The University of Michigan

IVHS

Intelligent Vehicle-Highway Systems

The Time to Change Lanes: A Literature Review

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September 1990

IVHS Technical Report-90-13

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-90-34		

4. Title and Subtitle	5. Report Date
THE TIME TO CHANGE LANES: A LITERATURE REVIEW	September, 1990
	6. Performing Organization Code
	8. Performing Organization Report No. UMTRI-90-34
7. Author(s) Paula Finnegan and Paul Green	
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute Ann Arbor, Michigan 48109-2150 U.S.A.	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. Gift account - 303188
12. Sponsoring Agency Name and Address IVHS Program Office University of Michigan Transportation Research Inst. 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.	13. Type of Report and Period Covered Interim Report
	14. Sponsoring Agency Code IVHS TR-90-13

15. Supplementary Notes

Funded by U of M IVHS basic research program
Sponsors: GM, Ford, Motorola, MDOT, NHTSA

16. Abstract

This report reviews five articles concerning driver lane-changing behavior. Four of them report driver visual scanning patterns while changing lanes, emphasizing the use of mirrors. It appears that driver eye fixations have a mean and standard deviation of about 0.3 seconds and are distributed log normally. Typically, when changing lanes, drivers make about 2.5 head movements which take about 1 to 1.5 seconds each. When glances to the road ahead are included, the mean visual search time for preparing a lane change is as much as 3.7 seconds without traffic and as much as 6.1 seconds with traffic (depending on the condition). Standard deviations of those estimates are about 0.3 seconds. Allowing for 2 standard deviations, this suggests that 6.6 seconds should be allowed for the visual search associated with a single vehicle lane change and about 1.5 seconds to execute the change.

These estimates should be applied with some caution since the data are primarily for moderately experienced drivers (who take less time than novice and elderly drivers). Further, while traffic volume is not specified, it is believed that the traffic counts were less than those found on contemporary highways. In addition, the literature tends to underplay the importance of visual sampling strategies, which vary considerably between individuals and markedly affect the total lane change time.

17. Key Words	18. Distribution Statement
Human factors engineering, ergonomics, driver behavior, eye fixations, driving, mirrors	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

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INTRODUCTION

This report is one of a series describing research being conducted at the University of Michigan as part of its program on Intelligent Vehicle Highway Systems (IVHS). This particular report was funded as part of the basic research gift program. That program is supported by gifts from GM, Ford, Motorola, MDOT, and NHTSA. The goals of the program are to explore fundamental issues relating to the design and evaluation of future road vehicles, roadways, and associated control and communication systems. Of particular interest are electronics and communications technologies.

Currently U.S. traffic is growing at a rate of several percent per year (as measured in vehicle-miles), and that growth is likely to continue indefinitely. On the other hand, there are no major programs in the works to build new highways, so all the additional travel will occur on existing roads. It is estimated that by the year 2000 there will be a 400% increase in delays (Lindley, 1986; Agnew, 1988). There are dire predictions that in the near future every major U.S. city will be as congested as Los Angeles. Many believe that by better management of traffic flow, more vehicles can be accommodated on the existing road network.

Associated with the increased travel is increased vehicle-related air pollution. Particularly wasteful is the pollution associated with vehicles stuck in traffic. Further, since much of the fuel used must be imported, the associated cost can have significant economic impact on the balance of payments.

In the U.S. in 1988 there were 49,000 deaths due to motor vehicle accidents and 1,800,000 disabling injuries. The cost associated with them was 70.2 billion dollars (National Safety Council, 1989). Many transportation safety experts believe that improving traffic flow will reduce accidents.

All of these consequences of motor vehicle travel have caused industry, government, and academia to take a fresh look at how electronics and communications technology can be used to improve ground transportation. The focus of the current basic research effort is based on a particular scenario in which a person is on a freeway in Detroit or the surrounding counties and an incident occurs on the freeway (probably an accident) that makes it necessary to divert traffic from the freeway. This particular effort is known as Diversion Advice and Recommendation Technology (DART). Some of the questions this scenario raises are as follows:

- How will information about the incident be communicated to a control center?
- What sort of communications network is required?
- How should processing and memory be distributed?
- How will traffic flows be measured?
- How should predictions of the incident's impact on traffic flows be calculated?
- How should suggestions about diversion be communicated to drivers?
- How long will it take drivers to absorb information from an in-vehicle display?
- How likely are drivers to follow the advice?
- How far before an exit should the advice be given?

This research addresses the last question. To design the communications system, engineers need to know how long after drivers receive diversion advice it will take them to (1) attend to it, (2) absorb it, (3) plan and, (4) complete the necessary lane changes, and (5) exit the freeway. This information can then be used to identify the location, power/size, and other characteristics of beacons, transmitters, signs, and other means used to communicate with drivers.

