Changes in Driver Performance with Time in Driving

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•DETERIORATION or failure in driving performance with continued time in driving is recognized by traffic and safety engineers to be a major cause of accidents and deaths on the highway. In order to learn more about this change in performance and perhaps ultimately find a way to reduce its hazards, The University of Michigan as a part of its research under a grant from the Ford Motor Company Fund has conducted a study of the changes in driving behavior that occur with increasing time behind the wheel.

The study has been made possible by the development during the last few years of a new research instrument that furnishes a continuous and integrated digital record of driver-vehicle performance.

SOME CONCEPTS

Since there are several concepts or explanations of what happens with increasing time spent in work be it mental or physical it may be fruitful to review some of these concepts before describing the methods used and discussing the results obtained in the present study. Although there has been hesitancy in using the term "driving fatigue" due to its controversial meaning it is under this heading that one must look for an explanation of changes in performance with time.

Captain Robert B. Bennett, Safety Officer, Fighter Interceptor Squadron, (5) states: "Actually, fatigue does not have a specific scientific meaning, nor can it be measured or defined. When we are fatigued we have feelings of tiredness, lassitude, sleepiness, etc., but these are incidental. Fatigue refers to loss of efficiency and skill, and level of anxiety."

The "feeling of tiredness, etc.", is usually defined as (1) subjective, or experiential fatigue; while (2) physiological fatigue is brought about by chemical reaction in the blood. When the amount of glycogen in the blood stream decreases and other by-products of prolonged activity such as lactic acid and carbon dioxide increase, the muscle or nerve tissue loses its ability to function; and (3) objective fatigue—work output or any and all changes in observable behavior. This report is concerned with observable behavior in driving.

Bartley and Chute (1) distinguished the three aspects of fatigue just mentioned, but hold that true fatigue arises in a conflict situation in which the general alignment of the individual is that of aversion. They also argue that fatigue is an experience of the whole person, that such an experience necessitates a science of the person, and that impairment and work output may or may not be related to fatigue. Fatigue (according to Bartley and Chute) is a personal aversive alignment; work output is an observable behavior and work output changes may be brought about by phenomena other than fatigue. Some workers distinguish between experiential, physiological, and behavioral phenomena, but they consider fatigue as somehow composed of all three rather than of just the experiential phenomena. Viteles (14), for example, states that fatigue is "characterized" by phenomena in the three classes. Starch, et al. (21) maintain a distinction between three kinds of fatigue corresponding to the three classes of phenomena. They also emphasize the fact (as do Bartley and Chute) that the three phenomena may have little or no rela-

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tion with each other, pointing out that subjective fatigue may not occur in highly emotional situations, even though physiological fatigue may be present. Thus, with intense grief, intense concentration on creative work, etc., one may not "pay attention" to fatigue and thus may not experience it. Fatigue feelings, by this view, are a device which warns the individual whenever the waste products in the muscles and blood stream are not released fast enough to maintain a certain energy level, and which may or may not operate, depending upon emotional and other personal factors.

Gilliland, et al. (13) consider the fact that long mental tasks sometimes do not incur feelings of fatigue. They hypothesize, then, that any phenomenon of "mental fatigue" reduces to physical fatigue, reasoning that mental activity sometimes results in holding certain muscles tense, thus producing fatigue feelings. The function of this fatigue feeling is to slow the body in order to allow it to undergo self-repair and regeneration.

Cattell (8) holds to the two-aspect view of fatigue, the physiological and the subjective. In so doing, he makes a statement, quite relevant to the problem of driving "fatigue," to the effect that the greatest decrement in performance occurs after the feeling of weariness passes and a feeling of well-being takes its place. Freeman (12) like Cattell, emphasizes the distinction between fatigue and performance, suggesting that the reason performance level is often maintained despite feelings of fatigue might be a temporary improvement in methods accompanying continuous and prolonged effort in a routine endeavor. Young (27) considers fatigue a motivation factor which he calls "will." By this view, performance level is determined by the extent to which the increments due to "will" off-set the decrements due to fatigue.

Crawford (9), citing Drew (11) and Bartlett (2), mentions three stages of skill fatigue. First the subject's timing is affected; parts of the cycle of operations being occasionally slowed and other parts hurried; second, the subject ignores some of the elements of the task; and at a third stage aches and pains are noticed.

Crawford, referring to Bartlett (3), states that fatigue "may be seen as a progressive widening of the field of stimuli to which response is made, so that the subject's actions lose direction. Insight deteriorates fairly early and standards are lowered. Actions the subject would normally consider hazardous are undertaken with little concern when he is overly fatigued."

Crawford further states that it is difficult to estimate how long it will take for these stages to be reached in driving. He also states that the more the whole being is engaged in a task and consequently the more varied the sources of stress the more gradually will changes take place, the less they will depend on specific physical effort and the harder they will be to detect.

That precise measurements of driving behavior as obtained by the Drivometer might make it possible to detect the effects of fatigue in driving has been demonstrated by Fletcher N. Platt (18), Manager, Traffic Safety and Highway Improvement Department, Ford Motor Company, who made a Pilot Study in 1962. Mr. Platt found that "driver stress and the effects of fatigue can be measured effectively by the Drivometer" and that "quantitatively rating a driver's performance compared to his norm provides a starting point for providing a specific measure of fatigue."

In general, from the findings mentioned, and those of others (see references) one would expect that all phases of driving performance would tend to deteriorate with time, but that motivation (strong emotional drive) could offset this deterioration.

In discussing the findings of this study, let us start with a description of the recordings furnished by the Drivometer—the key to this new study of fatigue. The Drivometer has been described in some detail in other publications. The description presented here is only that necessary for an understanding of the experiment.

