A New Method of Measuring the Effects of Continued Driving Performance

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A research instrument has been developed over the last four years and is now available for studying driver performance objectively under actual driving conditions. This report describes a new method of evaluating the effects of fatigue on driving performance using this equipment. A mathematical rating system is developed based on the results of this preliminary experiment and pre-tests. Examples demonstrate how the equations are used for rating the degree of driver fatigue at several stages of the test run. The results of this test are now being used in planning a new experiment for studying driving fatigue on a small population of drivers. The same approach can also be applied to study the effects of drugs, alcohol, and physical deficiencies on driver performance.

•FATIGUE has at least three meanings: subjective fatigue defined as the feeling of being tired; physiological fatigue as determined from bodily changes; and objective fatigue when performance of a task shows a progressive deterioration.

Crawford (1) discusses driving fatigue in the following manner: "It is generally agreed that performance can be impaired by driving for too long a period but it has proved extremely difficult to define what is meant by driving performance, to develop adequate techniques of measuring it, to interpret signs of deterioration in performance and to define the amount of deterioration which might reduce safety."

Because there has been no satisfactory means of measuring driver competence objectively, it has been necessary to study driving fatigue indirectly by measuring physiological changes assumed to influence driving skill, and by assessing decrements in tasks assumed to be related to driving safety.

SUBJECTIVE CLASSIFICATION OF DRIVER FATIGUE

In order to develop objective measures of driver fatigue, it is first necessary to agree on a subjective classification. The following categories, in order of increasing severity, are suggested by the author:

1. An increase in nervous tension resulting in stronger responses to minor irritations.
2. An acceptance of more errors because of a loss of desire to maintain accurate performance.
3. Larger errors resulting from a higher threshold of arousal to danger.
4. A momentary loss of operating control.
5. A complete loss of operating control.
6. A loss of consciousness.

The several levels of fatigue described may occur simultaneously, but it appears that a driver usually follows this pattern as the effects of fatigue increase. Recovery from one stage to a less critical stage occurs occasionally during the early periods of

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fatigue, but recovery will occur less often as fatigue progresses. Before the development of the Greenshields drivometer (2) it had been only possible to estimate the stages of driving fatigue by subjective observation and by physiological measurements. However, with the development of this equipment it now appears possible to directly record the performance of drivers in tracking and speed control. These fundamentals of the driving task indicate the first signs of fatigue including tension, errors, acceptance of wider tolerances and early indications of loss of control.

MOTIVATION

One of the complicating factors in human engineering research is motivation of the subjects. Certainly in driving experiments related to fatigue, the problem is one of major importance.

Jordan (3) claims that the problems of motivation have generally been overlooked. In discussing the subject he states, "To the extent that a job challenges the operator, it is intrinsically satisfying." He points out that a job must be difficult and requires skill to be challenging. "At the same time it cannot be too difficult. It must permit degraded performance. Inefficiency beyond certain tolerances cannot be tolerated. Each task must have a built in optimum range of permissible degraded performance on the part of the human operator. The operator must have relatively immediate feedback as to how efficiently he actually is operating so that, to the extent that he is inefficient he can improve his skills and to the extent that he is efficient he can maintain them. Feedback which is either too late or irrelevant in helping the operator is damaging."

The driving task fits Jordan's description of a satisfying task. Driving is usually a challenging experience. There is room for degraded performance, and there is a reasonable amount of immediate feedback under normal conditions. However, when the driver begins to tire he loses much of his attention to feedback. As a result he cannot track the vehicle as well or maintain as constant a speed as when fresh and alert. It is recognized that most people will be highly motivated to do their best when being tested. However, the motivation of the subjects can be modified by the experimentor by pre-test instructions when considered necessary.

The drivers participating in this pilot test were subjected to several motivating factors. They were making every effort to perform in a safe manner as the task was carried out on the highway; however, the subjects knew that a study of fatigue was the sole purpose so there was an incentive to permit fatigue to take over. The drivers also knew which variables were being measured so another bias was inherent. Nevertheless, in a 12-hr drive it is not humanly possible to influence the fundamental results appreciably. In the next experiment, it is planned that drivers will not know the nature of the experiment or the variables being measured to eliminate bias from these factors.

Motivation to perform in a safe manner might be considered as the opposing force to the degraded performance caused by fatigue. The oscillations in vehicle control caused by these two forces probably become less stable as fatigue progresses and an accident can occur when motivation weakens sufficiently to cause instability of control (see Fig. 12).

It may be possible to study the cycles of driver performance caused by the interaction of safety motivation and fatigue by the mathematical program of auto correlation and spectral analysis. The important result of such a study might be to predict the critical point of neutral stability without having to reach the danger point in actual highway driving tests. Also, this appraoch may provide an insight in developing practical methods to reduce fatigue and alert the driver before a dangerous situation occurs.

It seems reasonable to believe that drugs and alcohol will reduce a driver's performance in the same manner as fatigue. However, the motivation aspects of these mental depressants may be quite different. It is anticipated that alcohol and drug tests will be made using the drivometer, and performance rating suggested in this report will also be applicable to these experiments.

NATURE OF THE EXPERIMENT

A two-man team drove a car equipped with a modified Greenshields drivometer on a 1,200-mi trip from Ann Arbor, Mich., to Philadelphia and back. The test was made on four-lane divided highways with limited access because fatigue is accelerated by the monotony of the highway environment. Also, this kind of highway is probably the most important in loss-of-control accidents. Data were recorded by one man while the other was driving. Information included the number of steering reversals, accelerator reversals, speed changes, brake applications, time and mileage. The steering reversal rates per minute and speed change rate per minute were also recorded at certain intervals.

The trip east was started about 10 AM Sunday. Both drivers had about five hours sleep the night before. The drivers changed every one and one-half hours in accordance with recommended practice, with the exception of the first and last shifts. Rest stops were usually one-half hour or longer so that drivers had a reasonable length of time to relax between laps.

The trip west was started at 4:30 PM Tuesday. Both drivers were mentally tired from the day's activities. The drivers changed only when they felt too tired to drive farther. Intentionally, they made no reference to the time or distance traveled so that their changeovers would be based on a subjective feeling of fatigue. Rest stops were as short as possible to accelerate tiredness.

SUBJECTIVE SUMMARY OF TRIPS

The trip east was without serious incident. There were several severe rain squalls between the second and fourth hour. Also, there was a delay of 20 min at the first tunnel (Laurel Hill) and several 35-mph repair zones. Drivers showed some signs of stress occasionally, and moderate signs of lower standards of steering and speed control. Driver A drove the last lap of the trip and continued for nearly two hours to the final destination. During the last hour the driver mentioned speed change hallucinations but the record indicated a constant speed. It showed, instead, major changes in steering reversal rates. One-half hour from the end, the driver was irritated by a relatively minor change in reservation arrangements indicating some degree of fatigue. The trip ended at 11:25 PM without difficulty and both drivers felt well but ready for bed.

The trip west was more productive in terms of a study of fatigue. Both drivers showed subjective signs of fatigue from the very beginning of the trip at 4:25 PM. Numerous experiences show increasing degrees of fatigue. For instance, driver A failed to see several warning signs of an approaching tunnel during the second hour of his first lap. It was raining hard at the time and there was moderately heavy traffic, but neither was an excuse for the serious error. Driver B stopped driving at the end of 38 min of his third lap because of extreme sleepiness. Both drivers showed major effects of fatigue though each one slept occasionally during the time the other driver was behind the wheel. Rest stops were kept to a minimum throughout the whole trip west. The last leg of the trip, at 4:10 AM, was driven solo by driver A and his reactions changed appreciably from the normal pattern as speed dropped from a norm of 60 mph to 48 mph. Attention to the drivometer kept the driver somewhat attentive althought it was probably the most dangerous part of the trip from the standpoint of falling asleep. The combination of less responsiblity (for the other driver) and being on the last leg of the journey on a familiar highway contributed to the change in driver actions. (Details of both trips are given in the Appendix.)

TEST EQUIPMENT

The test equipment was a modified Greenshields drivometer (Fig. 1) mounted in the glove compartment of a 1962 Ford Fairlane 500 four-door sedan. The vehicle was equipped with seat belts, power steering, power brakes and dual brake and accelerator pedals. The drivometer, developed over the last four years, is described in detail in several earlier papers (2, 4). Its purpose is to measure the fundamental actions of the driver in controlling direction and speed of his vehicle, and in addition, to measure the fundamental parameters of vehicle motion.

From previous experiments, it was found that the steering wheel reversal rate (which is the same as vehicle tracking cycle rate) is the most sensitive variable to driver, environment and vehicle characteristics. Speed change rate (the number of increases

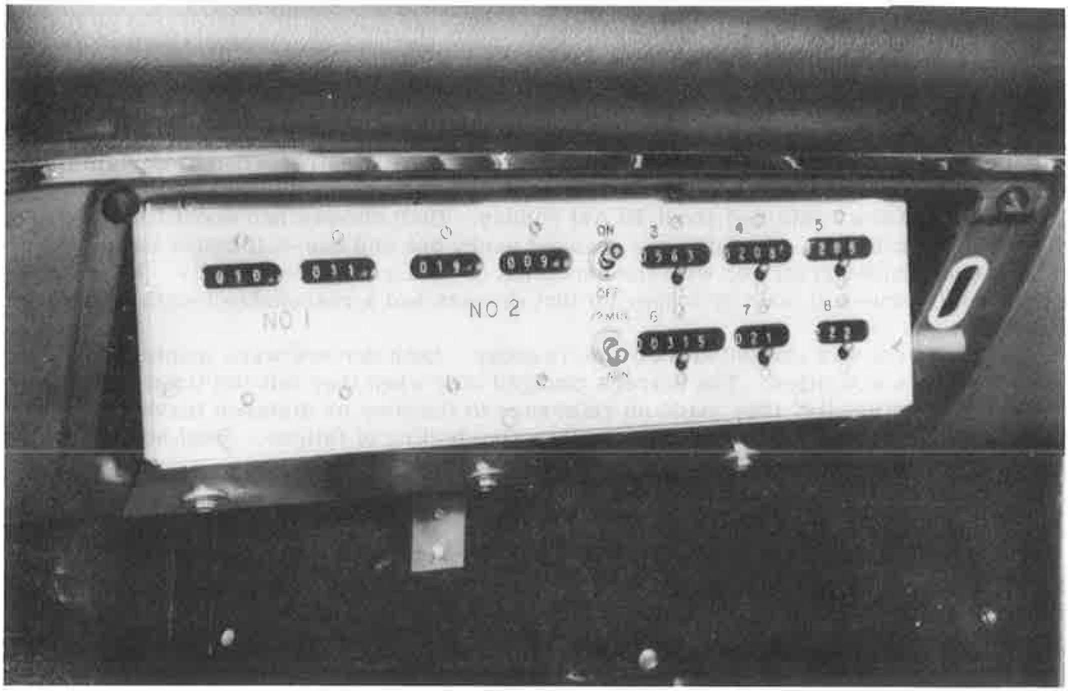

Figure 1. Greenshields drivometer.

or decreases in vehicle speed) is also important. Accelerator reversals and brake applications are also counted.