This document summarizes articles describing the tasks completed by drivers when changing lanes. This is not intended to be a comprehensive look at this issue but rather a first cut. The information obtained from this literature review will be incorporated into a model that predicts the time required and errors drivers will make while using a route diversion system. That model should provide improved estimates for lane change time under the heavy traffic conditions of primary interest. Specifically, this part of the literature examines the events which take place after the driver has been presented with information about the diversion and has decided to make the lane change or exit. The topics examined include driver eye and head movements patterns, driving experience, and traffic densities during execution of lane changes.

PREVIOUS RESEARCH

During driving, continual and often complex visual search is required by the driver. The maneuver of changing lanes places severe demands on the driver's visual system, primarily because of the large visual angles among the various images that must be examined. Following is a review of a few of the relevant articles.

Mourant, Rockwell, and Rackoff (1969)

Mourant, Rockwell, and Rackoff (1969) used a corneal reflection eye camera to record drivers' visual search patterns (at 16 frames/second). The subjects drove the test vehicle while wearing the eye-marker apparatus to the site of the trials. During this time, the eye-marker was calibrated, and the drivers became familiar with the feeling of the apparatus.

In addition, a 1963 Chevrolet was instrumented to record speed, accelerator motions, and steering wheel reversals. Eight men, ages 21 to 31, drove two memorized routes (roughly three-miles long) on several expressways near Columbus, Ohio. Each route was driven 6 times, 3 of which involved following a lead car and 3 of which were open road driving. During Trial 1, the participants were instructed to read all road signs as drivers not familiar with the route would do. During Trial 2, they were instructed to read only those signs necessary to complete the route. For Trial 3 they were asked to try not to read any signs as drivers familiar with the route would do.

Only the results for the open driving are examined here, since this situation most closely resembles that of a typical driver on the open road changing lanes. Data were reduced by recording the direction in which the driver looked on each frame (to the nearest degree). Of particular interest is where drivers looked and for how long. Table 1 shows were drivers looked on each of the three trials. Notice that except for the "Out-of-View" category, the mean eye fixation durations are very similar.

Table 1. Viewing Times and Percentages - Open Road Driving

Category	Trial 1	Trial 2	Trial 3	Mean Time (sec)
Look Ahead	50.4	54.2	58.3	.26
Out of View	26.9	25.2	20.5	.46
Bridges	8.0	8.1	7.1	.29
Road Signs	7.5	6.2	5.4	.31
Vehicles	5.0	4.0	6.7	.27
Road, Lane Marks	2.2	2.3	2.0	.29

(Source: Rockwell and Rackoff, 1969)

Figure 1 shows the distribution of fixation durations for the three open road trials. Notice the distributions are log-normal. The mean fixation duration, based on the tabular data in Rockwell and Rackoff, is about .27 seconds. Based on the data given in the figures, the mean is about .29 seconds and the standard deviation is .32 seconds.

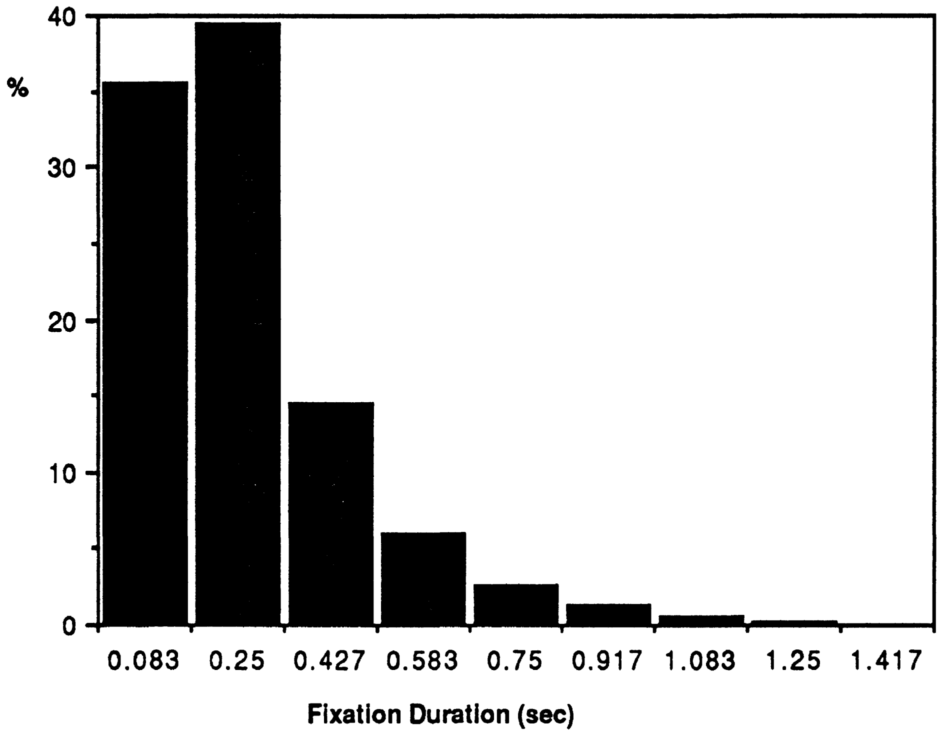

Figure 1. Fixation Distributions
(Source: Rockwell and Rackoff, 1969)