THE DRIVOMETER RECORDINGS

The "Drivometer" used in this study records the actions of the driver and the response motions of the vehicle. The counts recorded by the Drivometer include the following:

Steering Wheel Reversals. A count is made each time the steering wheel is reversed by $^{3}/_{8}$ in. or more at the rim of the wheel from clockwise to counter-clockwise or in

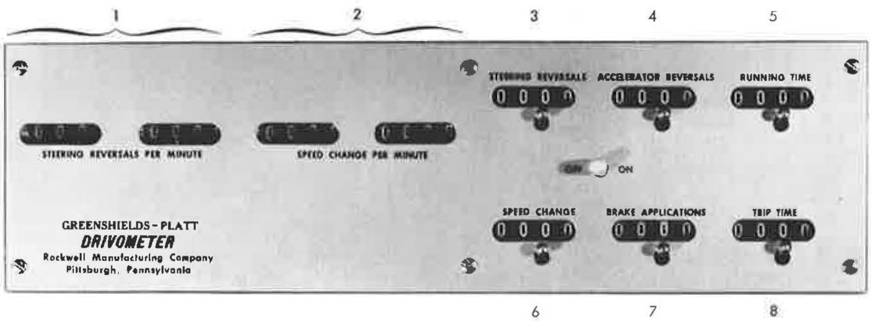


Figure 1.

the opposite direction. Only one count is made no matter how far beyond $^{3}/_{8}$ in. the wheel is turned. The steering wheel reversal counts are integrated minute by minute. (Dials No. 1; see Fig. 1).

Acceleration Reversals. A movement of the accelerator approximately $^{1}/_{8}$ in. up or down makes a one-half count. Thus, there is a count for each accelerator reversal whether at partial or full throttle.

Brake Applications. There is a count for each brake application.

Speed Change. Speed change is recorded by a one-half count for every two miles per hour increase or decrease in vehicle speed. Thus, the amount of speed change in miles per hour for any time interval may be found by multiplying the dial count by four. Since we are interested in fluctuations in the count rather than the amount, the dial readings are used directly in analysis. The amount of speed change, minute by minute, is shown on the No. 2 dials. The total speed change for a trip is shown on dial No. 6.

The Trip Time and the Running Time are shown by dials No. 8 and 5, respectively. It is obvious that by reading the dials at any time interval, the changes per interval may be obtained by simple subtraction.

PROCEDURE

It was decided to make the "fatigue" runs on an expressway where the physical features of the road would be practically constant. The drivers were all college students. No attempt was made to make sufficient runs to achieve statistical stability. It was anticipated from the findings of others already referred to that there would be little or no consistency in the times at which drivers would show the effects of driving fatigue.

The data from a number of "runs" or trips will be plotted and analyzed to give an indication of the differences in individual driving behavior. The data will then be summarized in tabular form.

A graphical representation of a typical "fatigue" trip is shown in Figure 2. The physical and mental condition of the driver at the beginning of the run could be described as normal. Each driver at the beginning of a trip filled out a questionnaire giving his own estimate of his condition.

Four variables are shown: (1) the speed in miles per hour for each 10 minutes of driving, (2) the number of accelerator reversals per 10-minute interval, (3) the amount of speed change for each one-minute interval, and (4) the number of steering wheel reversals for each one-minute interval. The number of brake applications was found to be insignificant and was not plotted.

The numbers at the frequency peaks of steering wheel reversals refer to the events that could have caused the fluctuations in the frequency of steering wheel reversals.

List of Events Corresponding to Numbers Shown in Figure 2

1. Adjusted sun visor and car window.
2. Slowed for car in passing lane.
3. Lit cigarette.
4. Used horn—talking.
5. Put out cigarette—slowed for truck.
6. Adjusted heat control.
7. Slowed for car in passing lane.
8. Gestured.

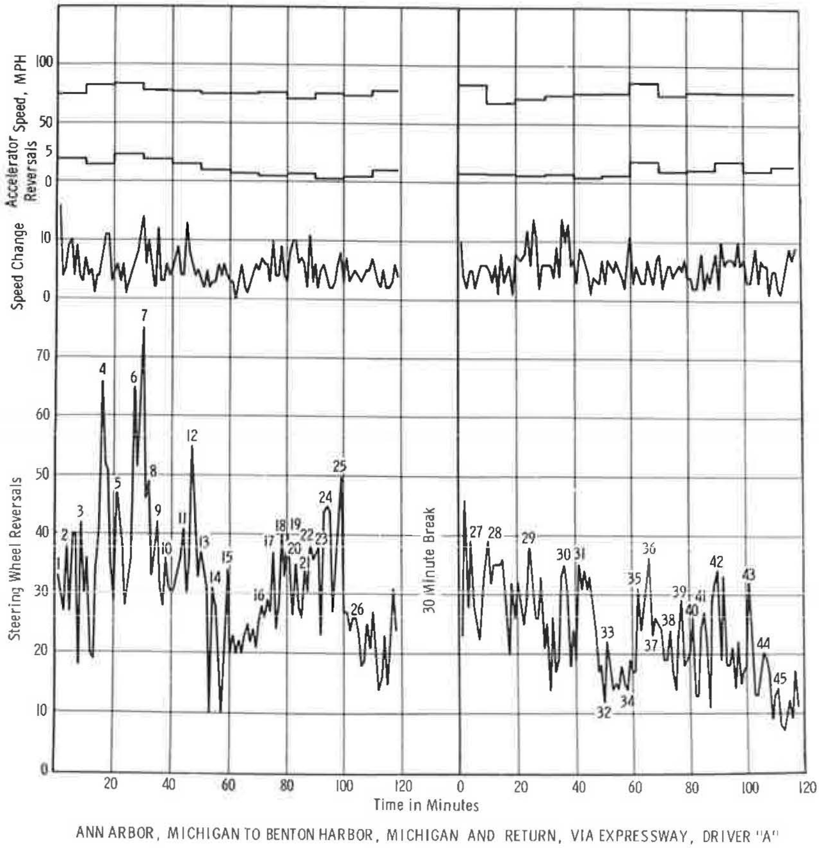


Figure 2.

9. Talked and gestured.
10. Slowed for one lane traffic.
11. Adjusted heat control.
12. Adjusted heat control.
13. Ate candy.
14. Slowed for truck.
15. Stretched—adjusted heat and vent.
16. Adjusted heat controls.
17. No observed reason.
18. Noted cross winds.
19. Changed to left foot for accelerator.
20. Lit cigarette.
21. Used horn.
22. Slowed for lane traffic.
23. Put out cigarette—adjusted heat.
24. Slowed for truck.
25. Driver stated he was drowsy—noted cross winds.
26. Stretched.
27. Slowed for pedestrian on highway.
28. Gestured.
29. Driver watched counters.
30. Changed back to right foot on accelerator.
31. Put out cigarette.
32. Noted cross wind.
33. Passed two trucks.
34. Road repair zone.
35. Driver seems to be over steering.
36. Changed position of hands on steering wheel.
37. Passing.
38. Changed position of hands on steering wheel.
39. Lit cigarette.
40. Wind from passing truck made car sway.
41. Stretched right foot.
42. Seemed to be over steering.
43. Changing grade.
44. Changing grade.
45. Changed position of hands on steering wheel.
46. Applied brakes to avoid slow car in passing.
47. Burning car on roadside.
48. Changed hands on steering wheel.
49. Again changed hands on steering wheel.