The two counters (number one) work as a pair recording the steering wheel reversal rate on a minute-by-minute basis. The second pair of counters (number two) records the speed change rate for each minute. While one counter is recording, the other is holding the total count for the preceding minute. Counter three records a cumulative count of steering wheel reversals from the start of the test run. Counters four, five, six, seven and eight record the total number of accelerator reversals, the time the car is in motion, the total speed changes (in mph), the brake applications, and the total trip time, respectively.

As this unit was designed for driver training, it does not have a camera attachment for automatic recording of data as the original model of the drivometer. Therefore, it was necessary for the passenger to record the data periodically during the test runs. Future tests will be made with an automatic camera recording unit.

PROCEDURE AND ASSUMPTIONS

Standard experimental procedure has been followed in this study. First, it was predicted that the drivometer could measure driving characteristics accurately enough to detect the early stages of fatigue. Next, pre-test experiments recording steering wheel reversal rates only were run by several drivers (see Appendix). Hypotheses were then established and a pilot test was made which is reported herein. An empirical performance rating is presented for quantifying the results and providing a systematic procedure. A driver's record is made during a particularly alert period (in this test at the beginning of a run) and the results are used as a norm for that driver.

This work sets the stage for design of a basic experiment to establish the measurable limits of fatigue and its degrees on a population of drivers. Further studies will permit evaluation of direct and indirect causes of driver fatigue and the development of counter measures.

The following assumptions are used in evaluating the test run data and in developing the empirical driver performance rating equations:

1. Driver fatigue will have effect on steering wheel reversal rates, speed change rates and average speed of the vehicle.
2. As the driver becomes fatigued, he will accept wider tolerances of both vehicle tracking and speed control.
3. As the driver gets tired, his speed may increase or decrease depending on whether his sensitivity to speed change or steering reversal rate is lost first.
4. The driver will usually take more risks as he becomes more fatigued. This will be indicated as an increase in tracking tolerance, and consequently, a decrease in steering reversals if speed is constant. Degree of risk may also be indicated by an increase in the speed of the vehicle.
5. As the driver becomes tired, his speed change rate increases but he usually makes some effort to keep it within balance by accelerator reversals or driving at a slower speed to accommodate it.
6. The most severe fatigue is encountered when the speed change rate increases and accelerator reversal rate decreases. This indicates the driver has ceased to care about speed control.

Experiments to date indicate that some drivers have more skill in tracking than in speed control; others are more skillful in maintaining a uniform speed. Relatively few drivers are well coordinated in both controls simultaneously. When a driver becomes tired, his sensitivity to both parts of the task deteriorates. The loss of ability in either tracking control or speed control can be critical from a safety viewpoint. The empirical equations (see Appendix) and the driver performance equation have each been developed and weighted on the basis of the tests reported in this study. It is anticipated that refinements will be made as additional data are collected on a larger sample of drivers.

DRIVER PERFORMANCE RATING SUMMARY

Table 1 shows the performance ratings of both drivers for parts of the two test runs. Figure 2 shows the routes. The following observations can be made:

1. Neither driver performed as well as his standard during any part of the trip.
2. Driver B had better recuperative powers than driver A, and seemed to maintain a consistent level of performance during each lap of the first test run. However, during the second run, driver B's performance showed rapid deterioration in the third lap, which was also noted in the subjective report by the observer.
3. The performance of driver A was relatively better on the second run than on the first, but in both tests the ratings show a major deterioration compared to his standard.
4. The one 90-min period, when data was taken continuously, showed a definite cyclic pattern of the steering wheel reversal rate. This may prove to be related to the attention span of the driver and be a valuable characteristic to interpret in future tests.
5. It is obvious from this pilot study that minute-by-minute data should be taken continuously throughout the whole trip so the performance ratings may be calculated at each 15-min time interval.

TABLE 1

Lap	Minutes	Rating[1]		Lap	Minutes	Rating[1]	
		Driver A	Driver B			Driver A	Driver B
(a) Test Run No. 1: Ann Arbor to Philadelphia				(b) Test Run No. 2: Valley Forge to Ann Arbor[2]			
First	120 to 135		71.3	First	1 to 15		41.2
					90 to 105		46.4
					1 to 15	70.6	
					120 to 135	48.8	
Second	1 to 15		48.1	Second	1 to 15		42.5
	16 to 30		44.9		30 to 45		53.2
	65 to 75		52.5		54 to 68	42.2	
					84 to 91	34.0	
Third	60 to 75	28.3		Third	1 to 15		41.8
	75 to 90	19.3			31 to 37		39.9
	1 to 15		62.6				
	16 to 30		46.9				
	60 to 75		56.7				
Fourth	60 to 75	39.0					
	90 to 105	27.1					

[1]Standard ratings: driver A, 70.6; driver B, 71.3.
[2]Minute by minute data discontinued because both participants were too tired to continue recording.

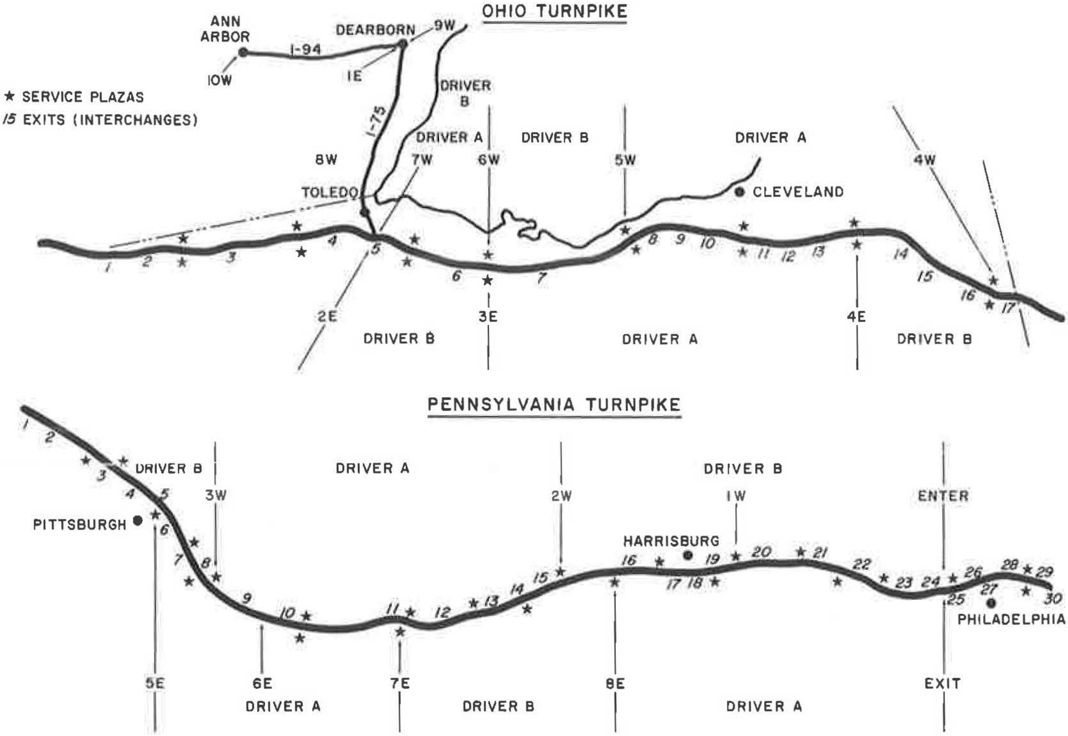

Figure 2. Test route.

CONCLUSIONS

1. The effects of driver stress and fatigue, as reflected in tracking and speed control, can be monitored by the Greenshields drivometer.
2. A series of empirical equations have been developed and combined to form a measure of driver performance compared to the driver's norm. These equations are based on logical hypotheses derived from the results of the research conducted to date.
3. The experimental techniques developed in these test runs will be useful in establishing a broad based study on driver fatigue.
4. Similar methods will be applicable to the study of the effects of drugs, alcohol and physical deficiencies on driver performance and safety.

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Appendix

EMPIRICAL EQUATIONS

Tracking Control Factors:

$$A_t = \sqrt{\frac{\left[(SRR)_X - (SRR)_N\right]^2}{(SRR)_N}} \qquad (1)$$

in which

$(SRR)_X$ = Average steering reversal rate over 15-min period; and

$(SRR)_N$ = Average steering reversal rate normal alert condition for subject (from pre-test).

$$B_t = \text{Standard deviation of } \frac{(SRR)_X}{(SRR)_N} \qquad (2)$$

$$C_t = \frac{(SRR)_{max} - (SRR)_{min}}{(SRR)_{min}} \qquad (3)$$

in which $(SRR)_{max}$ and $(SRR)_{min}$ are from 15-min periods.

Speed Control Factors:

$$A_s = \sqrt{\frac{\left[(S)_X - (S)_N\right]^2}{(S)_N}} \qquad (4)$$

in which

$(S)_X$ = Average speed over 15-min period; and

$(S)_N$ = Average speed normal alert condition (from pre-test).

$$B_s = \frac{(SCR)_X \ (ARR)_N}{(SCR)_N \ (ARR)_X} - 1 \qquad (5)$$

in which

$(ARR)_X$ = Average accelerator reversal rate over 15-min period;

$(ARR)_N$ = Average accelerator reversal rate, normal alert condition (from pre-test);

$(SCR)_X$ = Average speed change rate over 15-min period; and

$(SCR)_N$ = Average speed change rate, normal alert condition (from pre-test).

