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Advance Information on the Road: A Simulator Study of the Effect of Road Markings

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Accident statistics and studies of driving behavior have shown repeatedly that curved roads are hazardous. It was hypothesized that the safety of curves could be improved by indicating in advance the course of the road in a more effective way than do traditional road signs. A code of sequences of stripes put on right edge of the pavement was developed to indicate to the driver the radius of the curve ahead. The main characteristic of this code was the frequency of transitions from code elements to gaps between elements. The effect of these markings was investigated on a driving simulator. Twelve subjects drove on simulated roads of different curvature and with different placement of the code in the approach zone. Some positive effects of the advance information could be observed. The subjects drove more steadily, more precisely, and with a more suitable speed profile.

INTRODUCTION

Several analyses have shown that the task of curve negotiation is one of the more difficult driving tasks. Bitzl (1967), comparing different kinds of roads, found higher accident rates along curves with a radius of ≤250 m. The chance of having an accident increases rapidly with decreasing curve radius: 4.5 accidents per million km driven were recorded on curves with a radius of ≤250 m; 12.0 accident per million km driven on curves with a radius of ≤125 m. According to Pfundt (1969), 65% of single car-accidents occurred on or near a curve. An analysis by an automobile insurance association (HUK, 1973) showed that features of the road played a significant role in 17.9% of all accidents analyzed; 49% of this percentage was attributed to curves. Of course, the data reported here are representative for the road network of the FR Germany. Observations in the US will presumably result in different figures because of the specific structure of the road network and the habits of the drivers in the US.

Guiding principles for the design of roads were developed in part on the basis of accident analyses. They are to be applied to the design of new roads as well as the redesigning of older roads. But, as Pfundt (1970) pointed out, only a minority of roads meet the existing design standards. Also, the conclusion of Shinar, Rockwell, and Malecki (1975) should be considered: that a design on the basis of purely physical and traffic engineering considerations is insufficient. Therefore, measures other than physical restructuring of roads have to be installed in order to reduce the hazards of certain road curves, and the intent of these authors was to do this by putting warning signs on the road edge. The signs were supposed to give information to the driver about the curve ahead. However, those signs were overlooked very frequently (Johansson and Rumar, 1966; Häkkinen, 1971; Johansson and Backlund, 1970; Scremec, 1973). The effect of this signing on the reduction of accidents can be improved by a careful design and favorable placement of the signs. The combination of a curve warning sign with a recommended speed has turned out to be particularly useful (Hammer, 1969; Rutley, 1972).

These measures took into account that a major cause of accidents on curves was an excessive speed of entry into the curve. However, many drivers selected an entry speed much higher than the curve would allow, not because they had not seen a specific road sign or disregarded a speed recommendation, but because they could not estimate their own velocity in relation to road conditions. This occurred particularly after extensive periods of driving at high speeds. Therefore, aids should be given a driver approaching a curve for selection of entry speed and for the speed in negotiating the curve. An effective attempt in this direction was reported by Denton (1973). By painting transverse stripes on the pavement across the road in a section of an expressway before its merging with the main stream of traffic, he tried to provide a perception of the speed driven which is proportional to the real speed. This section of the expressway had a high accident rate due to excessive speed. After these markings were installed a lower speed was observed, and within the 19 months after installing the markings, only two accidents were reported compared with 14 accidents in the 12 months before installation. Along with some other modifications of the perceptual features of a curve, this procedure was employed by Shinar, Rockwell, and Malecki (1975).

Objective of the Study

Indication of curve features. It was the objective of this study to explore the possibilities of giving advance information to the driver concerning features of the road ahead more effectively than does the traditional road sign. A code consisting of a continuous sequence of markings on or beneath the road seemed to be an appropriate display. A code of this type is presumed to have the following advantages over traditional road signs:

(1) The information is present all the time and cannot be ignored.
(2) The markings on roadside do not have to be interpreted by the driver; they are self-evident and influence the behavior in a way which makes little demand on his central processing capacity.
(3) No learning is needed.

With this information available, the driver was expected to drive more smoothly and safely. Smoothness of driving was expected because the driver could avoid abrupt changes of speed. Safer driving was expected because the driver would be better prepared to select the appropriate speed.