Robinson, et al. (1972)

Robinson, Erickson, Thurston, and Clark (1972) reported data for driver visual search while entering a highway after a stop and for changing lanes on a multilane highway. (See also Hooper and McGee, 1983 for a brief discussion.) Only the lane changing data are described here. Specifically, eight men ranging in age from 20 to 25 each drove a course consisting of a four-lane highway in an urban setting. The test car was a 1969 Chevrolet station wagon equipped with the standard manufacturer's inside and outside mirrors. The drivers averaged 30 mph during the experiment. An observer accompanied the drivers and verbally instructed them to make a right or left lane change as they normally would.

Head movements were recorded by a potentiometer attached to a helmet. The potentiometer was also attached to an articulated arm that permitted freedom of head movement forward or to the side while maintaining its angular calibration. The signal was recorded as a function of time at an unreported frequency, probably once every 50 milliseconds. Traffic conditions were recorded as "none" or "some," the latter term meaning that at least one vehicle may have been in a position, judged by the observer, to interfere with a lane change.

The visual search by the driver prior to the lane change was partitioned into three categories. They were the time spent looking in the mirrors, searching "back" (defined as a head movement of over 100 degrees), and searching to the "side" (a head movement between 45 and 90 degrees). There were 221 lane changes made, 76 in traffic, with 128 to the left and 93 to the right.

In the on-the-road portion of the experiment, only head movements were recorded. Since the actual visual search pattern includes both eye and head movements, laboratory measurements were completed in which eye-movement-with-respect-to-head and head movements were measured. The head movements were recorded by using the same system used in the driving tests. In addition, eye movements were measured using a scleral detection-based system. To test the relationship between eye and head movement, the participants were asked to refixate, as quickly as possible, on targets at angles of 40 degrees, 60 degrees, and 80 degrees from a resting point straight ahead.

It was concluded that the actual visual fixation time is approximately 50 msec. longer than that indicated by the head "fixation" data. This is due to higher velocity of the eye (1000 degrees/second) than the head (450 degrees/second). (See Figure 2.)

