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REACTION TIME OF DRIVERS TO ROAD STIMULI

by

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Reaction time of drivers to road stimuli

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Abstract:

The assumption of a reaction time value for drivers responding to road situations is fundamental for the design requirements involving sight distance, in particular for vertical and horizontal curves. This response time is frequently referred to as the "perception-reaction time" in traffic engineering literature. Previous attempts to estimate an appropriate value for this time are discussed, along with other relevant laboratory and field reaction time literature. It is suggested that the procedures used have generally been deficient on one of several grounds. The majority of studies have used briefed subjects in an experimental situation. The duration of various processing stages have generally been arrived at by a subtractive technique. Responses have usually been assumed to be the result of speeded processes. Within single studies, the stimulus situations examined have typically been limited.

The requirement for unobtrusive observational techniques is stressed so that reaction time estimates can be obtained that are representative of real world performance. This approach was used in the study reported here to obtain data for a range of eliciting stimuli . The salience of the stimulus type was estimated by the driver response rate and form of response distribution. Vehicle speed was observed for some situations, so as to allow an assessment to be made of whether driver response times depend on vehicle speed. The data showed generally that faster drivers had lower reaction times under otherwise similar conditions. The road situations that yielded the highest responding rates were railway level crossing signals, and the amphometer (pairs of cables across the road surface used by Victoria police to detect speeding drivers). The estimates obtained are discussed in terms of the commonly assigned design value of 2.5 s. Values of the 85th percentile reaction time were found that were both above and below this design value. However, the pattern of results overall suggests that the current standard may be inadequate in some circumstances, and a review of this standard is strongly recommended.

Contents

Figures

Tables

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INTRODUCTION

Traffic engineers have long been concerned with driver response times when confronted with relatively unexpected road design features or emergency events that are likely to require a rapid response. (American Association of State Highway Officials (AASHO), 1931). What has been somewhat lacking in the past has been substantive and extensive human performance data for use in establishing bounds on those values that can be used for traffic engineering design.

The requirement for additional data has been recognised. For example, Richards (1960) suggested that too little attention was being given to the time between the occurrence of a road stimulus, and the necessary action. More recently, the recommendation made by the Australian Expert Group on Road Safety in a report to the Commonwealth Minister of Transport has taken note of the need. In that report entitled *Road Accident Situation in Australia in 1975*, a specific recommendation was made to "develop a more appropriate value for driver reaction time to be used in road design" (page 130). Experimental work and debate on the issue continues in the United States (McGee, Moore, Knapp and Sanders, 1978), and it is generally agreed that while design standards have long been established, these cannot be regarded as based on very firm evidence. For example, across a range of studies of reaction time related to driving situations, the values have ranged from fractions of a second to as high as about 7 s. Driver education manuals generally suggest that the average driver reaction time is approximately 1 s with values ranging from about .5 s to 2 s. It is known as well that drivers use information well ahead of them on the road where this reduces the need somewhat to make highly speeded responses, and allows advanced planning. For example, Greenshields (1961) has estimated that the time-distance at which events commenced to influence the driver may vary from 20 sec ahead on the highway to between 2 and 3 sec in the city. Longer visible distances give drivers more time to plan and react, given that such information can be used. For precise vehicle control, drivers also tend to look well ahead (McLean and Hoffmann, 1970; Triggs, 1980).

Currently, the National Association of Australian State Road Authorities (NAASRA) standard in the area of geometric road design for the visibility required ahead is based on a definition of the minimum time available for the driver to react to the road scene. Initially, the Australian standard was set at 1.5 s, and later this time was generally extended by the States to 2.5 s to match the standard adopted in the United States. An exception to this has been New South Wales, that has retained the 1.5 s value for two-lane rural roads and in urban areas. While it is usually assumed that brake lag times are very small, it should be noted that truck trailer brake lag times are sometimes as high as 1.4 s which would increase the overall delays involved. The current design sight object height is 0.23 m, and driver eye height of 1.4 m.