Parameters of curves. Among the parameters describing course and demands of a curve, the following were considered to be most important:

(1) The direction of a curve,
(2) The radius of a curve,
(3) The most appropriate speed for curve negotiation, and
(4) The relationship between the appropriate entry speed and the appropriate curve negotiation speed.

Early information about the direction of a curve may be useful to initiate anticipatory reactions of the driver, but this aspect alone does not sufficiently indicate the difficulty of a curve negotiation. The relationship mentioned in 4 above was proposed by Babkov (1970) as a coefficient which characterizes the safety of a road stretch. This figure alone, however, would presumably be too compli-

TABLE 1

Lengths of Stripes and the Assigned Radii of Curves

Stripe Number	Length of Stripe (m)	Radii of Curves (m)
1	1.00	20– 35
2	1.50	36– 50
3	2.25	51– 75
4	3.38	76–120
5	5.06	121–200
6	7.95	201–300

The radius. Curves with radii between 20 and 300 m were used. The curves were ordered in six classes to which stripes were assigned as indicated in Table 1. Each experimental road contained an equal number of curves. Details about the road design are shown in Table 2. In order to measure the mental load of the subject, a secondary task as well as physiological measures were included in the experiment. However, design and results of this part of the experiment have been reported elsewhere (Witt, 1976).

Dependent Variables

A first group of variables referred to the handling of the steering wheel, gas pedal, and brake pedal which were taken as indicators of specific aspects of driving behavior. For example, measures of control handling can register rapid movements which are not re-

TABLE 2

Summary of the Road Design (Roads 4–7)

	Class of Curves	Roads 4/5		Roads 6/7	
		Min.	Max.	Min.	Max.
1	Radius (m)	20.00	35.00	20.00	35.00
	Length (m)	15.00	25.00	37.50	62.20
	Length (deg)	43	41	107	102
2	Radius (m)	36.00	50.00	36.00	50.00
	Length (m)	18.00	30.00	45.00	75.00
	Length (deg)	29	34	72	86
3	Radius (m)	51.00	75.00	51.00	75.00
	Length (m)	22.50	37.50	56.25	93.75
	Length (deg)	25	29	63	72
4	Radius (m)	76.00	120.00	76.00	120.00
	Length (m)	29.25	48.75	73.10	121.85
	Length (deg)	22	23	58	58
5	Radius (m)	121.00	200.00	121.00	200.00
	Length (m)	39.35	65.60	98.45	164.00
	Length (deg)	19	19	47	47
6	Radius (m)	201.00	300.00	201.00	300.00
	Length (m)	54.55	90.95	181.90	227.35
	Length (deg)	16	17	52	43
	Straight Stretches (m)	180.00	360.00	90.00	180.00
	Advance Information (m)	35/70		35/70	
	Curvature (deg/m)	8.88		31.10	

flected by the vehicular dynamics. Vehicular dynamics were represented by position and speed of the simulated car.

Subjects

The 12 subjects employed in this study were male students of the Munich Technical University. They were paid volunteers, ranging from 21 to 32 years in age, and each had driven a car for at least 50,000 km.

Experimental Design

The subjects were randomly divided into two groups; one group drove on roads with low curvature (8.9°/m), the other only on winding roads (31.1°/m). Within a group each subject drove six different courses: two without advance information, two with late-displayed advance information, and two with early-displayed information. In each pair of roads, one road was driven with and one without a secondary task. The balanced sequence of the six experimental sessions designed to control effects of transfer and learning can be seen in Table 3.

TABLE 3

Experimental Design

		IiA-0		*IiA-1*		*IiA-2*	
	S	*ST-0*	*ST-1*	*ST-0*	*ST-1*	*ST-0*	*ST-1*
C=8.9	1	2	3	4	1	6	5
	2	3	2	5	6	1	4
	3	1	4	3	2	5	6
	4	6	5	2	3	4	1
	5	4	1	6	5	2	3
	6	5	6	1	4	3	2
C=31.1	7	2	3	4	1	6	5
	8	3	2	5	6	1	4
	9	1	4	3	2	5	6
	10	6	5	2	3	4	1
	11	4	1	6	5	2	3
	12	5	6	1	4	3	2

IiA-0: no information in advance
IiA-1: late information in advance
IiA-2: early information in advance
ST-0: without secondary task
ST-1: with secondary task
S: subject number
C = curvature (deg/m)
The numbers within the cells indicate the sequence of the experimental conditions.