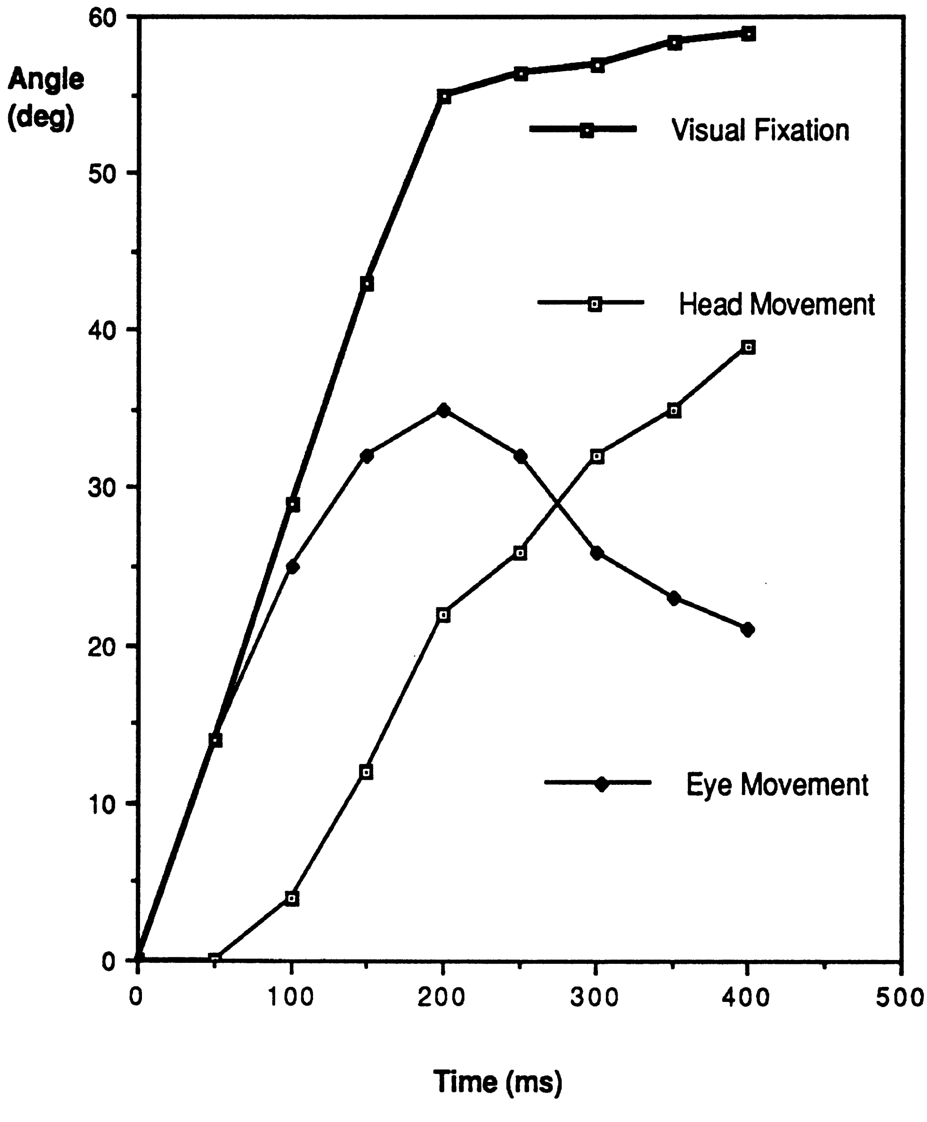

Figure 2. Eye and Head Movement Times from Robinson, et al. for Refixations at 60 Degree Target

In addition, it was found that the dynamic relationship between the eye and the head is reasonably stable for an individual, and remarkably consistent between individuals. Therefore, all input times have this correction. (See Mourant and Grimson for further discussion of the eye movement/head movement phase relationships.) Table 2 shows the mean times for left and right lane changes, with and without traffic. The mean time from the command to change to the initiation of the lane change was 4.35 seconds with a range of 3.25 to 5.23 seconds.

Table 2. Mean Times (sec.) for Visual Search

Lane Change		Change Left		Change Right	
Traffic		Some	None	Some	None
Total Time	mean	6.10	3.69	4.53	3.37
(command to start turn)	sd	0.56	0.26	0.30	0.18
Visual Input Time (mirrors, back, side)		1.90	1.25	1.79	0.99
Visual Loss: Eye-Head Movement		0.79	0.56	0.68	0.43
Remaining Visual Input Time (road ahead, traffic, etc.)		3.41	1.88	2.06	1.95

Source: Robinson, Erickson, Thurston, and Clark (1972)

The results show that approximately 30% of the total maneuver time is spent acquiring necessary visual input data, with an additional 15% lost due to eye-head dynamics (the additional 50 msec. previously discussed). Also, the presence of traffic increases (by 50% to 85%) both the mean total and mean visual input times.

The number and distribution of visual search inputs were also noted. The first search after the command was the outside mirror in 70 - 80% of the left lane changes and the inside mirror in 40 - 60% of the right lane changes. Between 25% and 50% of the right lane changes had a search back first. Table 3 shows the average number of visual inputs for each maneuver with and without traffic. Table 4 shows the search patterns.

Table 3. Number and Distribution of Visual Searches

	Change Left		Change Right	
	Traffic	No Traffic	Traffic	No Traffic
# of Looks	2.62	1.88	2.28	1.43
		Distribution (%)		
Inside Mirror	3	10	49	34
Outside Mirror	57	50	3	2
Back	33	24	42	56
Side	7	16	6	8

Source: Robinson, Erickson, Thurston, and Clark (1972)

Table 4. Search Sequences for Lane Changing

Condition	Search Sequence *
Left, Traffic	Outside-Outside-Back or Outside-Side
Left, No Traffic	Outside or Outside-Back or Outside-Back-Outside
Right, Traffic	Inside-Back-Inside or Inside-Back
Right, No Traffic	Inside-Back or Back

* Inside=Inside Mirror
Outside=Outside Mirror
Back=large head movement to rear (over 100 degrees)
Side=look to side of vehicle (45-90 degrees)

Source: Robinson, Erickson, Thurston, and Clark (1972)

The results show that with the addition of traffic (e.g., increased complexity of visual scene), more visual search by the driver takes place and, to a lesser extent, longer individual fixations occur. A high-risk aspect of changing lanes is the search to the rear, since this search removes the visual input completely from other sources. The time has a minimum value of 0.8 seconds, and thus, any traffic dynamics ahead of the vehicle that occur within 0.8 seconds may be critical.

Finally, Robinson, et al. also include probability density functions for the mirror and backward looks. While they were generally log-normal, there were a number of drivers whose distributions were almost flat (out to 2.5 seconds).