ANALYSIS OF GRAPH

An examination of Figure 2 reveals that the accelerator reversals per 10-minute period decrease in frequency at about the end of the first hour and then increase at about the end of the third hour.

The minute by minute amount of speed change is much more variable than the number of acceleration actions. This is to be expected for the speed change depends on the topography of the road and the varying position of the accelerator, not just the up and down movements of the accelerator.

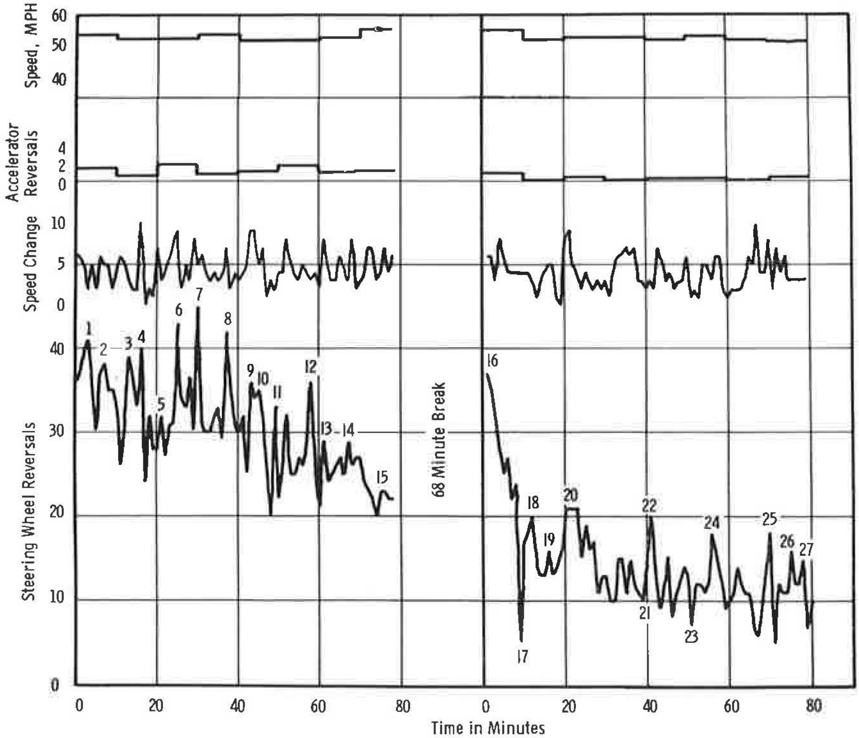
The speed change in both amount and variability decreases at about the end of the first hour and then increases but drops off again at about the end of the second hour.

After the 30-minute time break, the speed change starts, after the first minute, at a relatively low level, then after about a half hour increases, and then decreases to a fairly constant rate.

The numbers of steering wheel reversals per minute show a decrease in both amount and variability. There is also found to be a roughly defined rhythm in the number of steering wheel reversals. First, there is a rise, then a decrease at about the end of the first hour, then again a rise, followed by a decrease.

After the 30-minute break the reversals decrease for the first hour, then increase for a short time but not to as high a level, after which they decrease to a low point at the end of the four-hour drive.

The variation in the number of steering wheel reversals is more pronounced than other driving actions. But this is judging from only one trip, so let us turn to another drive by the same person.



ANN ARBOR, MICHIGAN TO MARSHALL, MICHIGAN AND RETURN. DRIVER "A"

VIA EXPRESSWAY. SPEED TO BE CONSTANT 50 MPH, CAREFUL TRACKING IN LANE

Figure 3.

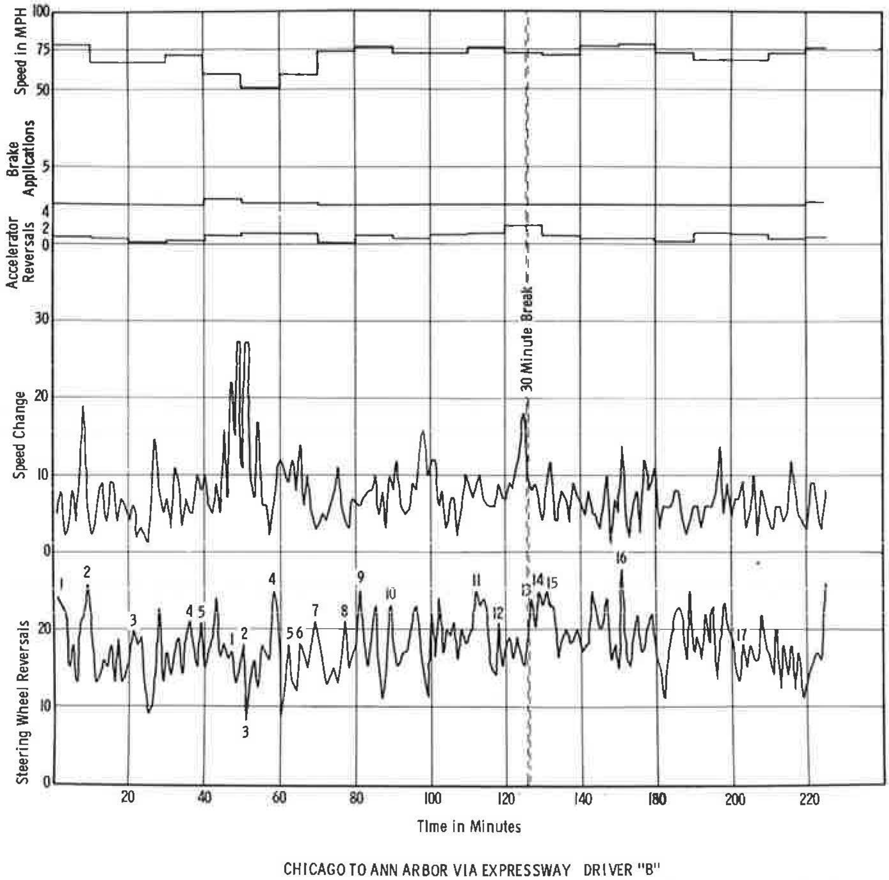


Figure 4.