There is a trade-off involved in any selection of a standard. The greater the time available, the longer the driver has to respond safely to changes in the road ahead. The shorter the time, the smaller the sight distances that can be accepted which means lower costs. Road construction costs are influenced by the radii allowed for horizontal and vertical curves, and these depend on the sight distance required. Mullin (1966, 1972) in support of the 1.5 s design standard has argued that there may be an advantage to using a short vertical curve with a brief curtailment of view rather than inserting a long costly vertical curve and reducing the sight value to a moderate value over a longer length of road. In addition, other factors influence these considerations. For example, it has long been argued that as design standards are improved, drivers reduce some of the assumed safety or in the vicinity of constrained alignments, benefit by driving faster and with less attention (O'Neill, 1977).

One argument that has been advanced for adopting a lower reaction time design value on lesser quality rural roads is that in these circumstances road users will drive with greater attention and as such might not require as much time to react (McLean, 1981). However, although not generally found (Boughton, 1975) there is some suggestion in the literature that increased sight distance is associated with a reduced accident frequency (e.g., King and Goldblatt, 1975; Cirillo, Dietz and Beatty, 1969). Glennon (1970), in fact has urged an increase in the perception-reaction time design value to 3.0 s. A report by the South Australia Highways Department (1976) has also suggested the adoption of this higher figure.

Do the types of traffic engineering event such as warning signs, road markings, etc, that the motorist encounters unexpectedly produce reaction times that are in line with the current NAARSA standard dealing with road design features? Relatively few data exist related to this issue that have been obtained in field situations.

The study reported here involved obtaining reactions of members of the driving public in actual driving situations. The responses of drivers who were unaware of their participation were recorded. Such unobtrusive measures were considered to be important in order to obtain realistic and appropriate estimates of their response times. While reaction time data obtained in the laboratory or from experimental subjects on the road will be valuable for studying speeded reactions in some aspects of driving performance and for understanding underlying processes, the results are likely to yield estimates that are systematically less than would occur in practice, because of the alerting nature of the experimental task.

Research areas relevant to the topic of reaction time in field situations and sight distance requirements have been reviewed briefly. It will be noted that previous applied reaction time studies associated with driver behaviour have made strong implicit assumptions concerning the nature of the underlying human processes involved. This earlier work has generally assumed that the responses obtained are the output of speeded processes. Therefore, two criteria have been discussed by which the emphasis to response speed given by the participants can possibly be assessed, namely the responding rate by the driving population, and the skewness of the distribution of individual response times.

CHARACTERISTICS OF REACTION TIME

BACKGROUND

Scientific interest, in the topic of human reaction time dates from about the beginning of the nineteenth century, initially in the area of astronomy and later in physiology. Considerable work on the basic properties of reaction time followed particularly in the laboratories of the German scientist, Wundt, and the Dutch physiologist, Donders (Woodworth, 1938).

However, interest waned around the beginning of this century because of a turning away from research in human performance in general, and because of a basic concern with the introspectionist methods that had developed. Introspection was used to obtain estimates from subjects of which various stages of processing had concluded. Scepticism developed when it was found that such methods did not yield reliable results.

Developing interest in information theory and processing led to a revival of interest in reaction processes in the early 1950's, which has been sustained until the present. Numerous detailed reviews of basic reaction time research exist (Woodworth, 1938; Teichner, 1954; Smith, 1968; Fitts and Posner, 1967; Welford, 1968), but an attempt will be made here to provide an overview of such work in a form that will provide a background for traffic engineers of the basic principles affecting the times required by humans to process information. Where appropriate for this project, some issues will be considered in more detail, and specific references supplied. Despite the great amount of information that is available concerning reaction time durations, it is still not usually possible to predict with certainty what human response times will be except for the simplest of events.

Most of the delay recorded between the presentation of a stimulus and the response by the human is due to central processing time rather than to the conduction delays along neural pathways. Reaction time tasks can be considered at different levels of complexity. In what is called a simple reaction time situation, an observer typically sees or hears a warning or alerting signal that indicates that a light or sound will occur at some instant within the next one to two seconds to which he should respond as rapidly as possible by, for example, pressing a button. Under ideal conditions, the reaction time value averaged over a large number of trials can be as low as 160 ms (for sounds). There will be a spread of response times around the average value, and, in the case described the standard deviation will be about 20 ms (Woodworth, 1938). If the human is given very precise information of exactly when the signal to be responded to will occur, the task changes to one of anticipation and synchronising the response with the signal, and delay values approaching zero can be obtained. It is to avoid anticipatory responding that investigators often introduce some uncertainty about when signals are going to occur, and provide "catch" trials, namely those trials where the alerting signal is given but where no stimulus follows. On these trials, no response should be made. It has been found in such situations that the reaction times obtained depend greatly on the explicit or implicit instructions given to subjects.