Mourant and Donahue (1974)

Mourant and Donahue (1974) examined the total time it takes to make right and left lane changes as a function of driver experience and mirror size. Nine drivers participated in the study, 3 novices (16-26 years old, 500-2500 miles driven), 3 experienced (ages 23-25, 27,000-32,000 miles driven), and 3 mature (ages 42-51, 200,000-350,000 miles driven).

The participants drove a four-door 1973 Buick LeSabre which was fitted with two different mirror systems. Both mirror systems were standard door-mounted designs that consisted of flat left outside and inside mirrors. (The horizontal coverage of the left outside and inside mirrors in system B was 25% greater than system A, which corresponded to a 25% larger field of view).

The participants drove a fixed course which consisted of a 12.8 mile loop on a freeway in downtown Detroit. The lanes were 12 ft. wide. Each driver was given five hours of practice so that each had about 250 miles of driving experience before the experiment began. Although it is not stated in the paper, it is estimated that the subjects drove approximately 50 miles per hour during this study.

The test equipment included a closed circuit television system consisting of three television cameras, special effects electronics, an electronic counter, a video monitor, and a video tape recorder. This equipment was installed in the rear passenger compartment of the test vehicle. The first camera monitored the driver's eye through a front surface mirror which was mounted on the panel. The second camera viewed the road scene directly in front of the test vehicle, and the third viewed the road scene behind the car.

Before the experiment began, participants were instructed to align the inside mirror to provide maximum field of view. In addition, they were instructed to adjust the left outside mirror so that a portion of the left side of the car could be seen in the inboard edge of the mirror.

The lane changes were monitored by the experimenter in the back seat of the test vehicle. The participants were not instructed to make lane changes, so the data reflect lane changes initiated only by the driver's preference to do so. An average of 11 left lane changes per driver and an average of 16.5 right lane changes per driver were recorded for system A. For system B, an average of 7 left lane changes per driver and an average of 16.5 right lane changes per driver were recorded.

Table 5 shows the average number of glances and the duration of glances for novice, experienced, and mature drivers for right and left lane changes. For left lane changes, glances include looks into the left-side mirror, inside mirror, and head-turn, and for right lane changes, glances include looks into inside mirrors and head-turns. Averaged for all drivers, the times for obtaining information during a left lane change from a head turn, the left-side mirror, and the inside mirror were 1.52, 1.02, and 0.74 seconds respectively. For a right lane change, the time for obtaining information for a right lane change was 1.09 seconds for a head turn, and 0.88 seconds for an inside mirror glance.

Table 5. Mean Number of Glances and Duration (Sec) Per Change

	Change Left		Change Right	
Driver	# Glances	Duration	# Glances	Duration
Novice	2.9	1.02	3.1	0.96
Experienced	2.0	1.05	2.8	0.92
Mature	2.4	0.96	2.9	0.88
Mean	2.4	1.01	2.9	0.92

Source: Mourant and Donahue (1974)

The execution time for the lane changes was defined when the leading edge of the test vehicle crossed the lane marking on the road. The average mean time per maneuver can be calculated by multiplying the mean number of glances per lane change by the mean duration of a lane change. Using the data in Table 5, Mourant and Donahue report, for example, that the average time for a novice driver to complete the visual sampling for a left lane change to be 2.4 x 1.01 or about 2.4 seconds. This time consists of a mean of 1.38 glances to the left side mirror (at 1.02 seconds each), 0.76 glances to the inside mirror (at 0.74 seconds each) and a head turn

(0.3 x 1.52 seconds). For a right lane change the average time is 2.9 glances times 0.92 seconds/ glance or 2.7 seconds. (That time consists of 2.8 glances x 0.88 seconds for the left side mirror, and 0.33 glances times 1.09 seconds for the head turn.) Mourant and Donahue do not present any data on fixation durations.

Bhise, et al. (1981)

Bhise, Meldrum, Jack, Troell, Hoffmeister, and Forbes (1981) did a study to determine the effects of mirror size and traffic conditions on lateral head movements for left lane changes. As a part of that research, data were obtained on glance durations and lane change times.

Four different mirror widths were tested: 10.6, 7.85, 5.1, and 2.35 inches. Only left lane changes were examined. Mirror glance time was defined as the time between the driver's initial head movement towards the left outside mirror and the time when the head first started to move back to the forward position. Hence this time included time spent fixating on the mirror as well as time spent getting to and from it. Lane penetration time was defined as the elapsed time between the first head turn toward the left outside mirror, and the point when the left front wheel of the driver's car first penetrated the lane marker.