In the next run (Fig. 3), the time is shorter but the driving task has been made more difficult. The driver was requested to maintain a constant speed and tracking position on the pavement.

List of Events Corresponding to Numbers Shown in Figure 3

1. Cross wind.
2. Lit cigarette—turned on heater.
3. Cross wind.
4. Put out cigarette.
5. Closed air vent.
6. Passed car.
7. Passed truck and car—talked.
8. Telling story.
9. Cross wind.
10. Slowed and passed truck.
11. No explanation.
12. Stretched.
13. Lit cigarette—opened vent.
14. Turned off heat—turned off dome light.
15. Slowed—cross wind.
16. Passed truck—increased speed.
17. No explanation.
18. Put out cigarette.
19. Driver checked speed.
20. Talking—no specific subject.
21. Talking.
22. Passed car.
23. Driver stated that he was very tired—having hallucinations.
24. Checking speed.
25. No explanation.
26. Lit cigarette—talking.
27. Closed vent—turned heat down.

The driving pattern for driver "B" (Fig. 4) is distinctly different from that of driver "A." The amount of speed change is slightly greater while the number of steering wheel reversals is less. There seems to be no decrease in the frequency of the steering wheel reversals as was experienced by Driver "A." Driver "B" stated that he was fresh and alert at the beginning of the trip. But other trips by driver "B" showed a similar pattern even though he was tired at the start.

List of Events Corresponding to Numbers Shown in Figure 4

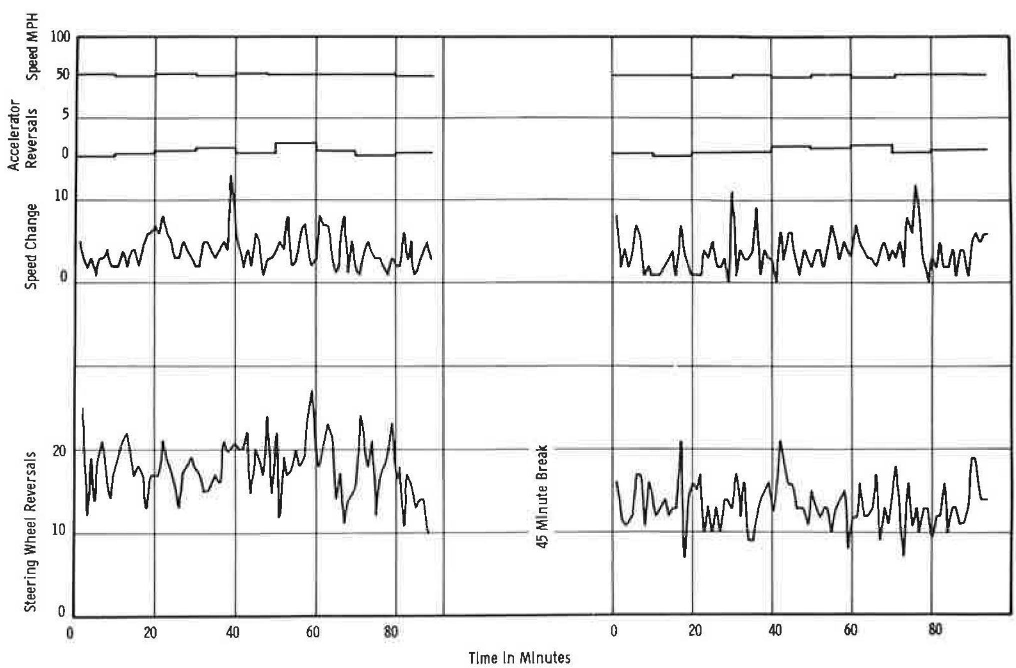
1. Strong cross wind.
2. Slowed—toll gate.
3. Left toll gate.
4. Cross wind.
5. Heavy traffic.
6. Toll gate.
7. Traffic backed up for traffic light.
8. Braked twice.
9. Stopped for light—speeded up.
10. Stop light.
11. Beginning to snow.
12. Adjusted seat—lit cigarette.
13. Rough pavement.
14. Barricade—one lane traffic.
15. Wheel off edge of pavement.
16. Snowing—pavement wet.
17. Traffic and weather conditions improved.

The driving patterns for driver "C" are shown in Figure 5. In this trip the driver was attempting to maintain a constant speed of 50 miles per hour.

It may be noted that the number of steering wheel reversals at about $1\frac{1}{2}$ hours dropped from an average of about 16.6 per minute to a rate of about 12.6 and then remained fairly constant.

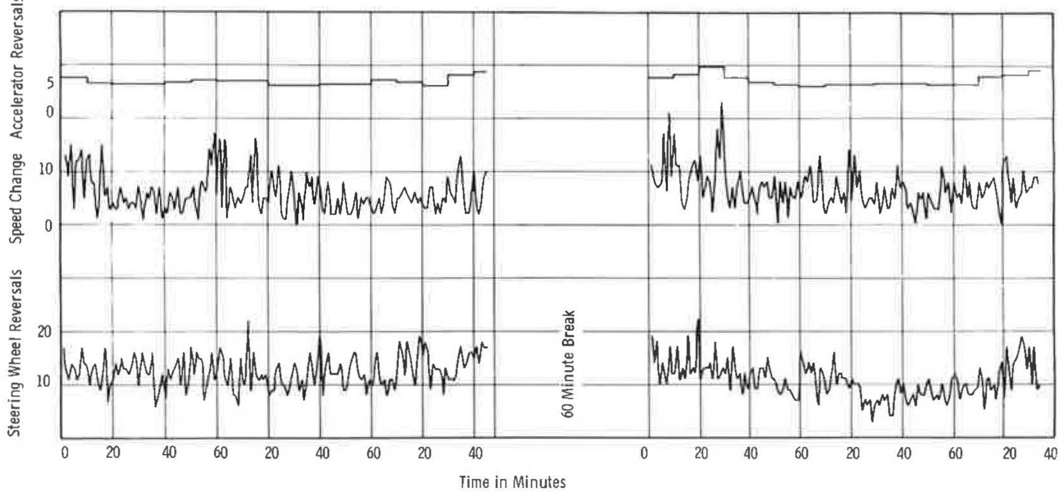
Another trip by driver "C" (Fig. 6) shows a similar driving profile. In this longer trip the rate of steering wheel reversals reached a low point after about $5\frac{1}{4}$ hours of driving.