To achieve response time values as low as those indicated, an easily produced response is required, such as a movement of a finger or eye. When larger response members and movement distances are involved, such as the shift of the driver's foot from accelerator to brake, delays will be greater because of the inertias and more complex movements involved. In such cases, much longer movement times will be involved in addition to the basic processing delays. Also, most applied situations involve human information processing which is more complex than the handling of the simple stimulus just discussed. It is worth considering briefly some of the general dimensions along which this complexity varies.

GENERAL CHARACTERISTICS

Reaction time depends on the number of possible alternatives that can occur. For a reasonable number of alternatives, there is a linear relationship between the reaction time and the log of the number of alternatives (or in technical terms the bits of information to be transmitted). The linear slope changes from situation to situation, where as the slope decreases, the information processing rate can be considered to increase. However, for a large number of possible alternatives (some hundreds), this linear relationship breaks down and the reaction time is less than would be predicted by this linear relationship. For many applied situations there are two comments that can be made. Most of the research in this area deals with the stimuli (that are possible) coded systematically along some dimension or dimensions, or belonging to some well-known grouping, such as numbers or alphabet characters. In the real world, the possible alternatives might not be so well grouped. Second, it is often very difficult to specify what the number of possible alternatives considered by the human are in such situations. However, it is possible to say that response time depends as much on what could have happened and did not, as on the event that actually occurred. Reaction time depends as much on what the observer expects to happen, and the possible range, as on the actual events that transpire.

Reaction time depends on the ease with which the one signal can be distinguished from the other possible signals. For example, one can distinguish between highway signs that differ in shape as well as message faster than those varying in verbal message alone.

This dimension of stimulus discriminability can have a large effect on response time and acts multiplicatively with the effect of information load. In other words, reduced discriminability decreases the information processing rate rather than simply increasing the response time by a constant amount as the number of possible alternatives is altered.

Two different models have been developed to explain reaction time performance in signal detection situations where the information is less than highly discriminable. These are the latency function model (Norman and Wickelgren, 1969) and counter theory (Pike, 1973). In the latency function model, a fixed sample is assumed to be obtained from the visual scene. If this sample yields a value on some sensory continuum above a criterion, the subject emits one response. If the value is below the criterion, another (or no) response is emitted. The response time or latency depends on how close the value obtained has to the criterion. The closer it is, the higher the response time.

The counter theory is based on the tenet that the response latency reflects the time the observer spends sampling evidence from the visual scene prior to making a decision. This approach assumes that subjects integrate the information from a number of observations of the visual scene. Each observation leads to an incrementing of one of a number of counters. This sampling of information is generally assumed to continue until one of the counters reaches a particular value. This model predicts that the observed discrimination sensitivity is a function of the number of samples taken prior to reaching a decision. Thus the spending of extra time should lead to an increase in accuracy. With investigations reported in the literature thus far, it is not possible to choose one of these models unequivocally.

Reaction time and the accuracy or appropriateness of the response are highly associated. For a wide range of real world tasks such as typing, flying etc., there is a high positive correlation across humans of speed and accuracy of performance. The faster responders are also more accurate, and the reverse also holds true. Experience on the task tends to improve both speed and accuracy over long periods of time.

On the other hand, given particular task requirements, the human operator can often change his performance characteristics so that he can respond faster if necessary but at the cost of reduced accuracy or appropriateness of his response (Swensson, 1972; Wickelgren, 1977). On the other hand, if high accuracy is required then reaction time must be increased. In many operational situations, the human looks at the situation ahead and uses planning activity so as to achieve rapid responding with high accuracy. But the opportunity to use preview is not always present in some types of road situation. In this case, the trade-off of speed and the appropriateness of the response is a relevant consideration. In fact, to assess processing efficiency appropriately, both speed and accuracy of responding must be taken into account, and the association between these two variables has been studied in some detail. The relationship between the two has been described in general as an exponential approach to a limit (Wickelgren, 1977; Wickelgren, Corbett and Docher, 1980).