Six drivers between 22 and 50 years old participated in the experiment. Tests were conducted in sunny to partly cloudy conditions and in light to moderately heavy traffic. The subject (in a 1979 Ford Fairmont Futura) followed a pickup truck (1979 Ford with a camper cap). The subject was followed by another truck (1978 Ford Bronco) which obstructed the subject's view and forced him to use the mirrors. Inside the lead truck was a movie camera that recorded the subject's head position. When the lead truck's right turn signal flashed, participants made left lane changes both with and without traffic. The traffic situation for each lane change was assessed and rated by an experimenter in the following truck. For each lane change, the experimenter recorded if a vehicle was present or absent in the adjacent lane that could interfere with the lane change. Each driver did this 20 times (5 times for each mirror size (which includes 1 practice trial) times 4 mirror sizes).

The results showed that mirror width did not have a significant influence on drivers' glance durations. However, as in the previous studies, the traffic conditions did significantly influence the duration of glances. Glance durations were about 1.25 seconds when no traffic was present and 1.5 seconds with traffic. For the 6 drivers, mirror glance times ranged from about 1.1 to 1.8 seconds for the no traffic condition to 1.0 to 2.3 seconds when traffic was present. Probability density functions and standard deviations were not provided for the glance durations.

Some of the most interesting data from this study are those on driver search strategies. Notice they are highly individualistic. (See Table 6.)

Table 6. Mirror Glance Sampling Modes

Subject	-1-		-2-		-3-		-4-		-5-		-6-		Total		
Traffic	n	y	n	y	n	y	n	y	n	y	n	y	n	y	all
Sampling Mode															
Eye Glance (EG) only no head turn	1	4											1	4	5
EG + Head turn to Inside Mirror (IM)													0	0	0
Head turn to Outside Mirror (HOM)	7	4			8	7	8	6				1	23	18	41
HOM + HIM			8	7				1	1	5			9	13	22
HOM + Direct Look to left rear (DL)						1		1	2		3	2	5	4	9
HIM only				1										1	1
HOM + HIM + DL									5	3	3	3	8	6	14

Source: Bhise, Meldrum, Jack, Troell, Hoffmeister, and Forbes (1981)

For lane penetration times, all data were taken for the no traffic condition. It was found that penetration of the left lane took about 2 seconds with each of the mirrors except for the smallest mirror, which was about one half second longer (as it required a larger head movement to find the mirror).

Fazio, et al. (1990)

Fazio, Michaels, Reilly, Schoen, and Poulis, (1990) constructed a mathematical model that predicts the behavior of freeway exiting. Specifically, the model is used to determine the length of speed change lanes (SCL) for exit ramps. Examining this model is useful because part of it incorporates predicting how long it takes a driver to make a lane change.

For the freeway exiting part of the model, the desired Speed Change Lane (SCL) is divided into three longitudinal segments ($SCLL = L_{SC} + L_G + L_B$): Steering Control Length (L_{SC}), the Deceleration in Gear Length (L_G), and the Braking Distance (L_B). (See Figure 3.)

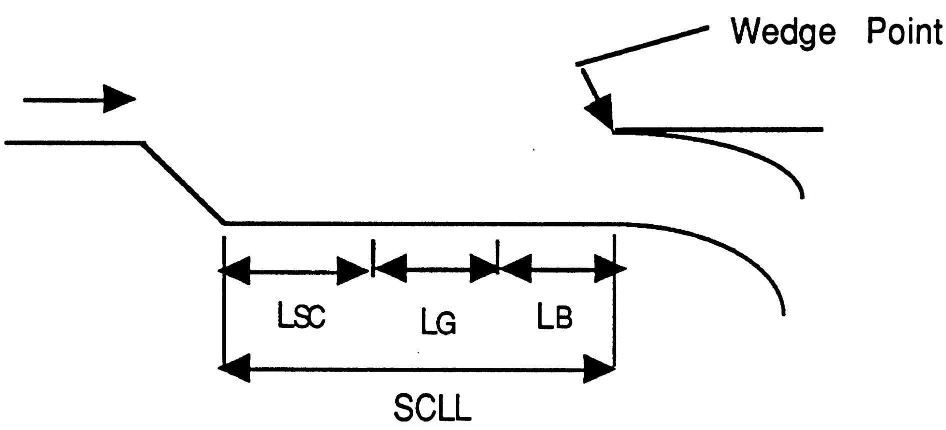

Figure 3. Illustration of Model Segments

The first of the three segments, the L_{SC}, is of concern because it encompasses lane changes. The model predicts that the driver will initiate the steering control maneuver from the right freeway lane onto the SCL at the point when the location of the wedge point generates an angular velocity greater than the threshold that the driver can detect. When elements at the driver's point of focus have an angular velocity which is less than angular velocity threshold, the points appear stationary.