Driver Performance Rating:

$$DPR = 100 - 100\,A_t - 100\,B_t - 10\,C_t - 200\,A_s - 10\,B_s \quad (6)$$

Basic assumptions used in developing the empirical equations are as follows:

1. A driver's performance may vary from day to day and hour to hour. A comparative performance rating with an individual's norm is proposed and therefore is non-dimensional. (The driver's norm is obtained at the beginning of a test run when he is most alert.)
2. Tracking control is more sensitive to driver performance than speed control.
3. Steering reversal rate should remain constant. A rate above or below the driver's normal (SRR) is a decrease in performance.
4. Deviation from mean (SRR) is a decrease in performance.
5. An increase in range of (SRR) in any 15-min period is a decrease in performance.
6. When (SRR) goes to zero the performance rating (DPR) is a minimum.
7. Average speed increase or decrease compared to norm is a decrease in performance if environmental and highway conditions are constant. (It may be desirable to have correction factors for night driving, highway characteristics and traffic conditions, but it is assumed that initial tests will be run on a limited access, 4-lane divided highway to maintain reasonably constant conditions.)
8. Speed change rate (SCR) is essentially the deviation from the average speed. Therefore, this factor should be minimized for best performance.
9. When the average accelerator reversal rate (ARR) approaches zero, the performance rating (DPR) is a minimum.
10. When speed change $\frac{(SCR)_X}{(SCR)_N}$ and $\frac{(ARR)_X}{(ARR)_N}$ ratios increase simultaneously, the driver is trying to keep performance up, but when the speed change ratio increases and the accelerator reversal rate ratio decreases, the driver's performance is decreasing.

TRIP LOG RUN NO. 1

Origin: Ann Arbor, Michigan
Destination: Philadelphia, Pennsylvania

Date: 6-10-62
Sunday

Driver	Time (EST)	Mileage	Running Time	Miles	Notes
	9:50 AM	5,026.7			Geddes Road, Ann Arbor, Michigan; Lap No. 1
A			48	40.1	I-94 East
	10:30	5,067.1			
			-	-	(1-E) Pick up driver B at home in Dearborn
	10:55	5,067.1			Lap No. 1
B			52	50.8	
	11:47	5,117.9			
			-	-	(2-E) Stop for gas before entering turnpike
	11:54	5,117.9			
B			30	30.5	
	12:24 PM	5,148.3			
			-	-	(3-E) Freemont Plaza 51-min stop for dinner
	1:15 PM	5,148.6			Lap No. 2
A			90	95.8	
	2:45	5,244.4			
			-	-	(4-E) Exits 13-14, rest stop (Plaza)
	3:07	5,247.2			Lap No. 2
B			39	42.1	
	3:46	5,289.3			Ohio Tollgate
B			54	52.7	
	4:40	5,342.0			(5-E) Rest stop (Exit 6) Oakmont, Pa.
	5:00	5,342.0			Lap No. 3
A			60	59.3	
	6:00	5,401.3			(6-E) Stopped at tunnel entrance (Laurel Hill)
	6:20	5,401.3			
A			41	40.3	
	7:01	5,441.6			
			-	-	(7-E) Exit 11 - Bedford, Pa. Stopped for supper
	7:50	5,441.6			Lap No. 3
B			30	29.4	
	8:20	5,471.0			Dark (night)
B			47	43.6	Lap No. 3
	9:07 PM	5,514.6			
			-	-	(8-E) Exit 16 - Plainfield Plaza
	9:10	5,514.6			Lap No. 4
A			110	108.9	
	11:00	5,623.5			
			-	-	Valley Forge Exit; no stop but wrong turn made—5 min delay
	11:00	5,623.5			
A			25	15.5	Schuylkill Expressway
	11:25	5,639.0			Marriott Motel, Phil., Pa.

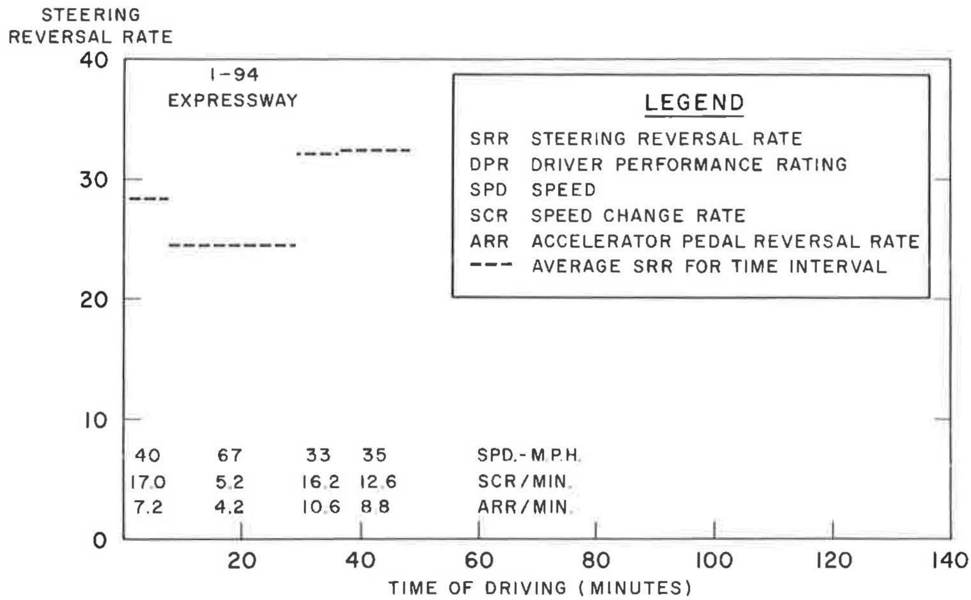

Figure 3. Driver A, 1st lap; weather: rain. If minute by minute data were available, this would have been used as standard for driver A. First lap of test run No. 2 was used instead.

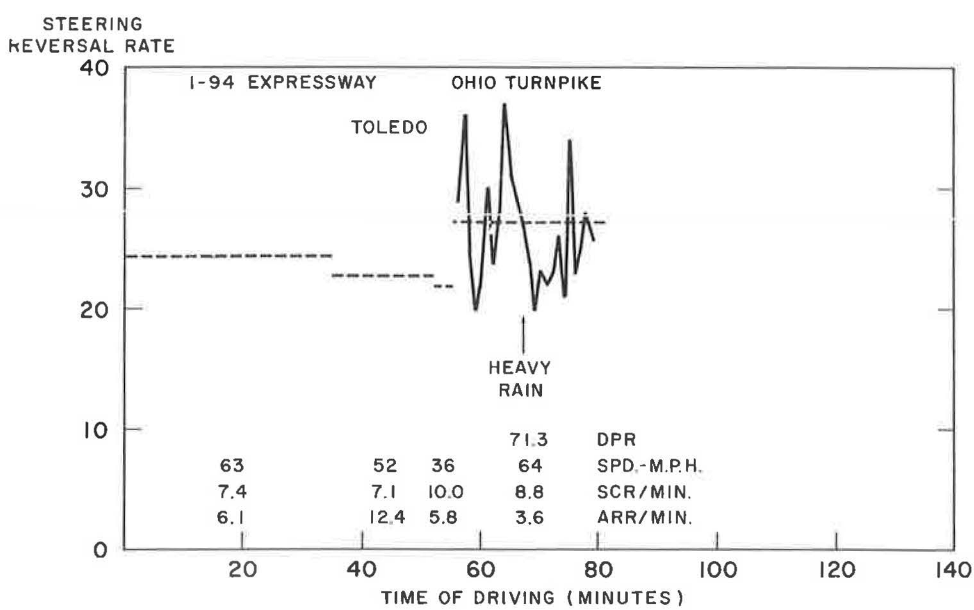

Figure 4. Driver B, 1st lap; weather: heavy rain, showers and gusts. This record was used as standard for driver B.

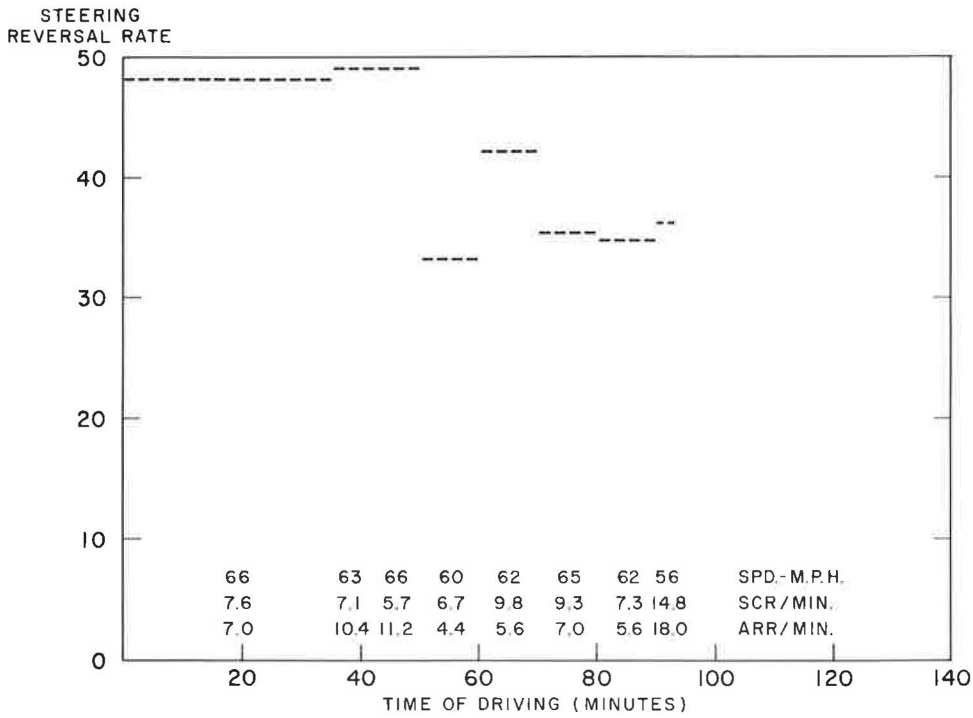

Figure 5. Driver A, 2nd lap; weather: heavy rain, showers and X wind gusts. Very heavy rain; radio very distracting. SRR remained high as a result of tension during first 45 minutes.

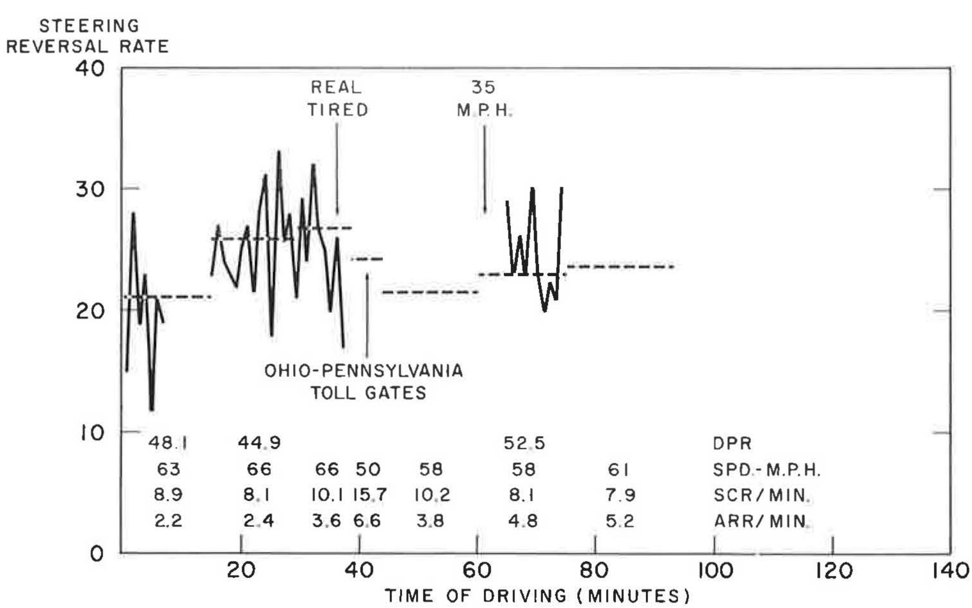

Figure 6. Driver B, 2nd lap; weather: partly cloudy. Signs of fatigue before toll gates.