Driver "E" (Fig. 7) displays a driving profile different from driver "A" when driver "A" was attempting to drive at a constant speed. Driver "A"'s steering reversal rate



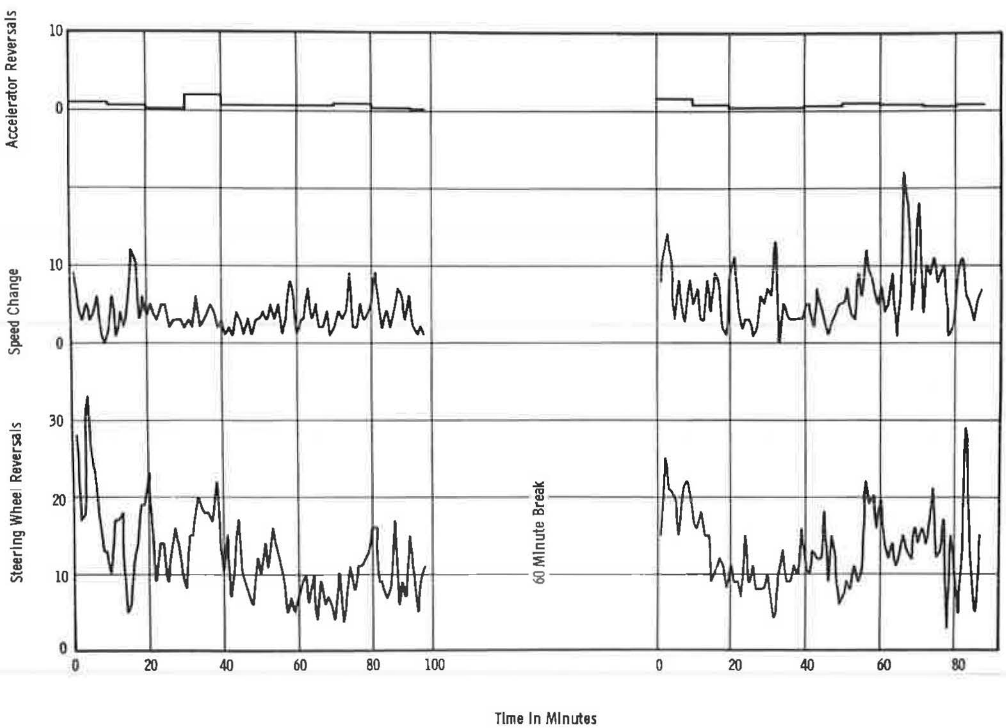
ANN ARBOR, MICHIGAN TO BATTLE CREEK, MICHIGAN AND RETURN VIA EXPRESSWAY. DRIVER "C"

Figure 5.



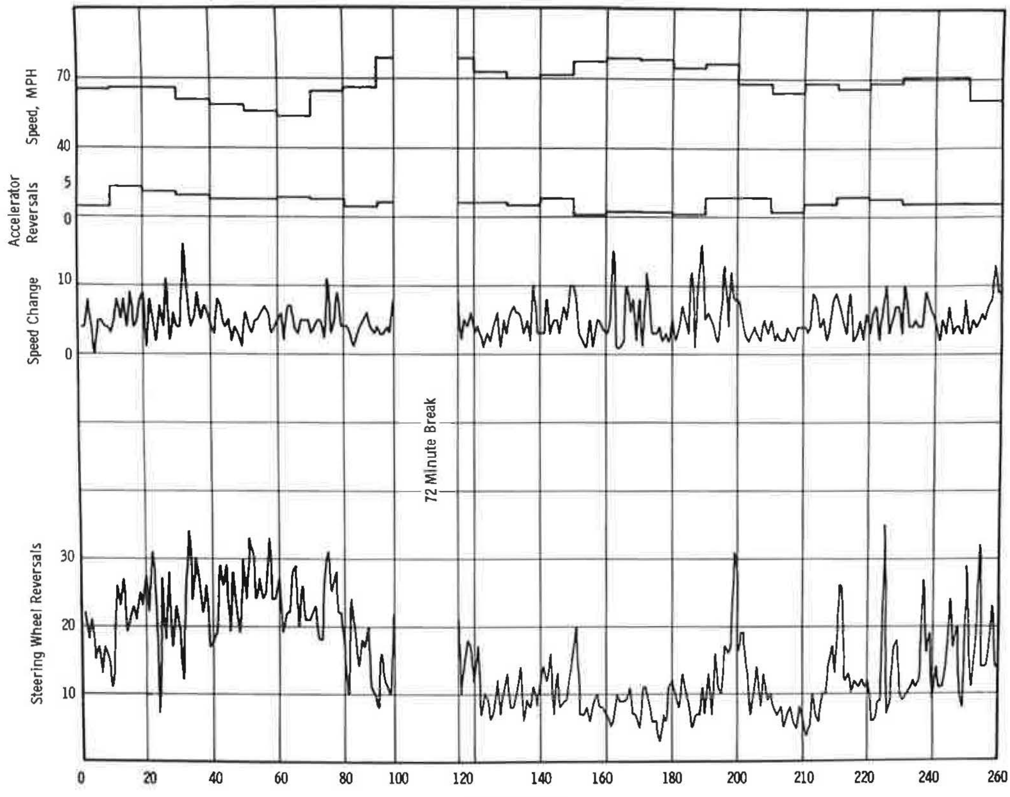
ANN ARBOR, MICHIGAN TO MUSKEGAN, MICHIGAN AND RETURN VIA EXPRESSWAY. DRIVER "C"

Figure 6.



ANN ARBOR, MICHIGAN TO KALAMAZOO, MICHIGAN AND RETURN VIA EXPRESSWAY. DRIVER "E", CONSTANT 60 MPH SPEED.

Figure 7.