Reaction time depends on "depth of processing" involved. A useful model of how the human performs in information processing tasks takes account of the depth of processing required. At the simplest level, purely physical changes in simple stimuli are coded faster than symbolic information, and symbolic or pictorial information is typically processed faster than verbal or semantic information, as long as the symbols used are highly familiar and legible. However, this is a complex issue (McCarthy and Hoffmann, 1977), and this model should only be treated as a general guide.

A number of theoretical representations of this concept have been developed (e.g., Fitts and Posner, 1967). Some of them postulate that the observer samples environmental information and accumulates evidence over time about which of the possible responses is appropriate.

As the process continues, some criterion will be reached that causes the sampling to end and a response to be selected. One example of such a model is based on Bayesian decision (Edwards, 1965).

Reaction time depends on the association between the input stimulus and response codes. A very important factor in determining the reaction time in choice tasks is the relationship between the possible stimulus set and the possible set of responses that the human must have available if required. Various considerations enter to determine whether the relationship is good or not-so-good. First, the experience and background of the human plays a part, and this is particularly important when he changes his environment. What is an appropriate rapid response when driving in Australia might be quite inappropriate when driving on the right hand side of the road in North America. Second, when extra code-translation steps between the input and output are required, the processing time will be increased, and the accuracy of the response will be decreased. Intersection signs restricting turns at certain times of the day typically would require extra or contingent processing steps. Third, geometry can play a role in what is natural and affects compatibility in the spatial relationship of the stimulus set to the output set. For example, early pre-warning curve road signs sometimes indicated the road starting on the left and moving to the right to indicate a right hand curve. Such use has probably lapsed because of the spatial translations required between the initial direction indicated on the sign and the direction of the travel of the vehicle when the sign was encountered.

Just as with the discrimination factor discussed before, the effects of this correspondence or compatibility factor act multiplicatively with information load. Increased compatibility increases the processing rate, hence decreases the slope of the curve relating the reaction time to the number of alternatives, rather than just shifting the total time taken to respond by a constant amount.

While it appears that some of the effects of the use of incompatible codes can be offset by significant practice, when the human is placed under stress the disadvantage of the incompatible code is again shown. The likelihood of an inappropriate response under stress is much higher in the presence of incompatible relationships than with compatible designs.

EXPECTANCY EFFECTS AND PREPARATORY PROCESSES

It is almost self-evident that a subject's reaction will be faster if he is alerted to an upcoming stimulus and has had the opportunity to prepare to respond before the signal actually occurs. Readiness to respond is clearly important for the types of applied reaction time being considered here. When a completely unexpected signal occurs on the road, the driver may have to change mental set to the new situation before being able to prepare and make his response. This will introduce a delay, particularly if he is startled (Woodworth, 1938).

Some relevant properties of preparatory processes will now be reviewed. There are some physiological data indicating the development of a preparatory process over time. Cortical activity in the form of a large negative waveform has been shown to develop as the subject waits for a signal to be responded to, and ends immediately after the signal (Walter, Cooper, Aldridge and McCallum, 1964). It was also found that the introduction of catch trials considerably reduced the development of the wave. It seems reasonable to consider this development to reflect a state of readiness.

Duration and variability of foreperiod (time between an alerting signal and the signal to respond) have been demonstrated to be determiners of simple reaction time (RT) (Klemmer, 1956; Karlin, 1959; Drazin, 1961; Nickerson, 1965) and choice RT (Boons and Bertelson, 1961; Bertelson, 1966). Klemmer (1956) proposed that the uncertainty of the subject about when the signal would occur can be manipulated in two ways. First, subjects cannot estimate the passage of time with complete accuracy, and the longer the foreperiod the less certain the human will be about when the signal will occur. Secondly, the foreperiod can be made to vary around some central value, so that further uncertainty can be introduced. Klemmer found that reaction depended on the amount of combined uncertainty from these two sources. The results suggested that how well the human can prepare to receive and respond to a signal depends on how certain he is about the possible recurrence and its time of arrival. Usually, the longer RTs occurred with the relatively shorter foreperiods, with the RT at a particular foreperiod depending on the foreperiods with which it was grouped.

Bertelson and Barzeele (1965) obtained data that suggested for choice RT that preparation tended to be specific for each of the alternatives, although some non-specific preparation might also be possible.