Procedure

The experiments were carried out in two phases: a period of training and the experimental session on two successive days. In the training period the subject was exposed to simple as well as difficult roads which were similar to the roads in the experimental sessions but were not identical with them. The training and the experimental phase together took about six hours, between 8 and 15 minutes to drive each course, with a rest between courses.

Hypotheses

By means of early and unambiguous information about the road ahead, a driver will be enabled to make anticipatory reactions. That is, he will develop an appropriate reaction pattern before a response is demanded. Also, he will not become embarrassed by unexpected features of the road and will respond less in a uncoordinated manner. Assuming a positive relation between anticipatory behavior of this kind and traffic safety, the general hypothesis can be formulated that advance information about the road ahead, given by markings on the road, will improve traffic safety. This general assumption has to be broken down into several testable hypotheses.

(1) The track driven on a road with information in advance will be more precise with respect to the course of the road. For example, it should happen less frequently that the driver can avoid going off the road only by "cutting" the curve.
(2) A road with advance information will be driven more steadily; the number of sudden and abrupt usage of controls will decrease.
(3) On a road with advance information, a greater number of speed changes are expected because the driver can better adapt his speed to

the course of the road, *i.e.*, the driver will speed up on straight stretches and decelerate before curves. The speed changes were expected to occur well-timed before a curve.

RESULTS

The dependent variables were registered with a frequency of 10 Hz. This resulted in about 50,000 data points for one road. The data were recorded and stored on magnetic tapes for each of the twelve courses for each subject. As mentioned earlier, several variables were established describing aspects of control actions (brake, gas pedal, steering wheel) and of vehicular dynamics. Brake applications had to be excluded from the data analysis because several subjects did not use the brake at all. Arithmetic means and standard deviations were calculated for the following variables:

(1) Time of gas pedal operation (s),
(2) Time of gas pedal non-operation (s),
(3) Position of gas pedal (deg),
(4) Speed of gas pedal motion (deg/s),
(5) Speed of gas pedal pedal forward motion (deg/s),
(6) Speed of gas pedal backwards motion or release (deg/s).
(7) and (8) 1st derivatives of gas pedal motion >0 deg/sec^2 and <0 deg/sec^2.

The variables (3) to (8) were calculated only for time periods within (1). With respect to turning the steering wheel respective variables were calculated (9-14) with some exceptions: the obtained indices covered the total experimental session not only certain time periods as in case of gas pedal operation. Instead of pushing and releasing the gas pedal, steering the wheel to the right and to the left were considered as separate variables.

Vehicular dynamics.

(15) Tracking error cm: deviations of track from the center of the lane.
(16) Speed (km/h).
(17) 1st derivative speed (>0 m/sec^2): acceleration.
(18) 2st derivative of speed (<0 m/sec^2): deceleration.
(19) 2nd derivative of speed (>0 m/sec^3).
(20) 2nd derivative of speed (<0 m/sec^3).

The calculations were done in two steps. First, in a general processing, the mean and standard deviation were calculated for the complete driving program to show if the independent variables had any effect at all on the dependent variables. In the second step, the figures were calculated only for curve approach zones and separately for each class of curves. A stretch of road 50 m preceding the curve was considered to be the curve approach zone. Arriving at the beginning of this stretch, the curve is just within view of the driver. Although the driver would be able to react to the curve at that point without additional advance information, this information, if it were available, should modify the driver's curve entry speed.

Statistical Procedures

To investigate the effects of the experimental treatments several three-factorial and four-factorial analyses of variance were performed: Factor A, curvature (2 levels), Factor B, advance information (3 levels); Factor C, secondary task (not reported here); Factor D, curve radii (6 levels, only included in the detailed processing). According to the experimental design, each subject runs at all levels of Factors B, C, and D, but at only one level of Factor A. Table 4 shows the results of the general processing and Table 5 the results of the detailed processing where (*) indicates F-tests with a level of significance of 0.05. Only dual interactions were considered.