Given the point where steering from the freeway begins, it is possible to calculate the length required for a driver to complete the steering maneuver ending on the SCL. By letting the steering control maneuver time equal 1.5 seconds (from McRuer and Klein, 1975), the time for normal drivers to complete a steering maneuver, and multiplying this number by the freeway speed, the L_{SC} can be calculated.

Further details of the model will not be provided here as they pertain more to the design of exit ramps than the problem of interest here. Those interested in further details should see Fazio, Michaels, Reilly, Schoen, and Poulis (1990).

Though the details in Fazio, et al. are sketchy, they describe an effort to validate their model (from data reportedly in Reilly, et al., an NCHRP study not listed in their references, and from unpublished data). In brief, an unknown number of vehicles were videotaped from an overpass near each exit ramp. Orange traffic cones were placed at 50 or 100 foot intervals to provide distance information. Seven sites were examined. Two were curved ramps. The other five were diamond exits.

The model predicted actual driver behavior rather well except for the diamond off-ramps where the actual and predicted braking distances differed. This was thought to be due to instrumentation errors.

SUMMARY

Because each study takes a slightly different approach to the problem of measuring lane change behavior, comparison of them is not simple. Further, the data should be viewed with some caution. Most of these studies involve younger subjects (typically 20-30 years old). Mourant and Donahue (1974) have shown that both novice and mature drivers make more glances (about .25 to .5 more) than experienced drivers before changing lanes. They do not report any difference in glance durations, which is surprising.

Second, much of the data were collected in the 1970's when traffic was much lighter than today. Where traffic was examined, it did increase the number of glances required and their duration, but the traffic volume was never quantified (e.g., in vehicles/lane/hour), only as "some" or "none."

In brief, the duration of an eye fixation for road scene objects (other vehicles, in mirrors, road markings, but not signs) is about .3 seconds with an equivalent standard deviation. The distribution of times is log-normal but further specification of the distribution does not appear in the literature. (See Mourant, Rockwell, and Rackoff, 1969.)

In most cases, the motion pattern is with the eye movement to lead the head movement to an object by about 50 milliseconds with the angular velocity being about 1000 degrees per second for eye movements and 450 degrees per second for head movements (up to about 120 degrees). (See Robinson, Erickson, Thurston, and Clark, 1972.) When head movement time is folded into the calculation, a typical glance to the side or a mirror takes from 1 to 1.5 seconds depending on the level of traffic and the study cited (Mourant and Donahue, 1974; Bhise, Meldrum, Jack, Troell, Hoffmeister, and Forbes, 1981). Standard deviations and distributions for these times are generally not reported.

Using the Mourant and Donahue estimates of about 2.5 glances to the side, the minimum time required for visual sampling (assuming the roadway is ignored) is about 2.5 seconds. Glances to the road ahead will add another second or so to the time to complete the sample. These estimates are in line with the times reported for left and right lane changes by Robinson, et al. of 3.7 and 3.4 seconds without traffic and 6.1 and 4.5 seconds with traffic. Standard deviations for these times are surprisingly small, around .3 seconds. The actual time to change lanes is another 1.5 seconds. (See Fazio, et al.)

Thus, these data do provide some values useful in developing a first cut model of driver lane-changing behavior, though better descriptions of the distributions and how they are affected by driver age are desired. In identifying how far before an exit a message must be presented, one must design for a reasonable worst case, not for the average driver. A reasonable estimate is to present the message at least 6.7 seconds (the mean plus two standard deviations) before the beginning of the exit lane This number assumes that only a single vehicle is diverting to the exit, not several of them as would likely be the case if the system were installed.

PROPOSED MODEL

Each of the variables that affect the time to change lanes will be considered in a preliminary model of lane changing. The model will be implemented into the simulation package, Extend, for the Macintosh (Imagine That, Inc., 1987). Using Extend, four block diagrams will be created that represent a portion of the simulation. Each of the pictures in Figure 4 represents a block, and is used to describe one part of the lane changing process. The squares with connecting lines between the block diagrams represent information coming and going from the blocks, and are referred to as connectors. The input connectors are symbolized by a small hollow square, and are the points at which information is fed to the block by others. The squares with the heavier borders are output connectors. These connectors are where information is fed from the block to other parts of the simulator.