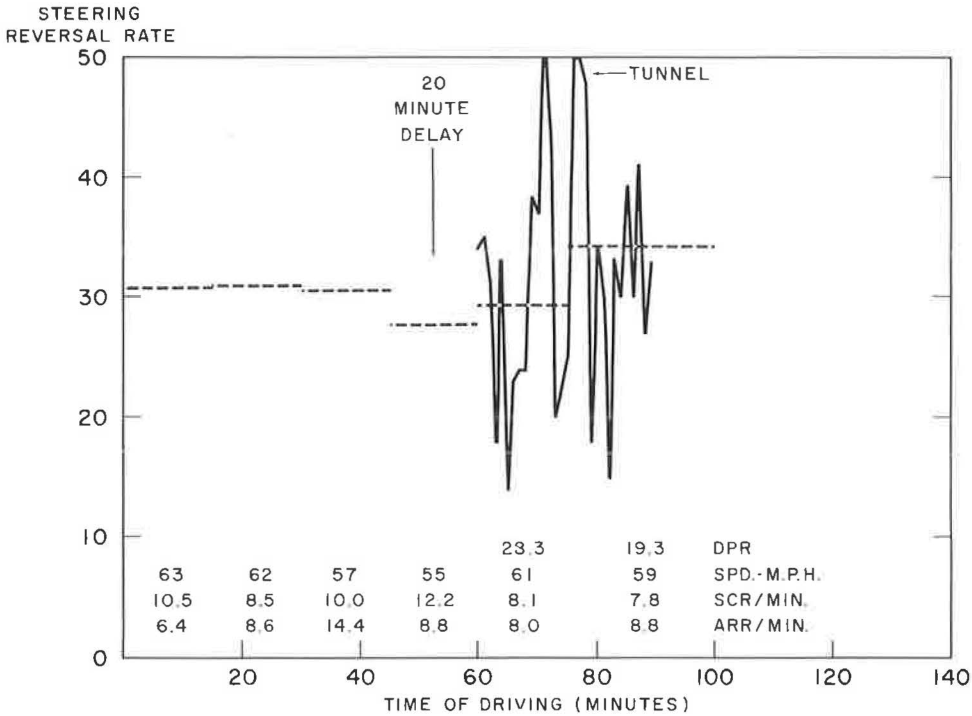

Figure 7. Driver A, 3rd lap; weather: clear. Extreme tension shown, particularly in tunnels and let down immediately after.

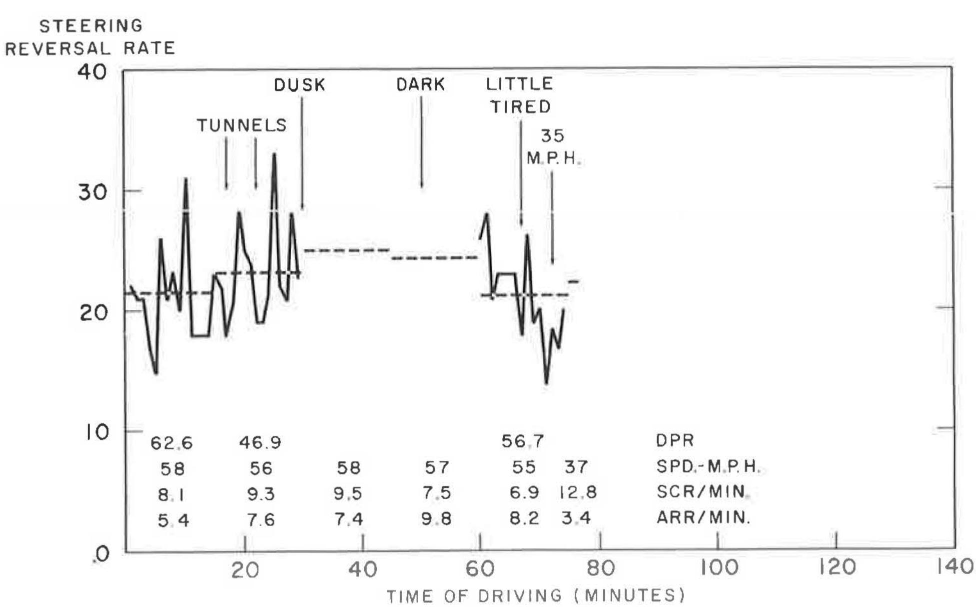

Figure 8. Driver B, 3rd lap; weather: clear. Slight increase in tension during first 30 minutes (SRR) and wider tracking tolerance after 60 minutes resulting in lower SRR.

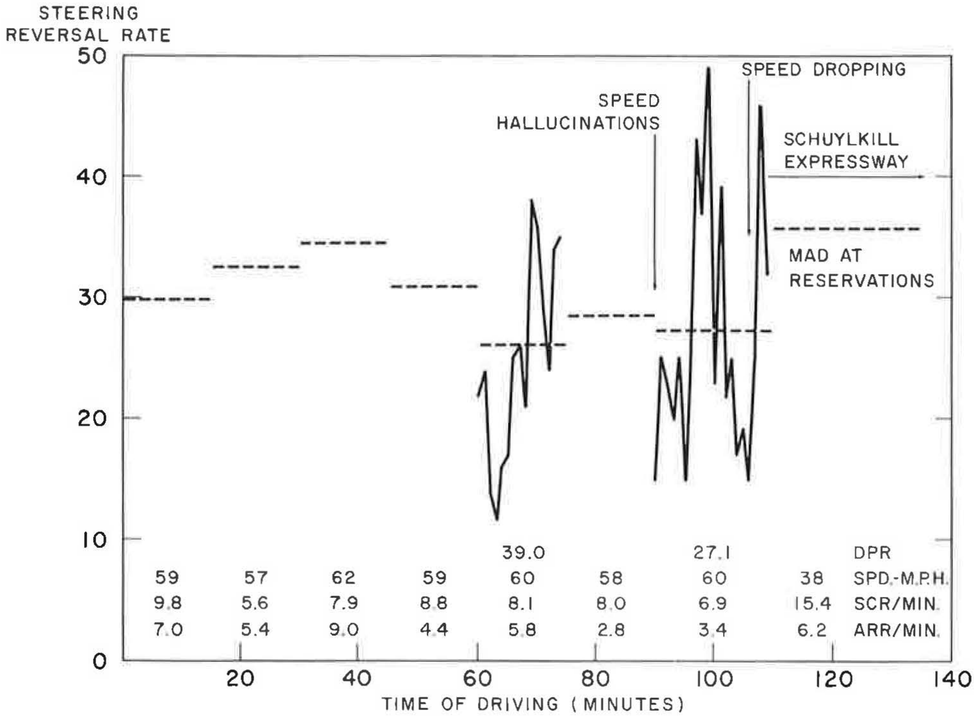

Figure 9. Driver A, 4th lap. Extreme deviation from mean SRR resulting from tension of fatigue.

TRIP LOG RUN NO. 2

Origin: Valley Forge Entrance to Pennsylvania Turnpike — Date: 6-12-62
Destination: Ann Arbor, Michigan — Tuesday

Driver	Time (EDT)	Mileage	Running Time	Miles	Notes
	4:25 PM	5,859.9			Valley Forge, entrance - lap No. 1
B			67	70.1	
	5:32	5,930.0			
			-	-	(1-W) Rest stop between exits 19 and 20
	5:35	5,930.0			
B			52	56.7	
	6:24	5,986.7			
	7:15		-	-	(2-W) Stopped for supper at Blue Mountain
A			135	127.3	Lap No. 1
	9:30	6,114.1			
			-	-	(3-W) New Stanton Plaza - stopped for snack
	9:54	6,114.1			Lap No. 2
B			90	83.7	
	11:24	6,197.8			
			-	-	(4-W) Stopped - Ohio Plaza
	11:45 PM	6,198.0			Lap No. 2
A			94	99.8	
	1:19 AM	6,297.2			
			-	-	(5-W) Stopped for snack at Elyria, Ohio
	1:43		38	39.8	Lap No. 3
B	2:21	6,337.4			
			-	-	(6-W)
	2:25	6,337.4			Lap No. 3
A			31	29.3	Exit 5 - Toledo, Ohio
	2:56	6,366.7			Driver B asleep
			-	-	(7-W) Driver B asleep
	2:56	6,366.7			
A			46	43.5	Detroit-Toledo Expressway
	3:42	6,410.2			
			-	-	(8-W) Change drivers
	3:45	6,410.2			
B			24	17.2	Driver A asleep - Lap No. 4
	4:09	6,427.4			
			-	-	(9-W) Left Driver B in Dearborn, Mich.
	4:10 AM	6,427.4			Lap No. 4
A			40	31.7	Driver A - Solo
	4:50	6,459.1			Ann Arbor, Mich.