Influence of Advance Information

Precision of driving. Hypothesis (1) formulated earlier predicted that on roads with advance information the driver will drive more

TABLE 4

F-tests of the Analysis of Variance: General Processing

		AM							SD						
Number	*Variable*	*A*	*B*	*C*	*AB*	*AC*	*BC*	*ABC*	*A*	*B*	*C*	*AB*	*AC*	*BC*	*ABC*
1	Time of handling the gas pedal (s)														•
2	No handling of the gas pedal (s)														
3	Position of gas pedal (deg)			•						•					
4	Speed of gas pedal motion (deg/s)	•		•		•					•		•		
5	Forward motion (deg/s)														
6	Backward motion (deg/s)	•		•		•					•		•		
7	1st deriv. of gas pedal motion >0 (deg/s²)														
8	1st deriv. of gas pedal motion <0 (deg/s²)					•							•		
9	Position of steering wheel (deg)	•							•	•		•			
10	Speed of steering wheel motion (deg/s)	•	•							•		•			
11	Motion to the right (deg/s)		•							•		•			
12	Motion to the left (deg/s)		•							•					
13	1st deriv. of steering wheel motion >0 (deg/s²)		•												
14	1st deriv. of steering wheel motion <0 (deg/s²)									•					
15	Tracking error (cm)														
16	Speed (km/h)			•						•					
17	1st deriv. of speed >0 (m/s²)														
18	1st deriv. of speed <0 (m/s²)			•							•	•	•		
19	2nd deriv. of speed >0 (m/s³)			•							•				
20	2nd deriv. of speed <0 (m/s³)			•							•				

• $p < .05$
A = Curvature
B = Information in advance
C = Secondary task

precisely, that is, the driver will be more able to keep the desired course. A measure of this precision is the tracking error (15). According to Table 4 this measure was not affected significantly by any of the treatments, although the tracking error tends to decrease on roads with advance information (Figure 2a). Table 5 and Figure 3a show the *F*-tests for the tracking error for the approach zones. Apparently, course following before curve negotiation was influenced by the radius of the curve. This explains the significant *F*-test on Factor D: the tracking error was greater when approaching a sharp curve than when approaching a flat curve. However, this tendency was evidently modified by advance information as indicated by the significant interaction between Factor B and Factor D. If advance information were available, the tracking error was smaller when approaching a sharp curve but was independent of the advance information in case of flat curves.

These results support the hypothesis with regard to the precision of driving. The advance information did not, however, influence the precision of driving everywhere to the same degree, but only before sharp curves.

Steadiness. According to hypothesis (2), the subjects were expected to drive more steadily on roads with advance information, that is, sudden and abrupt control actions should be observed less frequently. These expectations referred primarily to brake pedal and steering wheel operation. With respect to hypothesis (3), this behavior was not assumed for the gas pedal. This will be explained in more detail in the next section. Because the brake handling had to be excluded from the

TABLE 5

F-tests of the Analysis of Variance: Detailed Processing of the Approach Zones

Number	Variable	AM										SD									
		A	*B*	*C*	*D*	*AB*	*AC*	*AD*	*BC*	*BD*	*CD*	*A*	*B*	*C*	*D*	*AB*	*AC*	*AD*	*BC*	*BD*	*CD*
1	Time of handling the gas pedal (s)				*					*	*										
2	No handling of the gas pedal (s)		*		*			*		*											
3	Position of gas pedal (deg)		*	*	*					*				*	*	*					
4	Speed of gas pedal motion (deg/s)		*	*	*	*				*				*	*	*				*	
5	Forward motion (deg/s)																	*			
6	Backward motion (deg/s)		*	*	*					*			*		*					*	
7	1st deriv. of gas pedal motion >0 (deg/s²)																				
8	1st deriv. of gas pedal motion <0 (deg/s²)		*	*	*	*				*						*					
9	Position of steering wheel (deg)				*				*						*					*	
10	Speed of steering wheel motion (deg/s)			*	*					*				*	*					*	
11	Motion to the right (deg/s)	*			*				*			*			*				*		
12	Motion to the left (deg/s)				*					*					*			*			*
13	1st deriv. of steering wheel motion >0 (deg/s²)	*			*							*			*						
14	1st deriv. of steering wheel motion <0 (deg/s²)				*										*	*			*		*
15	Tracking error (cm)							*							*					*	
16	Speed (km/h)			*	*					*			*		*			*		*	
17	1st deriv. of speed >0 (m/s²)	*		*	*			*		*		*		*	*		*			*	
18	1st deriv. of speed <0 (m/s²)				*			*							*			*			
19	2nd deriv. of speed >0 (m/s³)		*		*								*	*	*						*
20	2nd deriv. of speed <0 (m/s³)				*						*							*			