MACKINAW CITY, MICHIGAN TO ANN ARBOR, MICHIGAN VIA EXPRESSWAY. DRIVER "A"

Figure 8.

shows a fairly constant decrease throughout the trip. Driver "E" reaches a low point after about 1 hour and 10 minutes of driving and then his rate increases and shows much more variation.

In Figure 8 there is shown a driving pattern for Driver "A" that appears to be quite different from the two previously shown driving patterns for "A." This figure shows the last part of about a 9-hour drive. At the beginning of the chart shown in Figure 8, "A" had been driving for about 3 hours. The low point in the frequency of steering wheel reversals was reached after about 6 hours of driving and about 1 hour and 20 minutes after a stop period. Both the rate of speed change and rate of steering wheel reversals were increasing at the end of the drive. This was quite different from the experience shown in Figure 4.

This phenomenon shown in Figure 8 may be compared to the finding of Herbert and Jaynes (15) who found an improvement in performance after 9 hours as compared to 7 hours. They state that one explanation may be that a gradual but unconscious buildup of fatigue occurs over several hours of driving. "Once the condition becomes obvious to the operator, a conscious effort is made to compensate and thus effect a return to a higher skill level."

All of the runs taken were plotted as shown in the examples given but to show all these would add little if anything to the report. The data for the other runs are summarized in Table 1—"Changes in Driver Behavior with Time Behind the Wheel." The items listed in the table are as follows:

TABLE 1

CHANGES IN DRIVER PERFORMANCE WITH TIME BEHIND THE WHEEL

Type of Run	Driver	Condition of Driver	Date	Time	Steering Wheel Reversals			Speed Change			Accelerator Reversals			Speed M.P.H.		
					N. Rate	Rate	Avg.	N. Rate	Rate	Avg.	N. Rate	Rate	Avg.	Events Obsvd.	Hwy.	Per.
Av.	A	Normal	11/25/62	20'-30'	12	11.8		4.0	3.8		1	5		78	4	
Av.		Normal	2/1/63	20'-30'		11.3			3.6			0.9		65.0	1	
Av.		Normal	12/9/62	20'-30'		15.3			4.2			1.1		76.0		1
Av.		Normal	12/22/62	20'-30'		15.5			5.7			0.2		67	1	
CS/TR		Sleepy	3/16/63	20'-30'		15.3			5.3			1.4		60	2	
CS		Tired	11/13/62	20'-30'		12.3	13.6		5.0	4.7		0.6	0.78	71.0	2	
CS	B	Tired	1/20/63	20'-30'	32	34.1			4.5			2.0		53.0	1	1
CS		Normal	1/22/63	20'-30'		27.7			3.8			2.7		45.1	1	1
Av.		Tired-Sleepy	12/4/62	20'-30'		47.5	30.6		6.5	5.04		4.6	3.1	82.1	1	2
CS	C	Normal	2/5/63	20'-30'	13.0	13.0		5.5	3.7		2.0	1.5		61.8		2
CS		Normal	2/7/63	20'-30'		16.8			10.0			2.9		65.0	3	2
Av.		Tired	2/4/63	20'-30'		17.5			3.7			1.0		53.0	1	0
CS		Normal	2/12/63	20'-30'		12.8	15.02		4.8	5.54		1.9	1.82	71	0	0
Av.	D	Normal	11/23/62	20'-30'	9	10.0		3.9	4.5		1	0.2		65	1	2
Av.		Fresh	11/20/62	20'-30'		14.8			5.3			0.9		71.0	1	2
Av.		Tired	11/25/62	20'-30'		9.8			3.7			2.3		74.0	1	2
		Tired	12/21/62	20'-30'		6.5			4.4			1.2		69.0	1	1
		Tired	12/18/62	20'-30'		10.4			4.7			.1		74.0	2	0
		Normal	1/31/63	20'-30'		11.7			4.0			.5		67.0	0	2
		Tired	12/16/62	20'-30'		6.1	10.53		4.0	4.44		.2	1.04	72.0	0	0
CS/TR	E		4/10/63	20'-30'	20	12.3		4.0	3.5			0.3		62.4	1	
Av.	F	Fresh	11/19/62	20'-30'	25.0	26.6		4.0	4.8		2.0	1.4		71.0	0	2
Av.	A		11/25/62	50'-60'		12.5			4.5			0.9		79.0	2	0
Av.			2/1/63	50'-60'		9.6			4.2			1.0		62.0	0	0
Av.			12/9/62	50'-60'		19.1			4.8			1.2		71.0	1	1
CS			12/27/62	50'-60'		15.4			10.9			1.4		51.0	3	
CS			3/16/63	50'-60'		12.5			3.7			1.1		60.0	0	0
			11/13/62	50'-60'		14.0	13.85		5.8	5.65		0.8	1.06	72.0	1	1
CS	B		1/20/63	50'-60'		25.8			3.8			1.8		52.0		1
50 mph			1/22/63	50'-60'		29.0			4.9			2.6		50.5		2
45-50			12/4/62	50'-60'		23.7	26.16		3.8	4.17		1.8	2.07	75.0	0	0
	C		2/5/63	50'-60'		12.7			5.7			2.2		60.3	1	1
			2/7/63	50'-60'		16.5			7.7			3.1		64.5	0	0
			2/4/63	50'-60'		19.0			3.9			1.9		52.0		1
			2/12/63	50'-60'		9.9	14.52		4.8	5.52		2.2	2.35	70.0	0	0
	D		11/20/62	50'-60'		17.7			7.1			0.4		74.0	2	4
			11/25/62	50'-60'		15.9			15.6			3.3		48.0	3	1
			12/21/62	50'-60'		5.1			5.9			.5		76.0	0	0
			12/18/62	50'-60'		8.9			2.9			.2		76.0	2	3
			1/31/63	50'-60'		9.3			3.3			.3		60.0	0	1
			12/16/62	50'-60'		7.4	10.41		3.9	6.4		.5	.86	74.0	1	0
	E		4/10/63	50'-60'		10.1			3.8			0.7		50.4	2	
	F		11/19/62	50'-60'		22.0			3.2			1.9		68.0	0	1
	A		11/25/62	80'-90'		12.5			3.5			0.5		78	2	
			2/1/63	80'-90'		11.9			3.9			0.5		65.0	1	
			12/9/62	80'-90'		23.5			6.2			2.7		66.0	2	
			12/22/62	80'-90'		18.3			6.3			1.1		77.0		2
			3/16/63	80'-90'		10.2			3.9			1.1		61.0	3	
			11/13/62	80'-90'		14.5	13.48		3.8	4.61		0.8	1.11	75.0		4
	B		1/20/63	80'-90'		25.0			4.6			.9		55.0	1	1
			1/22/63	89'-90'		25.5			5.2			1.4		59.0	1	2
			12/4/62	80'-90'		32.4	27.66		6.9	5.57		1.3	1.2	71.0	2	3
	C		2/5/63	80'-90'		10.4			5.2			1.2		63.0	2	3
			2/7/62	80'-90'		16.1			7.8			4.2		64.0		1
			2/4/63	80'-90'		13.3			2.8			.8		52.0	0	0
			2/12/63	80'-90'		10.1	12.47		5.5	5.33		1.9	2.02	67.0	1	0
	D		11/20/62	80'-90'		17.8			7.4			2.5		60.0	1	4
			11/25/62	80'-90'		9.9			4.1			2.1		73.0	1	0
			12/21/62	80'-90'		6.0			5.4			1.6		67.0	2	0
			12/18/62	80'-90'		7.2			3.3			.2		75.0	0	0
			1/31/63	80'-90'		8.6			5.3			.6		63	0	2
			12/16/62	80'-90'		7.6	9.51		5.5	5.16		1.3	1.38	63.0	1	0
	E		4/10/63	80'-90'		10.4			4.8			0.4		65.0	1	0
	F		11/19/62	80'-90'		22.1			4.9			2.8		68.0	2	1
	A		11/25/62	110'-120'		12.2			5.5			1.3			1	0
			2/1/63	110'-120'		10.6			4.4			.9		61.0	1	
			12/9/62	110'-120'		17.7			7.9			2.4		63.0	1	0
			12/22/62	110'-120'		19.5			6.1			1.4		77.0	0	0
			3/16/63	110'-120'		12.3			10.2			1.3		60.0	0	0