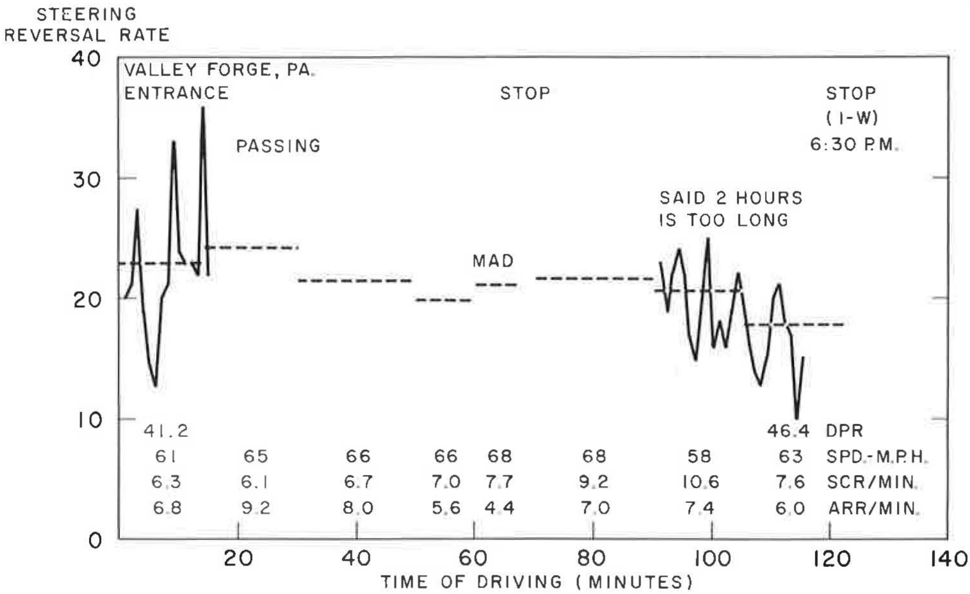

Figure 10. Driver B, 1st lap; weather: rain. Note apparent wider tracking tolerance, causing decrease in SRR.

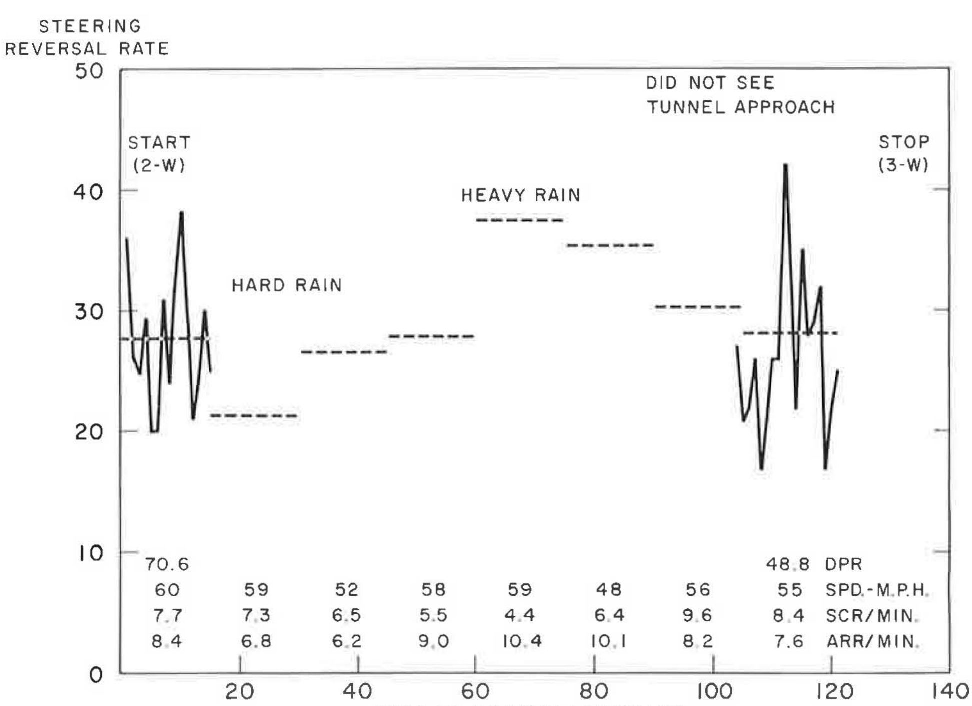

Figure 11. Driver A, 1st lap; weather: rain. Note increase in deviation from mean SRR.

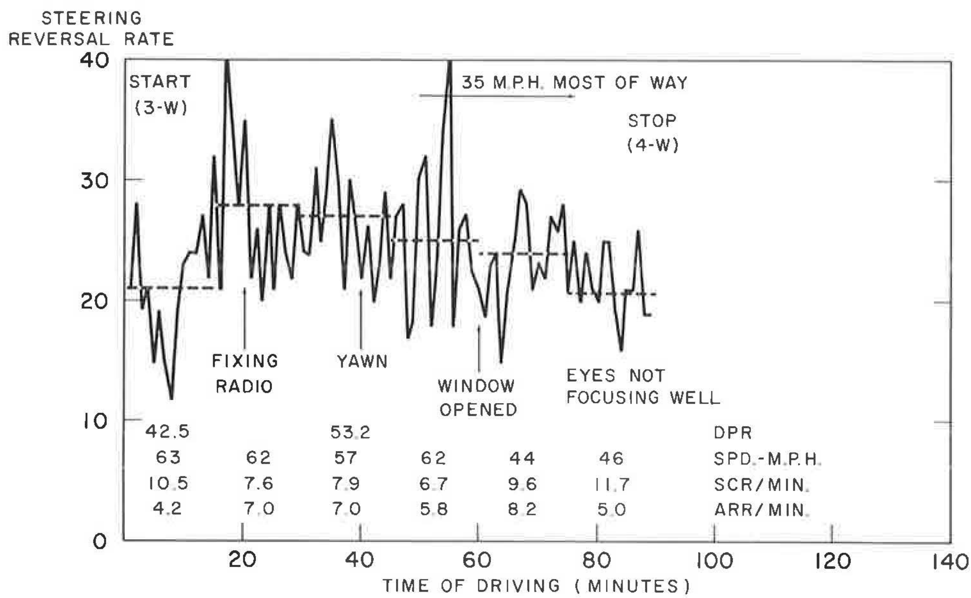

Figure 12. Driver B, 2nd lap; weather: rain and mist. Note apparent cyclic variation in deviation from mean SRR.

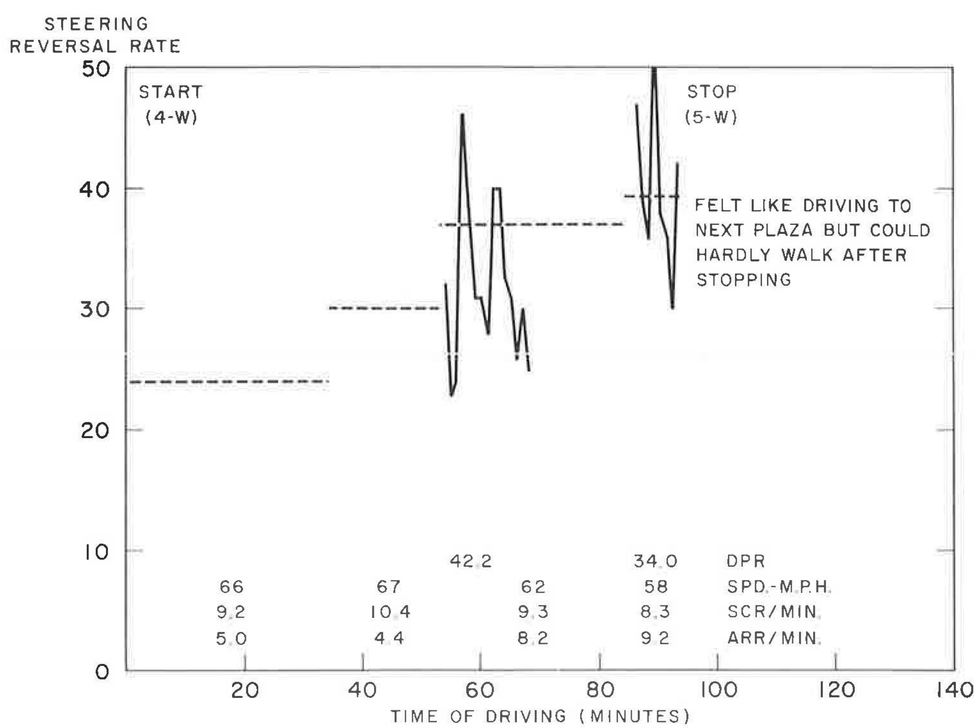

Figure 13. Driver A, 2nd lap; weather: clear. Note apparent increase in nervous tension; driver B dozing at times resulting in irregular time of recording data.

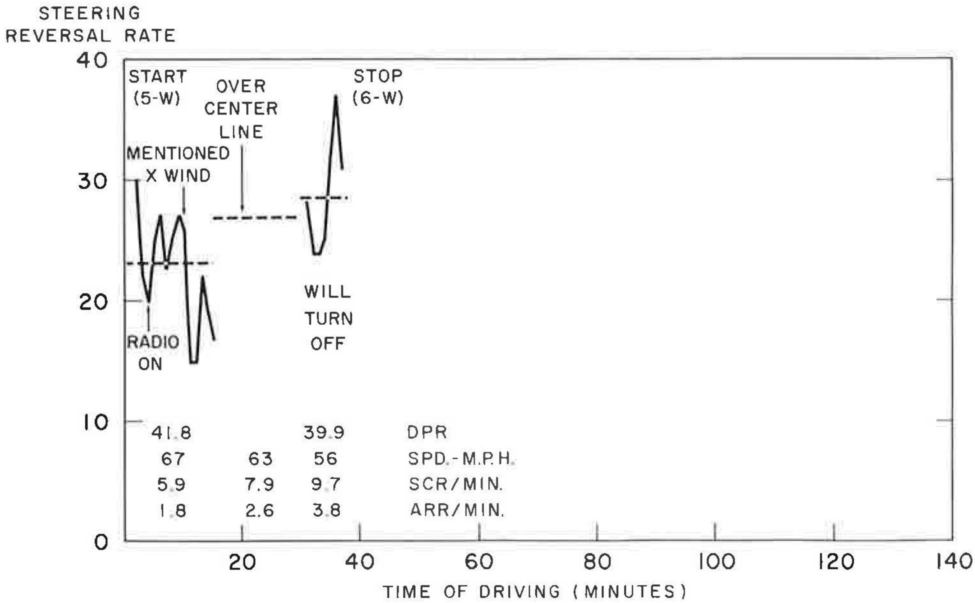

Figure 14. Driver B, 3rd lap; weather: clear. Note increase in tension and drop in average speed.