*$p < .05$
A = curvature
B = information in advance
C = secondary task
D = radius of curves

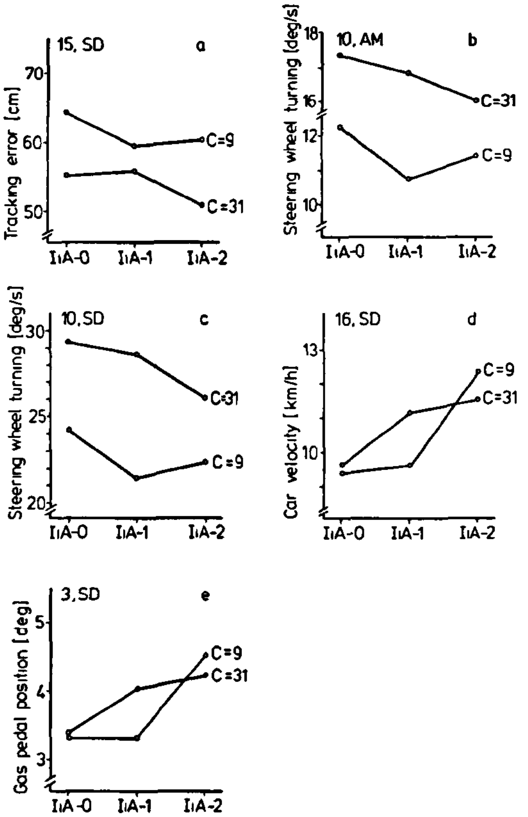

Figure 2. *Graphic presentation of some analyses of variance—general processing of Factor A and B.*
IiA - 0: no advance information; C: Curvature
IiA - 1: late advance information; AM: Arithmetic Mean
IiA-2: early advance information; SD: Standard Deviation

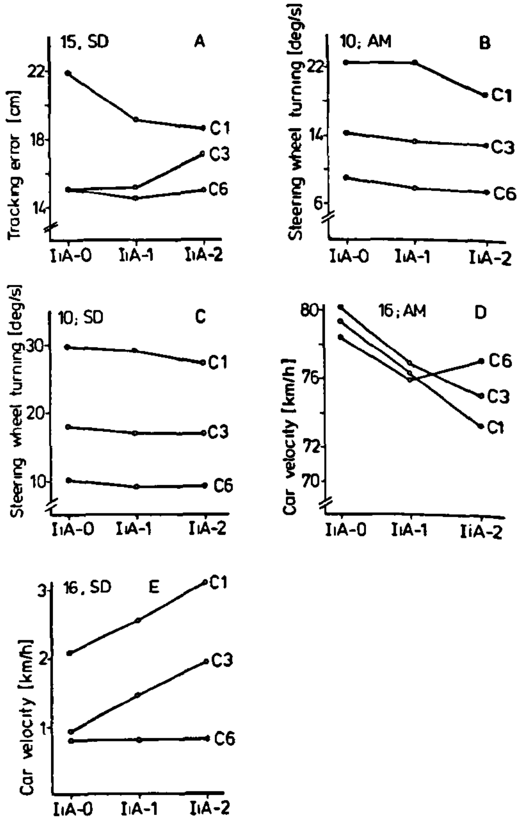

Figure 3. *Graphic presentation of some analyses of variance—detailed processing of Factor B and D. C1, C3, C6; Curves 1, 3, and 6*

data analysis, only the steering wheel control will be dealt with here.

This analysis resulted in a number of significant *F*-tests indicating a systematic influence of the advance information. Because abrupt steering wheel control actions would increase the recorded average speed of these actions, it could be predicted from hypothesis (2) that the average speed of turning the steering wheel should be lower on roads with advance information than on roads without advance information. As can be seen from Figure 2b, this was the case.