			2/7/63	110'-120'		12.7		7.0		2.5		64.0	0	0
			2/4/63	110'-120'		12.8		3.1		.8		51.0	0	0
			2/12/63	110'-120'		10.3	11.90	6.8	4.97	2.1	1.70	68.0	0	0
	D		11/20/62	110'-129'		18.3		6.4		1.2		75.0	0	0
			11/25/62	110'-120'		9.6		3.9		2.3		72.0	1	3
			12/21/62	110'-120'		4.6		3.3		.7		66.0	0	0
			12/18/62	110'-120'		8.9		5.0		1.2		78.0	1	1
			1/31/63	110'-120'		8.9		2.8		.6		65.5	0	0
			12/16/62	110'-120'		5.4	8.28	3.5	4.31	.6	1.1	81.0	0	0
	E		4/10/63	110'-120'		9.4		4.5		0.5		64.0	0	0
	A		11/25/62	140'-150'	12									
			12/9/62	140'-150'		17.9		5.3		2.0		75.0	0	0
			12/22/62	140'-150'		19.3		4.8		0.7		78.0	0	0
			3/16/63	140'-150'		12.8		3.8		1.7		60.0	1	4
			11/13/62	140'-150'		11.9	15.48	4.2	4.53	0.7	1.28	78.0	1	2
	B		1/20/63	140'-150'		10.9		4.0		2.0		54	10	4
			1/22/63	140'-150'		17.1		3.7		0.7		68	1	1
			12/4/62	140'-150'		28.3	18.8	7.9	5.2	1.2	1.3	71.0	2	0
	C		2/5/63	140'-150'		12.6		3.8		1.2		61.8	0	2
			2/7/63	140'-150'		14.9		7.7		1.3		63.0	2	0
			2/4/63	140'-150'		12.3		3.8		1.4		53.0	0	0
			2/12/63	140'-150'		10.0	12.46	5.8	5.27	1.9	1.45	68.5	1	0
	D		11/20/62	140'-150'		14.8		7.3		1.3		70.0	0	2
			11/25/62	140'-150'		11.5		9.2		5.3		73.0	2	1
			12/21/62	140'-150'		8.3		13.3		2.8		48.0	3	0
			12/18/62	140'-150'		7.1		5.5		.5		77.0	0	1
			1/31/63	140'-150'		8.6		2.5		.4		61.0	0	0
			12/16/62	140'-150'		7.2		7.8		1.8		81.0	1	1
	E		4/10/63	140'-150'		14.5	10.28	7.0	7.51	1.0	1.87	59.0	1	0
	A		12/9/62	170'-180'		9.9		3.9		0.5		82.0	0	0
			12/22/62	170'-180'		19.3		6.2		1.4		68.5	0	0
			3/16/63	170'-180'		12.9		2.6		1.7		59.0	1	0
			11/13/62	170'-180'		11.0	13.24	2.5	3.80	1.0	1.15	78.0	0	0
	B		1/22/63	170'-180'		20.6		4.8		1.3		68.0	1	0
			12/4/62	170'-180'		16.6	18.6	5.8	5.3	1.2	1.25	77	2	0
	C		2/5/63	170'-180'		13.9		8.2		3.2		65.0	0	0
			2/7/63	170'-180'		14.9		5.8		1.9		65.0	0	1
			2/4/63	170'-180'		12.6		2.4		1.1		53.0	0	0
			2/12/63	170'-180'		6.8	12.05	6.2	5.65	3.0	2.30	68.5	0	0
	D		11/20/62	170'-180'		14.6		5.2		0.7		68.0	1	3
			11/25/62	170'-180'		9.7		4.4		5.0		80.0	2	0
			12/21/62	170'-180'		8.1	13.13	7.6	5.17	.7	2.36	60.0	0	0
			1/31/63	170'-180'		7.0		3.5		.7		63.0	1	0
	E		4/10/63	170'-180'		13.8		6.8		0.7		64.0	1	0
	B		1/22/63	200'-210'		14.0		4.2		1.4		58	0	1
			12/4/62	200'-210'		23.0	18.5	4.5	4.35	2.2	1.8	78.0	1	0
	C		2/5/63	200'-210'		11.6		6.0		1.7		65.0	0	0
			2/12/63	200'-210'		9.0	10.3	9.5	7.75	2.4	2.05	68.5	1	0
	D		11/23/62	200'-210'		13.0		4.8		0.6		62.0	1	2
			11/25/62	200'-210'		14.5		8.5		5.7		75.0	0	0
			12/21/62	200'-210'		12.0		7.9		2.0		63.0	1	0
			1/31/63	200'-210'		6.1	15.2	4.3	8.3	1.6	3.3	62.0	0	0
	B		1/22/63	230'-240'		22.0		5.6		3.8		64.0	3	1
			12/4/62	230'-240'		11.0	16.50	5.4	5.55	2.9	3.35	77.0	0	0
	C		2/5/63	230'-240'		11.0		5.2		1.2		66.0	0	1
			2/12/63	230'-240'		11.7	11.35	5.6	5.4	3.9	2.55	68.0	0	0
	B		1/22/63	260'-270'		26.5		7.3		3.2		65.0	3	0
	C		2/5/63	260'-270'		7.8		4.8		1.3		64.0	0	0
	B		1/22/63	290'-300'		16.5		4.9		1.5		61.0	0	0
	C		2/5/63	290'-300'		9.9		6.7		2.9		64.0	10	0
	B		1/22/63	320'-330'		23.3		6.1		3.2		58.0	0	0
	B		1/22/63	350'-360'		22.6		4.0		2.9		51.5	0	0
	B		1/22/63	380'-390'		13.7		3.6		2.1		71.0	0	0
	B		1/22/63	410'-420'		11.8		5.6		2.8		66.0	1	0
Av.	B	Normal	1/22/63	440'-450'		7.9		3.5		0.8		72.0	0	1
	B		1/22/63	470'-480'		12.2		3.0		2.8		63.0	0	1
	B		1/22/63	500'-510'		14.2		3.8		3.1		63.0	1	0
	B		1/22/63	530'-540'		15.4		4.1		2.1		66.0	1	0