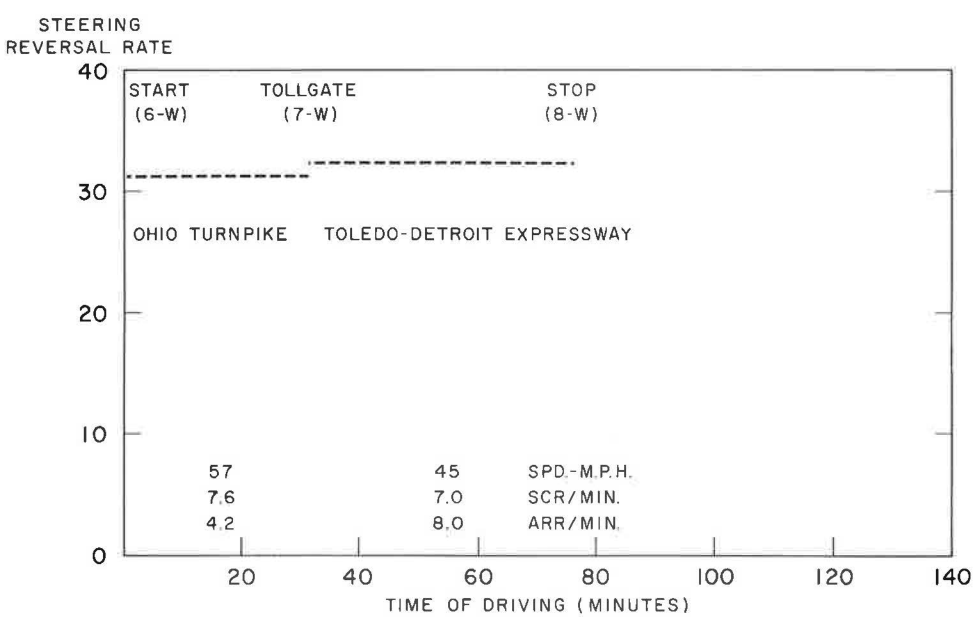

Figure 15. Driver A, 3rd lap; weather: clear. Note drop in speed.

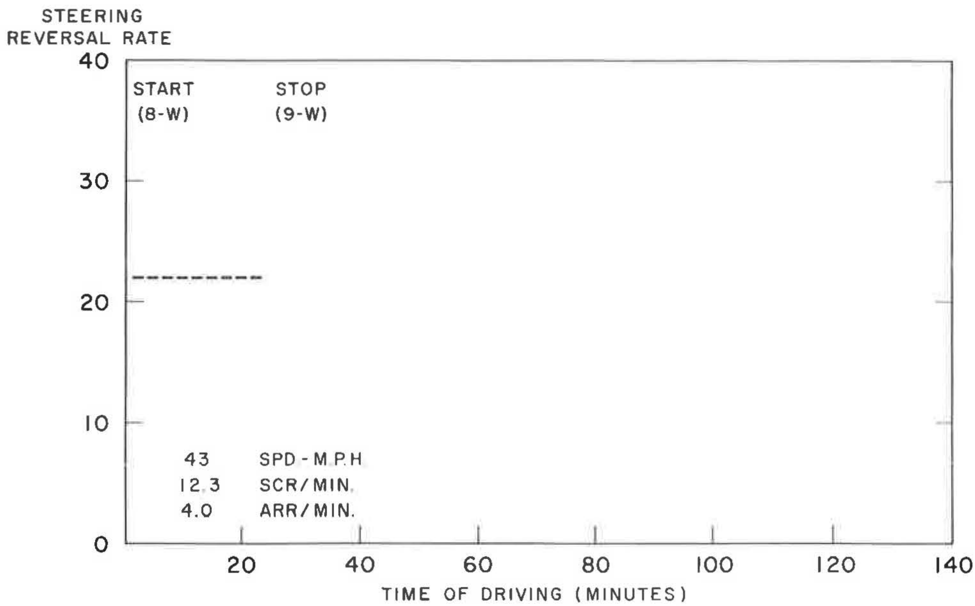

Figure 16. Driver B, 4th lap; Toledo Expressway and residential driving in Dearborn—several traffic lights. Driver A asleep on back seat.

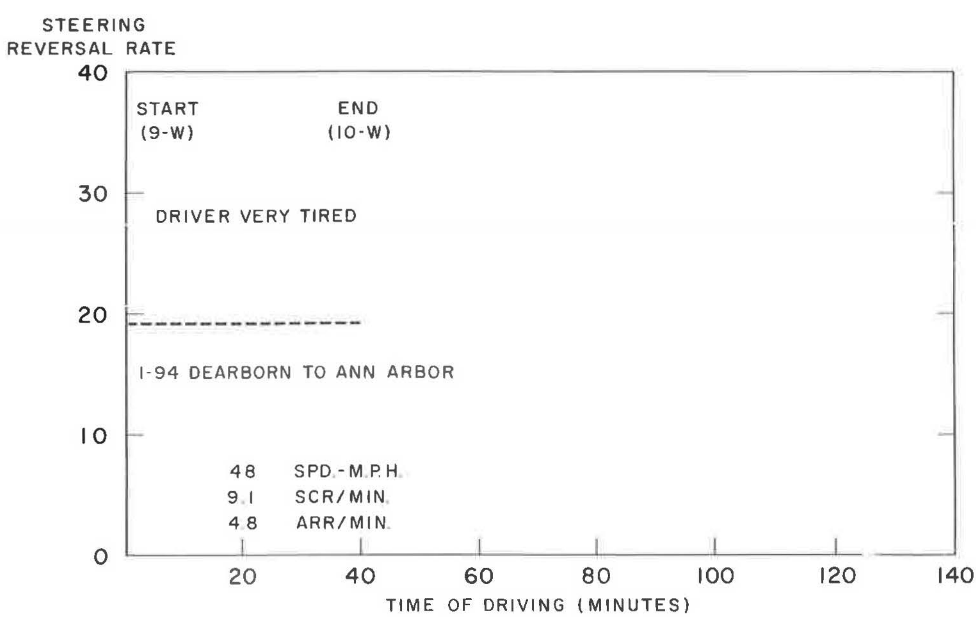

Figure 17. Driver A, 4th lap. Note drop in speed and SRR; some readings as low as 9 seen by driver.

PRELIMINARY TESTS ON STEERING WHEEL REVERSALS, JANUARY 1962

The original drivometer was designed by Greenshields for traffic flow studies. The steering wheel reversal sending unit had an adjustment which permitted a wheel turn tolerance of several inches before the signal was initiated. This tolerance was satisfactory for traffic flow studies in urban and residential streets but tests at rural highway speeds indicated that normal tracking movements of the steering wheel were not being recorded.

The author conducted experiments to determine the fineness of adjustment necessary to include all tracking maneuvers at high road speeds. During these tests it became apparent that the fine steering wheel reversal measurements were related to driver emotions as well as to traffic and environmental factors. It also was discovered that each driver has a basic steering wheel reversal rate, which seems to be the stabilizing signal (feedback) to the driver for a speed control of his vehicle.

Nearly a year of tests followed to evaluate the various effects of psychological factors, to improve the design equipment and finally, to develop the modified drivometer that has been used in this pilot study on fatigue.

Figures 18 through 29 are representative of nearly 100 test runs made with several drivers leading up to the first two hour test to study fatigue.

Both steering wheel reversal rates (SRR) and accelerator reversal rates (ARR) were measured in the pre-tests but it was quickly found that (SRR) were primarily sensitive to driver characteristics and (ARR) were predominantly related to environment. For this reason, only (SRR) are plotted in the attached curves.

The equipment used in these tests was shown elsewhere (3, Fig. 7). It was not as sensitive as the latest drivometer used in the main study reported herein, and for this reason, the rates are generally lower. Also, the timer was set on a 50-sec interval in the preliminary tests compared to the 60-sec interval now used.

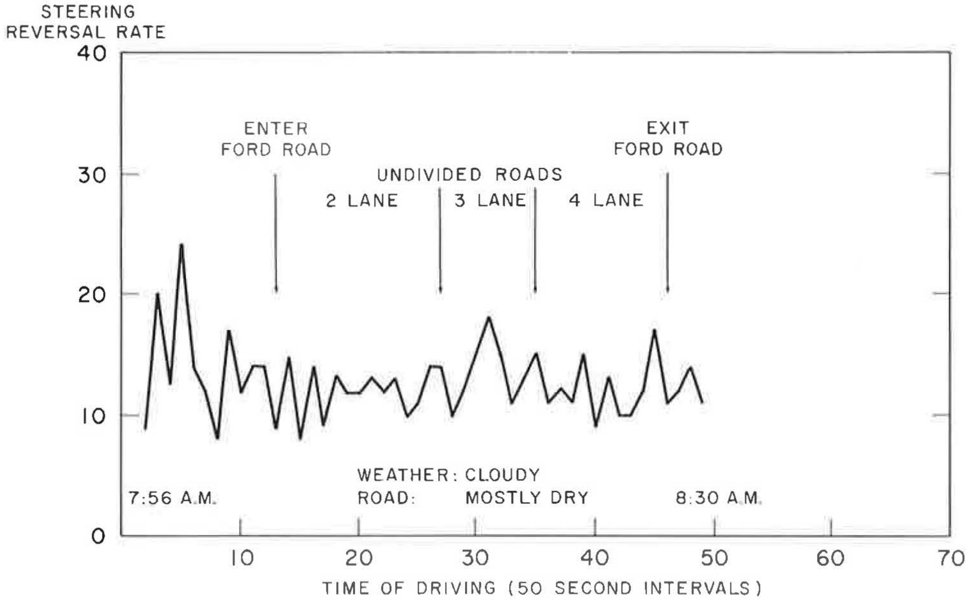

Figure 18. Ann Arbor to Dearborn via Ford Road, 1-4-62. Modified speed to try to maintain constant steering reversals.

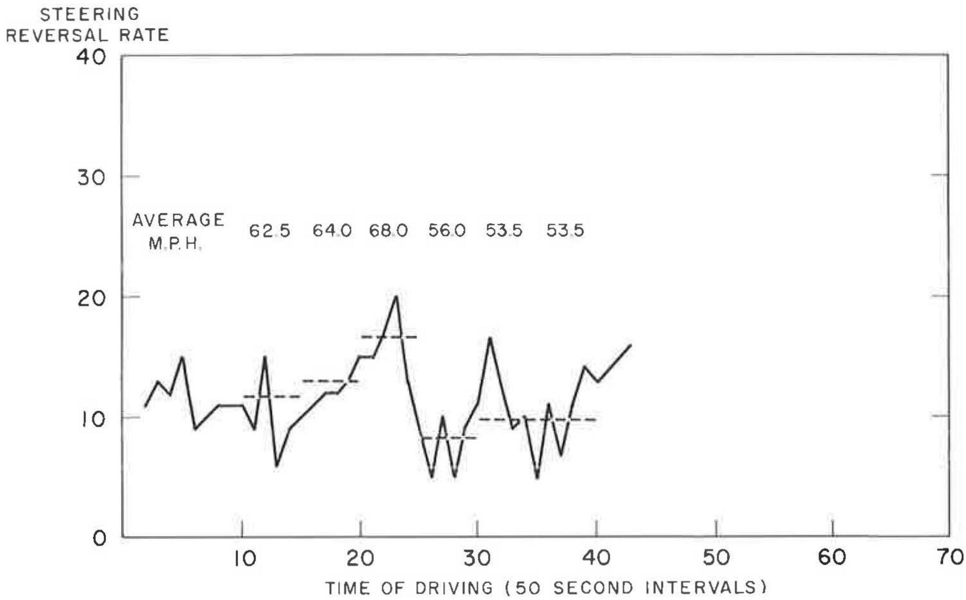

Figure 19. Ann Arbor to Dearborn via Expressway, 1-19-62. Test was a demonstration of the equipment; note sensitivity of steering reversals to speed.