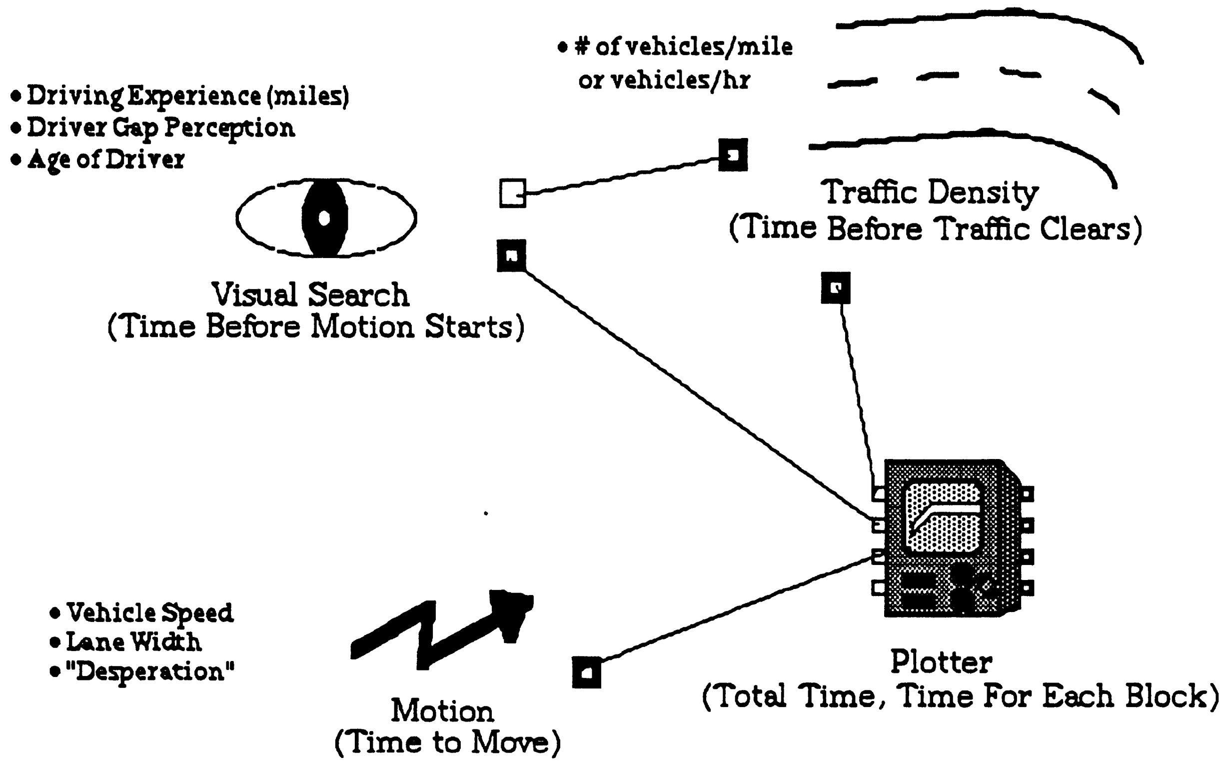

Figure 4. Graphic Representing the Extend Model

The user of the model enters the appropriate information into each block prior to running the simulation. A description of each block and the variables included in each block follows.

The first block, Visual Search, is based upon the literature reviewed in the first part of this report to predict how much time a driver spends during the visual search before the lane change begins. The three variables entered into this block include the age of the driver, driving experience, and gap perception by the driver. The last of these is a subjective measurement, and can be considered a type of "risk factor" for each individual driver. In addition, information from the block, Traffic Density, is fed into the Visual Search block since it affects how much time the driver spends looking before the lane change begins.

The second block, Traffic Density, will predict how much time, if any, before the lane is clear and the driver can begin the lane change. The density is measured by either the number of vehicles per mile or the number of vehicles per hour.

The third block, Motion, will be used to predict how much time the actual movement of the car into the lane will take. The information entered into this block includes the vehicle speed, the lane width, and the "Desperation" factor involved with the change. This last factor takes into consideration the amount of time until the destination, such as an exit, appears.

The last block is a plot which takes all of the output from the three former blocks and visually displays the results of the simulation. The time for each of the three blocks will be displayed in the Plotter, as well as a total time for the lane change.

Within each block, probabilistic calculations will take place that predict, for example, the probability of the lane being clear according to the traffic density. Also, many other variables can be implemented to make the model more complete. While certain variables will be left out of this preliminary model, such as the width of the rear view mirror (because they where found not to have an impact on driver's visual search time), others have not yet been examined. For example, road conditions, such as bad weather, and night vs. day conditions will not included in the model. Furthermore, if the model is used to simulate a particular set of known roads, then time of day can be added to the Traffic Density block to increase the accuracy of that block.

Finally, if more than one lane change has to take place to complete a diversion, this can also be implemented in the model. After the first change is complete, the process starts again with a visual search, traffic density rating, and time to move. In other words, the simulation is run twice for a two-lane change maneuver.

Thus, the literature provides sufficient data to begin to model driver lane changing behavior and the necessary software tools exist. However, there are many gaps. In particular, information on the parameters associated with eye fixation distributions is needed. Also missing are comprehensive data on individual sampling strategies. If these data existed it would be possible to compute the worst case estimates in order to specify design limits.

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