Some investigations have stressed the informational aspects of waiting time with variable foreperiods. Elithorn and Lawrence (1955) first considered the postulate that expectancy changes as the probability of the signal occurring in the next instant increases with waiting time. Almost invariably in this type of experiment, rectangular distributions have been used for foreperiods. In this case, the conditional probability that the signal would arrive at a particular moment in time given that it has not already arrived will rapidly increase as waiting time continues, and as such the longer foreperiods will yield shorter RTs.

However, two studies have challenged the relevance of this informational characteristic of waiting time while providing more direct evidence that developing a preparatory state takes time.

Nickerson (1967) used a distribution-generating technique to remove the informational characteristic of waiting time. Conditional probability can be kept constant over waiting time, if the signal occurrence times are determined by a Bernoulli process, which yields a geometric distribution of waiting times. On the other hand, as Nickerson was careful to point out, despite the constancy of conditional probability with this process, it does not follow that psychological expectancy will not change with waiting time.

His results indicated that for short inter-stimulus intervals, simple RT varied inversely with the foreperiod. The rate of anticipatory responding, on the other hand, did not increase at longer foreperiods which is the case with rectangular distributions. This provides evidence indicating that the procedure may have been somewhat effective in stabilizing psychological expectancy over waiting time. However, the RTs obtained demonstrated that despite this possible constancy in expectation the preparatory state took time to develop. Nickerson and Burnham (1969) extended this work on non-aging foreperiods. They found that simple reaction times in this situation fell as foreperiods increase up to about 300 ms, but after that they increase quite substantially. This demonstrates the strong role of expectancy in response time.

A number of different types of short foreperiod distributions were studied by Karlin (1966) who found that the human's readiness develops with the probability of occurrence of a foreperiod of any length, and in relative independence of the conditional probability of occurrence. This result favours more the expectancy ideas of Mowrer (1940) and Adams (1962). On the other hand, Nickerson's results did not specifically support this alternative notion as minimum RTs did not consistently occur with some central tendency measure of the distribution.

Karlin considered that the subject presets the course of development of preparation which proceeds independently of when the stimulus occurs, so that waiting time is apparently not used for updating expectancy. Furthermore, his RT data indicated that the rate of development of preparation influences the length of time over which the subject can maintain a state of heightened readiness. It has long been considered that reaching a high level of preparedness takes time and can only be transiently maintained (Poulton, 1950; Bertelson and Boons, 1960; Bertelson and Barzeele, 1965). This was supported in Karlin's experiment.

With simple reactions it is not really possible to evaluate whether the path of preparation differs between constant and varied foreperiods, as with constant intervals the subject may just keep track of time and respond independently of a signal. However, with choice reactions, this would not be a reasonable strategy. There are some data with two-choice reactions. Bertelson and Boons (1960) have shown that RT at a fixed foreperiod of 500 ms was faster than with varied foreperiods ranging from 250 ms to 5.0 s. On the other hand, Boons and Bertelson (1961) found when a long constant foreperiod was used that RT was slower than when variable foreperiods were used. Gottsdanker and Way (1966) obtained data showing that with constant foreperiods of between 1.05 s and 1.80 s the RT increased the longer the foreperiod, and at the longer foreperiods was clearly .inferior to the variable foreperiod RT which was constant across the range of foreperiods.

These data can be understood in terms of the preparation required for the two types of interval manipulation. In the case of a constant foreperiod, the subject would attempt to reach a maximum level of preparation at the known interval but the peak would be short-lived. At short intervals, this constant time would be relatively accurately estimated. However, at long intervals, it would be poorly estimated and the subject's RT would suffer as a result since the peak of preparation does not coincide with the occurrence of the stimulus. In the case of variable foreperiods, as the human must maintain a state of preparation for some time, a lower preparatory state is chosen, and so RT tends to be constant across a fairly wide foreperiod range, but slower than with relatively short constant foreperiods.

Most of the research concerning level of preparation to respond rapidly to signals has been concerned with relatively short intervals of time. In contrast, one study by Warrick, Kibler, and Topmiller (1965) introduced waiting periods amounting to days. In such a case of very high uncertainty about when a signal would occur (on average, once every two and half days) where the subjects could be expected to be quite unalerted, the reaction times were between 100 and 140 ms longer than in the conditions where the subjects were alerted to the stimuli. The subjects were secretaries who were engaged in the normal routines of their work, and were required to press a quite accessible key to turn off a buzzer. In the unexpected signal condition, subjects were able to respond in about 700 or 800 msec after onset of the buzzer. In this experiment, subjects were busy with secretarial duties, and likely to have a reasonably high level of general alertness.