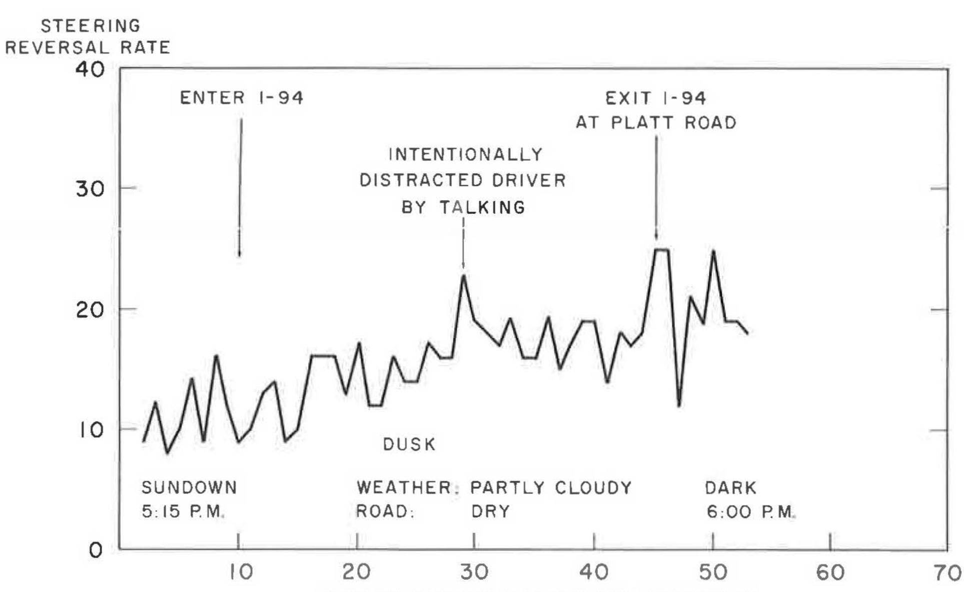

Figure 20. Dearborn to Ann Arbor via Expressway, 1-15-62. Increasing rate may be fault of driver tension or because of decrease in visibility.

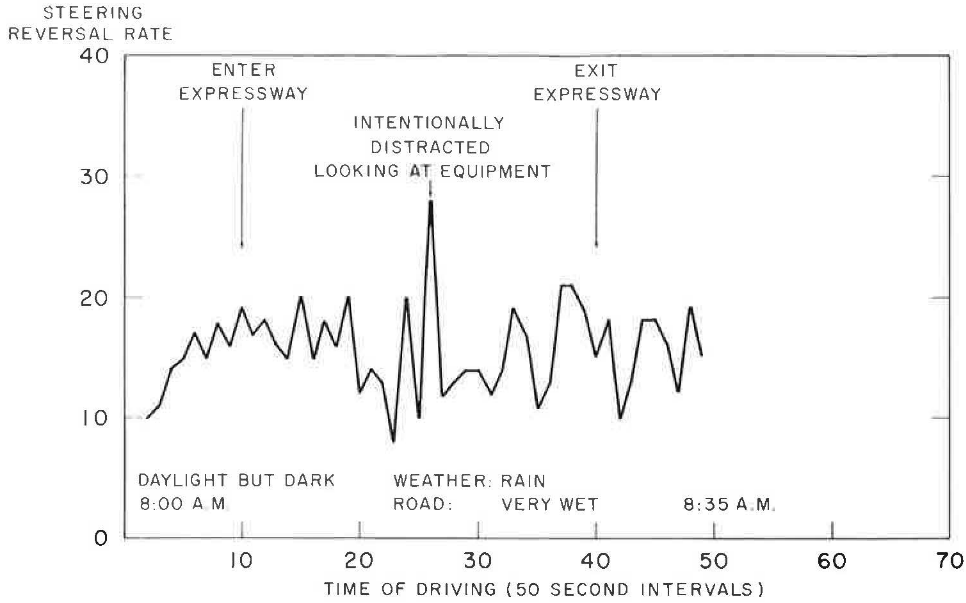

Figure 21. Ann Arbor to Dearborn via Expressway, 1-15-62. Note constant steering reversal rate but increase in deviation from mean.

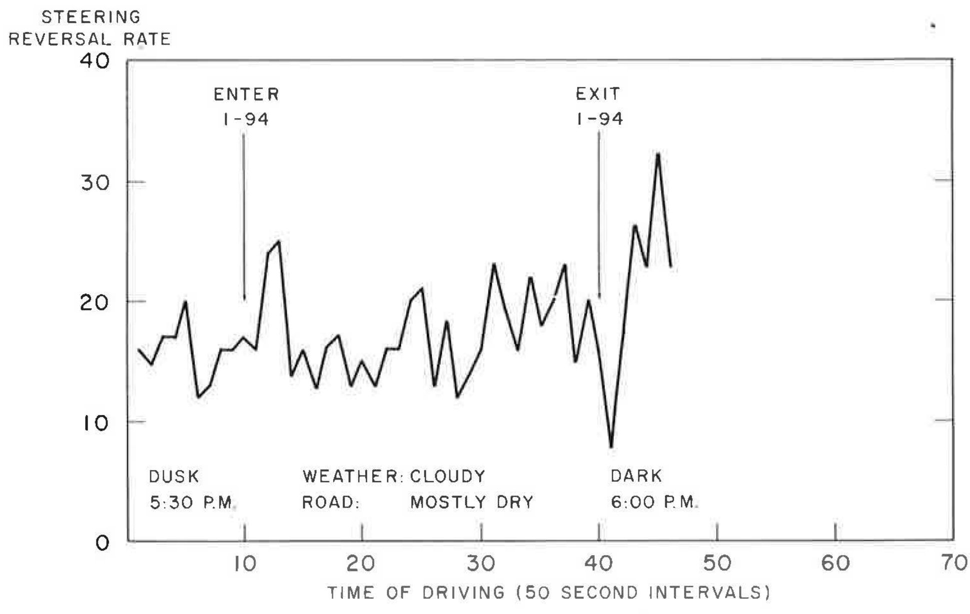

Figure 22. Dearborn to Ann Arbor via Expressway, 1-4-62. Rate increase between the 30th and 40th intervals probably the result of decreasing visibility without decreasing of speed.

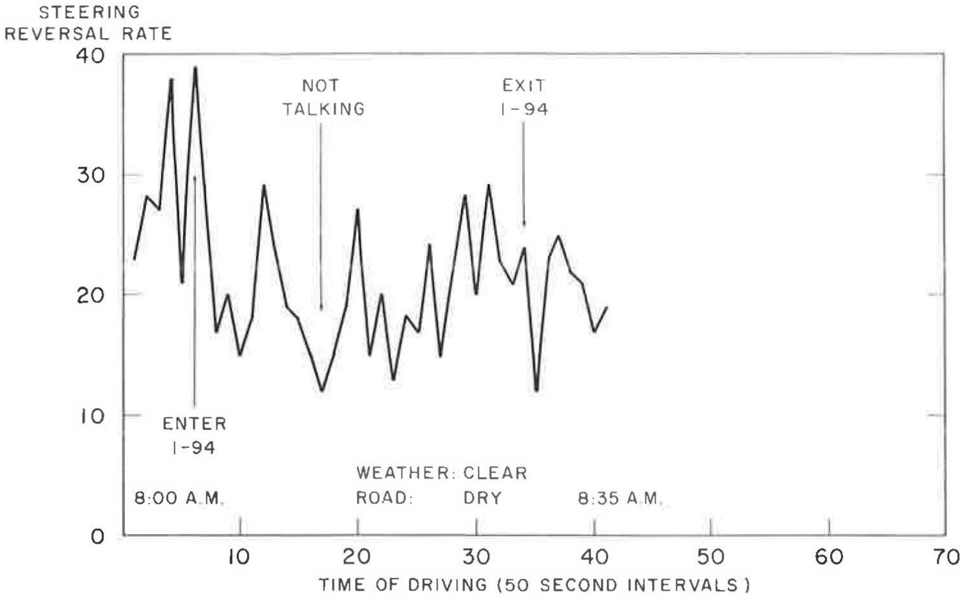

Figure 23. Ann Arbor to Dearborn via Expressway, 1-16-62. Driver very upset about accident which occurred the night before; probably caused the large deviations from mean.

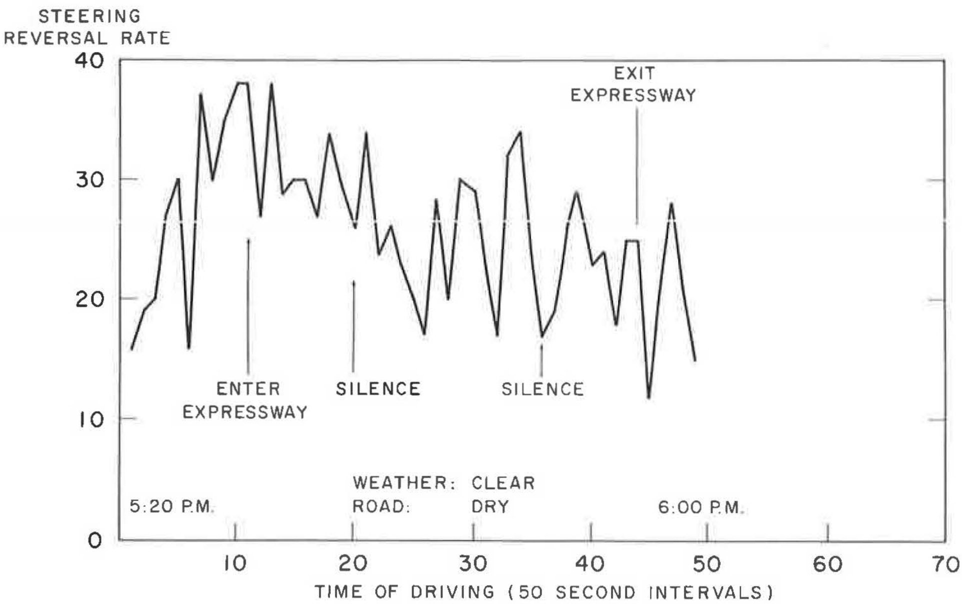

Figure 24. Dearborn to Ann Arbor via Expressway, 1-16-62. Driver shows nervousness when driving resulting in high rate and large deviations.