Also the dispersion of the turning speeds was expected to be smaller on roads with advance information because a steady handling of the steering wheel would reduce the variation of the turning speeds. This is shown in Figure 2c. This figure also allows us to interpret the significant interaction between Factors A and B. Obviously, the advance information was able to reduce the speed of turning to a greater extent on winding roads than on straight ones. The interaction between Factors B and D in the detailed processing can be understood in the same way: the advance information had a stronger influence in approaching sharp curves (Figure 3b and c). The turning speed data support the conclusions already reported.

Speed variability. It was hypothesized that a greater variability in driving speed would occur on roads with advance information because the driver could develop a speed profile better suited to the course of the road. It was also hypothesized that the driver would change his speed in a well-timed manner, that is, before curves, not in curves. The standard deviation of speed measures, as well as the handling of the gas pedal, could be used to test the effect of the advance information (Table 5; Figure 3e). This diagram also explains the interaction between Factor B and Factor D. Again, the advance information had more effect on approaching sharp curves than on approaching flat curves.

With respect to the handling of the gas pedal, contrary predictions could be drawn from hypothesis (2) and (3). According to hypothesis (3), a greater variability of driving speeds was predicted which could only be the result of manipulating the gas pedal. Therefore, the standard deviation of the position of the gas pedal should be greater on roads with advance information than on roads without. This prediction turned out to be correct as can be seen from Table 4 and Figure 2e. This result was not in contradiction to hypothesis (2) which only predicted the speed of gas pedal handling, not its position.

Moreover, according to hypothesis (3), one would have expected that the more frequent activation of the gas pedal on roads with advance information should result in a higher average speed of gas pedal activation as well as in a larger standard deviation of these speed measures. This expectation, however, is not compatible with the predictions from hypothesis (2).

DISCUSSION

The purpose of the simulator experiment reported was to find out if advance information about the course of a road ahead displayed to the driver by markings on the pavement might improve traffic safety. The advance information was introduced as an aid to facilitate the driving task, not as a tool to regiment the driver's actions as many road signs attempt to do. This could be done particularly by providing information which is important and/or hard to get.

The experiment was based on the assumption that advance information can enable the driver to make anticipatory responses to future circumstances, that is, to develop a pattern of actions before he is confronted with the circumstances in question. These results supported this assumption based on data from both handling and vehicular dynamics. The following specific effects were observed:

(1) The precision of course-following increased, especially in the approach zones to curves.
(2) Steering wheel turning became more steady and smooth.
(3) The subjects developed speed profiles better suited to the course of the road; they drove slower on difficult road sections and faster on easy road sections; this adjustment was well-timed during approaching curves. Therefore, the following conclusions can be considered as confirmed sufficiently.
(a) The subjects were able to receive and to process the advance information.
(b) The predictive character of this information was recognized by the subjects.
(c) The advance information contributed to a modification of driving actions critical to safe driving on a winding road.

On the other hand, these results did not reveal very much about the way the driver was processing the advance information. The question remains open as to whether effect was due to the fact that the advance information directly influenced speed perception or whether the driver decoded the information and consciously selected a more appropriate speed.

Also, this investigation did not allow a comparison of the effects of markings on the pavement and of the traditional road signs, because the driving simulator could display only a schematic picture of the road. The probability that the driver would ignore a road sign would be much lower in the simulated environment which contains much more limited stimuli than the real world. On the other hand, the probability that the driver will ignore the stripes on the pavement is much lower than the probability of overlooking a road sign. The stripes on the pavement will appear in the driver's field of view with great certainty; also this information will be permanently available.

Because the results obtained were based on simulated driving behavior, the question has to be asked as to whether these results can be generalized to the real world. The answer to this question can only come from field studies. It might be possible to validate the results of simulator experiments to some extent by more indirect criteria. Similarities between driving on real roads and driving on simulated roads can provide indirect criteria. For example, average speeds on real and simulated roads which have the same design characteristics should be comparable. The speed profile should depend on the width of the lane and the curve radius in both the simulator and on real roads. Attempts in this direction, however, have not yet begun.

The final decision about the usefulness of road markings can be made only after investigating the effect of the suggested codes in the real world. An investigation of this kind is highly recommended. As far as our results can be interpreted, the modification of the road characteristics by markings will not introduce new hazards, *e.g.*, increasing the overall speed. The simulator experiment carried out allows only conclusions about the effect of advance information on single vehicles. In a second study the effect in question will be investigated with another simulated car in front of the subject vehicle.

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