Whether this can be compared with driving under highway conditions in terms of the differences between alerted and unalerted conditions can be questioned. Nevertheless, the Warrick et al study represents one of the notable attempts to manipulate the conditions influencing the alertness of humans in a situation requiring speeded reactions to infrequent signals.

Physiological arousal has also been suggested as an associated concept to account for differences observed in reaction time as a function of social environment, heat, and gender differences (Bell, Loomes and Cervone, 1982). Activation has also been cited (Duffy, 1962).

STAGES INVOLVED IN SPEEDED REACTIONS

Reaction times are almost invariably assumed in traffic engineering to be made up of a number of different components. This is also largely true in the psychological literature, but recently questions have been raised of the appropriateness of the assumptions concerning this approach.

Stage analysis of reaction time is taken to include the breaking down of the reaction time into stages and the analysis of processing within these stages (Taylor, 1976).

Typically, viewing reaction times as made up of a series of stages has been based on the assumption that the reaction process is a linear sequence of discrete stages so that the overall reaction time is made up of the sum of the series of stage times. The stages are assumed to be initiated in a fixed serial order for a particular task, and that the duration of one stage is independent of another. Various of these assumptions have been questioned, for example, Smith (1968) raised doubts about whether the successive stages might overlap in time. However, stage analysis can be regarded as theoretically well established.

Stage analysis as a substantive approach was first considered by Donders (1868). He appears to be the first person to propose that the times taken by speeded mental activity were long enough to examine. He developed the subtraction method as a means of measuring the durations of stages. To use the method, two different tasks need to be selected in which reaction times can be measured where the second task is considered to require all the mental operations of the first, plus an additional operation. The difference between the mean reaction times in the two tasks is interpreted as an estimate of the duration of the inserted phase. While initially accepted, this approach fell into disfavour at the turn of the century. The validity of the approach depends on the assumption that the change from one task to the other only inserts a new processing stage without any change in the remaining stages. The application of the technique is limited by this requirement. The absence of general tests other than introspection for determining whether the remaining stages have been left invariant led to decline of the method. More modern procedures (Sternberg, 1969) of applying the subtractive technique are still open to question. Much of the work concerning the analysis of driver reaction times make very strong assumptions, often implicitly, about the validity of the subtractive technique. Consideration of such issues has not appeared in the traffic engineering literature.

Another approach for the analysis of stages has received a great deal of attention over the last decade. This is the additive factor method (Sternberg, 1969). Although this procedure has been debated (e.g., Taylor, 1976), it provides a technique for distinguishing the processing stages involved in the course of responding. However, it does not in itself determine the temporal order of the stages. Most importantly for the practical context of driving, it does not provide any measure of the stage durations themselves.

PSYCHOLOGICAL REFRACTORY PERIOD AND INTERFERENCE BETWEEN SUB-TASKS

When a human is occupied in processing information and emitting responses, the reaction time to any one stimulus may be delayed by the occurrence of an earlier stimulus. This delay is referred to as the psychological refractory period, and a number of theoretical explanations have been developed to account for this effect (Triggs, 1968). Furthermore, this delay associated with the following reaction time may be accompanied by a delay in responding to an earlier stimulus caused by the expectation that another stimulus would occur. Thus, marked delays in responding to stimuli in the real world may be caused in part from the information processing that the human operator is already involved in. Such effects would also contribute to an increase in reaction time variability across the population, as some subjects would have such delays while others would not, depending on their state of processing at the time.

MOVEMENT TIMES

Many speeded reactions in real world tasks involve a reaction time, followed by a precise movement which also contributed to the overall response time. Fitts (1954) has developed the notion of an index of difficulty to determine the time required to make accurate skilled movements. This approach has received a good deal of attention since that time, and the finding has been shown to be generally robust (Welford, 1968). The initial reaction time was claimed to be relatively independent of the following movement time by Fitts and Peterson (1964) for simple movements requiring accuracy. However, when the response involved components of greater complexity such as a number of changes in direction or reversal of movements, the latency before initiation of the response may be influenced by substantial increases in complexity (Glencross, 1973).