1. Column 1 indicates the type of run, such as "N" meaning normal with no instructions as to speed or tracking, or "C.S." for maintaining constant speed and position in lane.

2. Column 2 designates the driver making the run.

3. Column 3 shows the condition of the driver at the start of the trip.

4. Column 4 gives the date of the trip in order that the trip may be identified.

5. Column 5 gives the time after starting the trip, thus 20'-30' indicates that the time interval was that from 20 to 30 minutes after the beginning of the run.

6. Columns 6, 7 and 8 have to do with the number of steering wheel reversals per minute. Column 6 gives the normal rate as determined from several runs. These normal rates are characteristic for each individual and tend to be constant. Column 7 gives the average rate for the 10 minute period designated in Column 5. Column 8 gives the average rate for all the trips for the driver designated in Column 2.

9. Columns 9, 10 and 11 refer to the amount of speed change. Column 9 gives the normal amount of speed change per minute period, Column 10, the rate for the 10-minute period, and Column 11, the average rate for all the runs by the driver given in Column 2.

12. Columns 12, 13 and 14 similarly to speed change, give the normal rate, the rate and the average rate.

16. Columns 16 and 17 list the events. Column 16 gives the highway and traffic events external to the car, while Column 17 gives those occurring in the car, such as actions of the driver. Compare with the events listed in connection with the graphs of driving patterns.

CONCLUSIONS

An examination of the graphic charts of the individual "fatigue" runs and of the summary table showing the changes in driving patterns at half hour intervals plus other findings from Drivometer tests leads to several conclusions.

The Drivometer is sensitive enough to monitor the changes in driving behavior that occur with time behind-the-wheel. The most pronounced measurement is the frequency of the steering wheel reversals. The amount of speed change is less pronounced than the steering wheel reversal rate. The accelerator reversals seem to mean little as a measure of driving change and the number of brake applications is even less significant.

Each driver, according to tests not included in this report, seems to have an individual rhythm or rate of steering wheel reversals that he tends to maintain. It is the rate at which the driver tends to be comfortable. If a driver's rate is twenty steering wheel reversals per minute and he has been driving on an open highway, he will on encountering urban conditions lower his speed but maintain his steering reversal rate. This would indicate that a change in rate may be due to a change in the driver's condition, and not to driving environment.

A driver may, as shown in Figure 3, display a steering wheel reversal rate that decreases in amount and variation with time behind the wheel. The steering wheel reversal rate as shown, drops from a norm of about 32 per minute to about 15 at the end of the trip. But most drivers do not show such a well defined change in performance with time.

For some drivers, with the passage of time, there may be less response to events. For example, for the first four trips for drivers "A", "B" and "C" listed in the table, the number of events responded to in the time interval 20 to 30 minutes after starting were respectively 7, 8, and 11, while in the interval 170-180 the responses were 1, 1, and 7.

As shown in Figure 4, the change in performance is greater if the difficulty of the driving task is increased. In this instance the driver was attempting to maintain constant speed and tracking.

Perhaps the most important attribute of driving "fatigue" is its variability. Either the "will" or the messages of "fatigue" may be in the ascendancy. An emotional urge may overcome the physical effects of fatigue to such an extent that fatigue is simply not experienced.

But with long continued driving the effects of "fatigue" can become operative and accidents often result. The writer has never fallen asleep on the highway but he recalls that twice while teaching an evening class at the end of a day that began at 9 A.M. and ended at 11 P.M., with about 6 hours of lectures plus laboratory periods, he found that he had "blacked-out" in front of a class. Such a black-out of only four or five seconds in front of a class may only be humorous; but on a highway it can be fatal.

It is recalled that after rather intensive investigation, the writer being one of the investigating engineers, it was decided (by the court) that Pasquale Tomasette, died on Aug. 16, 1950 because he went to sleep and not because of a "ghost" hole in the shoulder of the road. According to a newspaper account the accident involved the biggest damage suit against the state of New York up to that time.

The tests performed in the present study were not conducted to the point of failure but it could be that the effects of "fatigue" on driving performance may be detected by a monitoring device before the driver is aware of the change in his performance. A monitoring device could actuate a warning bell.

Testing to the point of failure could perhaps best be done by use of a simulator, but it may be mentioned that all test runs in this study were made with dual brake controls for the observer. It is hoped that this pilot study will lead to further and more extensive investigations.

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