 Effect of vehicular speed on relative frequency of AT.

The sign system of the test road which was used in the experimental work was improved during 1974, in addition to some other safety measures which were applied to make the road much safer and easier for driving. This test road is characterized as an industrial road passing many factories and warehouses. The two directions of a 2-km section of the road is considered in this problem, which deals with the factors affecting sign recognition in order to obtain the variation in trends of both the sign system's ELI and accident patterns in 1973 and 1975, i.e. before and after the improvements, by using the accident reports of the traffic department, Osaka Prefecture.

The factors involved include reducing the speed limit from 50 to 40 km/h, installation of more functionally recognizable signs, changing the overhead/roadside signs mixing ratio from 0.49/0.51 to 0.65/0.35, and increasing the lateral clearance between the curb-lane driver's eyes and roadside signs from 4.0 to 4.8 m. The corresponding values of *ELI* before and after ap-

Table 2 Number of Signs Before and After Improvements.

Sign	Number	
	Before	After
R1	13	9
R2	19	17
R3	4	6
G1	-	4
G2	1	6
G3	2	3
G4	1	11
G5	3	14
Total	43	60

Table 3 Number of Accidents Before and After Improvements.

Accident Type	Before	After
Human-Vehicle Accidents (HVA)	9	5
Vehicle-Vehicle(s) Accidents (VVA)	108	65
Single-Vehicle Accidents (SVA)	3	4
Total Accidents (TA)	120	74

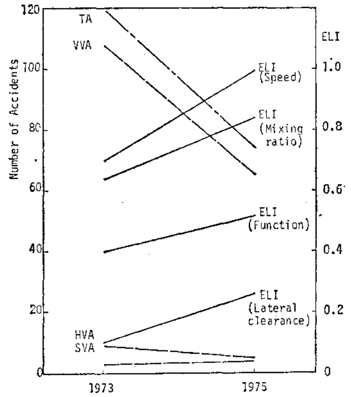

Fig. 5 Signs' efficiency-level index and accident pattern before and after improvements.

plying these improvements were estimated by using the simulated model. For the signs' functions, **Table 2** gives the number of signs for the 2-km section before and after the improvements, and, by considering the signs' quantity for each type, the *ELI* can be estimated as the weighted mean of all signs.

As for the accident patterns in 1973 and 1975, **Table 3** gives the number of accidents as classified into 3 groups: human-vehicle accidents (*HVA*), vehicle-vehicle(s) accidents (*VVA*), and single-vehicle accidents (*SVA*), in addition to the total accidents (*TA*).

The variation in trends for both the *ELI* of the signs and accident patterns before and after the improvements is clarified in **Fig. 5** for the different improvement measures. Generally, they represent inversely proportional quantities for the two variables, but in different degrees. The total number of accidents decreased by 38% in the time the *ELI* increased by about 20%. Increasing the efficiency of the sign system can be considered as a direct cause of decreasing the rates of accidents, it is certainly one of the main measures which is necessary for providing more safety on roads. These improvement might also be analyzed separately, without considering its interaction with signs, but here this research is dealing with the traffic-sign system recognition as an evaluation factor to get the relation between signs' *ELI* and traffic accident according to this point of view.

9. CONCLUSIONS

The performance of this simulation model is dependent upon the adequacy of the submodels describing the component functions of the system —including the roadway, the signs, the driver, and the traffic conditions, and upon the accuracy of the input information for the simulation runs. Its validation was conducted on the basis of available field data collected in actual situations. The results from the model are in reasonable agreement with the experimental observations for both recognition rates and efficiency- level indices.

Two applications were conducted by changing specific parameters, one at a time. The results show that, from the driver-sign recognition point of view, a road sign system can be modified to give a higher efficiency-level index. In any traffic-sign system, there are many non-visible signs but they are very essential for the road traffic. These signs will give a low *ELI*, and in this case, they should be also improved in order to fulfill their assumed function. These modifications of the sign system can be made mainly on the signs' positions to match the driver's visual input system. Other modifications can be made by applying some changes to vehicular speed and limitations of large-sized vehicles. Effects of these improvements on the *ELI* of the signs and their relationship with the accident patterns were explored, and the results represent inversely proportional quantities between both variables.

The model can be applied in evaluating and developing a road sign system according to human visual limitations and characteristics under different conditions of driving. This can be helpful in giving a road sign system the chance to be more effective.

REFERENCES

1) Hewes, L. I. and C. H. Oglesby: *Highway Engineering*, John Wiley & Sons, Inc., New York, 1960.
2) Ishii, I. and F. Kawabata: Signs' assessment, *Dōro Kensetsu*, 357, 40–46, 1977. (in Japanese)
3) Matson, T. M., W. S. Smith and F. W. Hurd: *Traffic Engineering*, McGraw-Hill, Inc., New York, 1955.
4) Mōri, M., S. Tanaka and M. H. Abdel-Halim: Driver eye-movement characteristics when driving in main roads, *Kaihō, kansai Dōro Kenkyū-kai*, 3, 3–11, 11/1977. (in Japanese)
5) Mōri, M., Y. Nitta and Y. Matsumoto: Simulation model for bus-mixed traffic flow, *Kansai Branch of the Japan Society of Civil Engineers*, IV-5, 1978. (in Japanese)
6) Mōri, M. and M. H. Abdel-Halim: Road sign recognition and non-recognition, *Accid. Anal. & Prev.*, 13(2), 101–115, 1981.
7) Nakahira, A., M. Mōri and Y. Nitta: Bus flow characteristics in constant conditions of mixed traffic, *Proceedings of the 33rd Annual Conference of the Japan Society of Civil Engineers*, IV-69, 1976. (in Japanese)
8) Naylor, T. H., J. L. Balintfy, D. S. Burdick and K. Chu: *Computer Simulation Techniques*, John Wiley & Sons, Inc., New York, 1966.
9) Nitta, Y., M. Mōri and Y. Matsuba: Characteristics of bus-mixed traffic flow concerning the bus-mixing ratio, *Proceedings of the 32nd Annual Conference of the Japan Society of Civl Engineers*, IV-165, 1977. (in Japanese)
10) Powell, M. J. D.: A rapidly convergent method for minimization, *The Computer Journal*, Vol. 6, pp. 163～168, 1963.
11) Powell, M. J. D.: An efficient method for finding the minimum of a function without calculating derivatives, *The Computer Journal*, Vol. 7, pp. 155～162, 1964.
12) Pritsker, A. A. B.: *The GASP IV Simulation Language*, John Wiley & Sons, Inc., New York, 1974.
13) Takata, H.: Application of computer simulation techniques to road traffic analysis, *Transactions of the Japan Society of Civil Engineers*, 12, 28–41, 1965. (in Japanese)
14) Zeller, A. F.: Accidents and safety, In De-Greene K. B. (ed.), *Systems Psychology*, McGraw-Hill, Inc., New York, 1970.

(*Received February 10, 1982*)