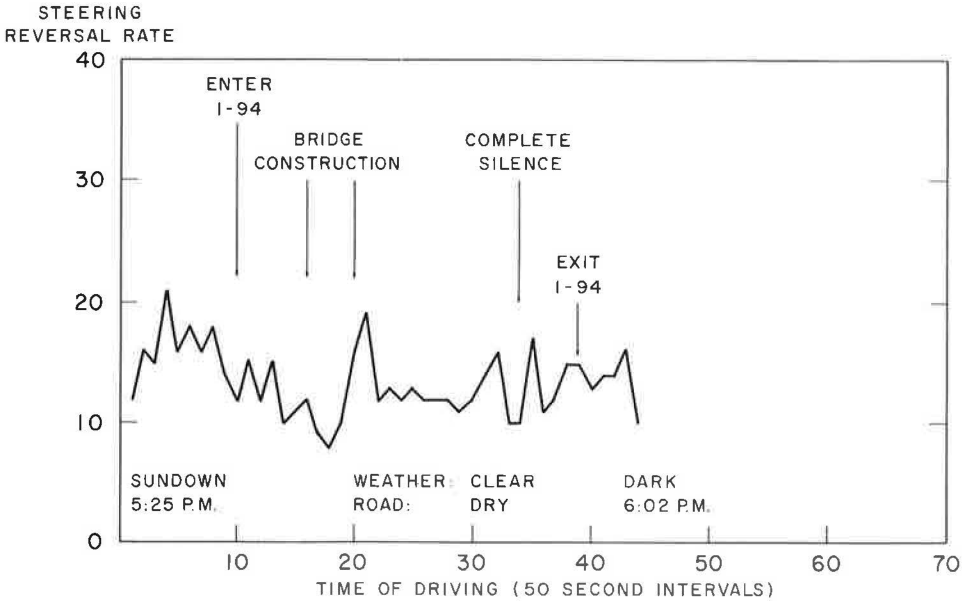

Figure 25. Dearborn to Ann Arbor via Expressway, 1-17-62. Driver was calm, consistent driver and was influenced very little by traffic conditions.

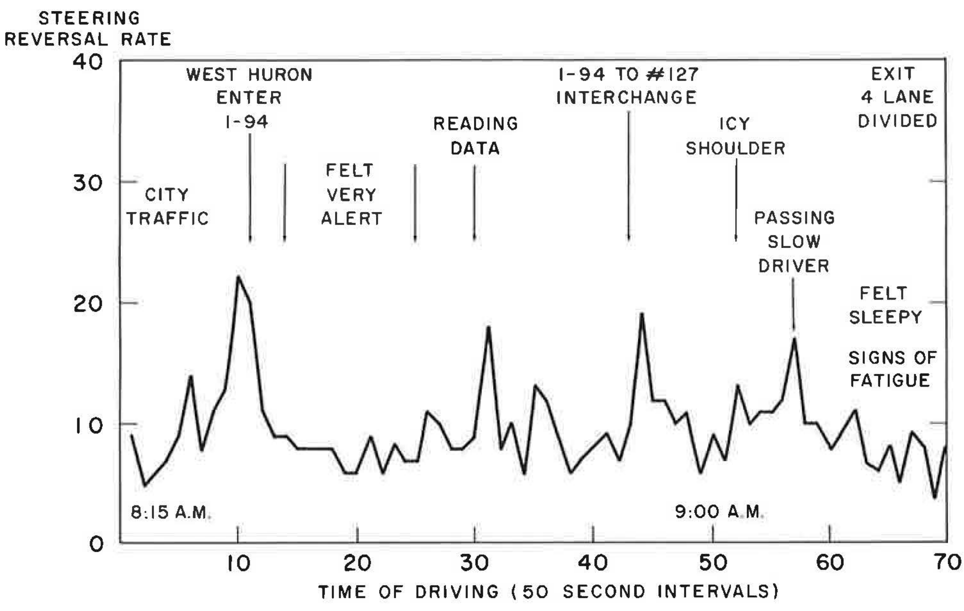

Figure 26. Ann Arbor to Lansing, 1-18-62. Test run was incidental to the primary objective of driving to a meeting. The driver took data while driving thus causing some distractions.

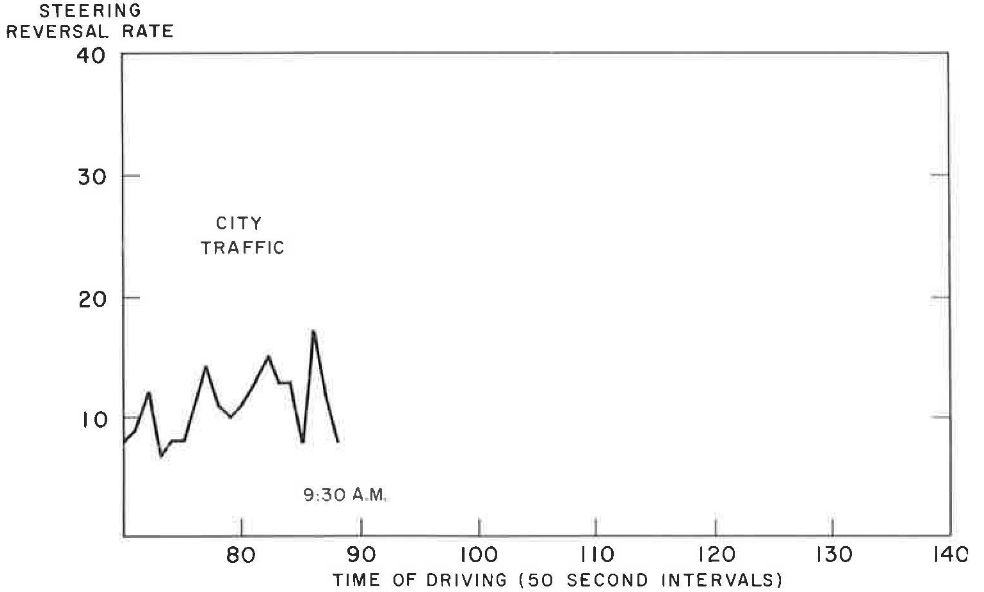

Figure 27. Conclusion of Ann Arbor to Lansing Test Run, 1-18-62. First signs of serious decrease in steering reversal rate caused by acceptance of wider tracking tolerance between the 60th and 70th interval.

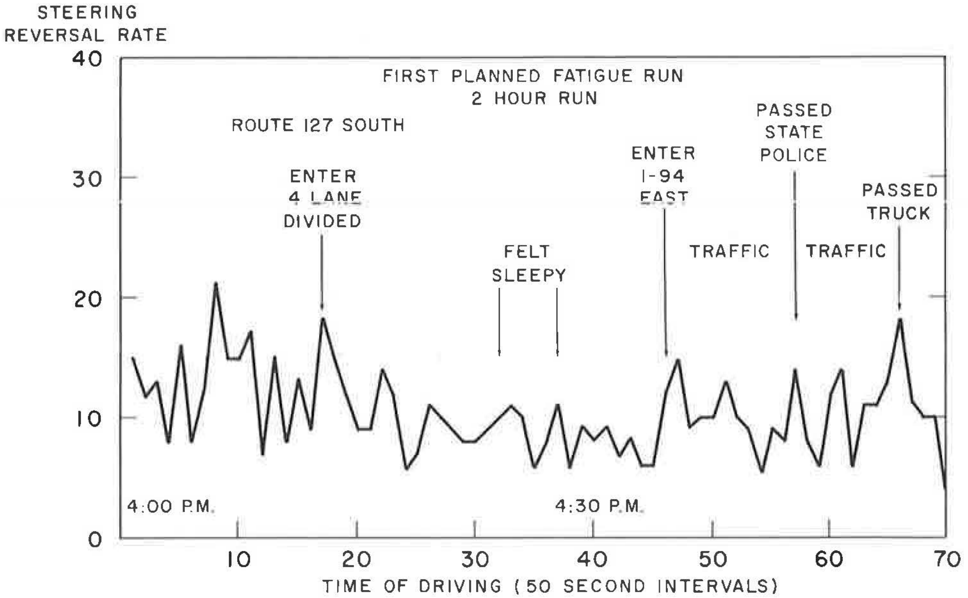

Figure 28. Lansing to Metropolitan Airport to Ann Arbor, 1-18-62. First planned fatigue run shows gradual decrease in steering reversal rate to the 80th interval.

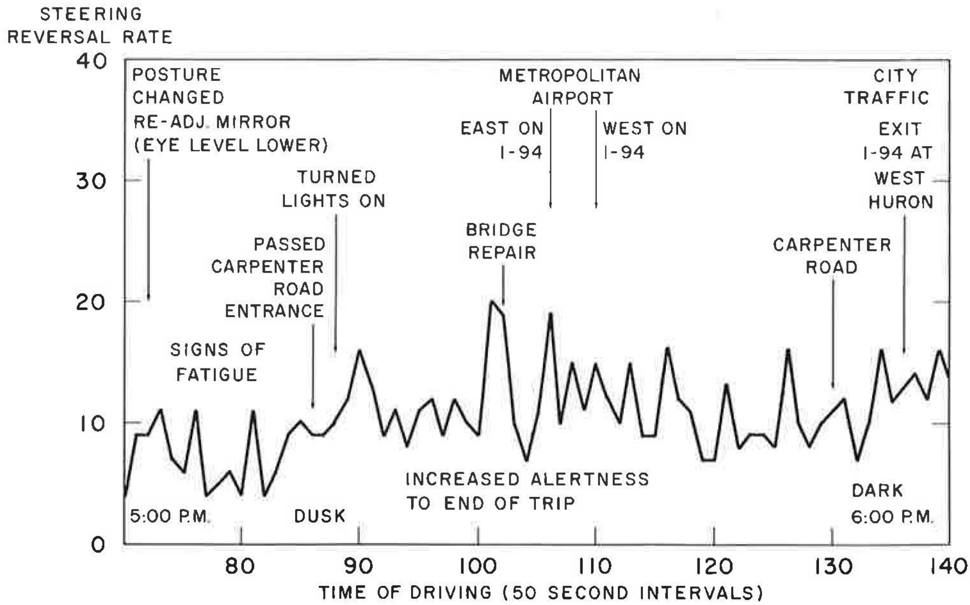

Figure 29. Conclusion of Lansing to Metropolitan Airport to Ann Arbor Test Run, 1-18-62. Driver regained alertness after 80th interval although deviations were generally greater than during first part of run.