SPEEDED VS UNSPEEDED RESPONSES

Because the human physiological system imposes a lower bound to the reaction times that can be emitted while there is no corresponding upper limit, one can predict that where subjects are attempting to minimize reaction time that the distribution of values will be positively skewed. The distribution will tend to be truncated on the left (lower RT values) and spread out on the right (higher RT values). Such a form of distribution should be found for the reaction times for a large number of responses from an individual, and also for the distribution based on single observations of the performance across a wide range of individuals. On the other hand, distributions of mean reaction times from a number of trials for each individual should be closer to a normal distribution because of the central limit theorem. One might also expect that complex speeded reactions might be less skewed than similar reactions in simple tasks because the contribution from additional stages of processing could tend to "blur" the lower bound.

On the other hand, tasks where the time to respond is recorded but where the subject is not under time pressure would not be expected to yield distributions with marked positive skewness. Thus precautionary, anticipatory, or synchronising responding in a wide range of tasks would not require processing mechanisms to operate to a limit. The elapsed time between some initiating event or warning signal would thus not have a lower bound caused by processing limitations. The obtained distributions might be less positively skewed, approximately symmetrical, or even negatively skewed in some circumstances.

Thus, the argument can be made that if the obtained response distribution for single responses from a range of subjects does not demonstrate positive skewness, then the responses do not represent speeded reactions as normally assumed in reaction time experiments, or when reaction time standards are used in road design. In general, the less the "payoff" for the subject to make the response truly fast the less skewed the distribution should be. For example, one would expect less skewness when the instructions to the subject emphasised very high accuracy of response selection compared with the speed of the response. It is known that humans can trade-off response speed with accuracy depending on their cognitive set (Fitts and Posner, 1967).

Any response time distribution will, of course, be influenced by the characteristics of the subject group. For example, age may have some influence on the basic reaction time capabilities. If the subjects are drawn largely from an older group, the distribution may be shifted somewhat to higher reaction time values. The shape of the distribution may also be affected. However, based on previous research, these population effects tend to be relatively small at least for simple reaction time situations (Woodworth, 1938).

If a real-world stimulus is particularly crucial or salient, it would be expected that a higher proportion of humans would respond to it. Stimuli that are less relevant to the performance of a task may only evoke precautionary responses from a fraction of the population. Thus, in addition to the shape of the response distribution, the proportion of subjects responding should represent to some degree the emphasis given to the speed of responding. This provides a second criterion by which eliciting stimuli can be compared in order to determine the relative emphasis on speed.

One explanation for occasional very long response times is that response 'blocks' occur. In serial responding tasks, a short gap will appear from time to time in the performance sequence, and the frequency of such 'blocks' will increase as the task continues (Bills, 1931; Bertelson and Joffe, 1963). This may have some relevance in long tedious car driving tasks.

It is necessary to consider such criteria in addition to measures of central tendency of a distribution. Differences in means, for example, may represent differences between the two situations being compared, and not the relative emphasis being given by subjects to the-actual speed of responding. To give one example of this, the mean response time to a policeman's outstretched hand at night might be relatively long, because of difficulty in discriminating the stimulus, compared with the mean response time to an amber traffic light signal. However, the first might cause a greater emphasis on the speed of responses than does the second. In this project, it is important to have an indication, albeit not complete, of whether the reaction time distributions are obtained from speeded responses.

RESPONSE TIMES RELATING TO THE DRIVING ENVIRONMENT

In this section, those studies relating directly to the driving environment will be reviewed. Experiments have covered a wide range of situations. Some have been laboratory- or simulator-based, using simulated views of the driving environment. In-vehicle performance has been recorded using briefed subjects, and some observations have been made unobtrusively of the reactions of drivers in normal traffic situations. Reaction times have been obtained as measures for a variety of reasons. It has been judged an appropriate dependent variable by which the relative efficacy of information presentation techniques can be compared. Reaction time has been used as a measure to detect differences between individuals and to record the onset of fatigue. Most importantly for this report, reaction times have been recorded in studies in order to provide estimates of suitable design values for the road situation.

LABORATORY-BASED STUDIES

Reaction times have frequently been used to evaluate road sign presentations in the laboratory. Such laboratory measures have been found to correlate significantly with on-the-road measures of legibility distance of signs (Dewar, Ells and Mundy, 1976). Such correlational results have been taken to add credibility to laboratory measures of reaction times as valid measures of traffic sign perception. However, some questions have been raised concerning the appropriateness of such measures (Johnston, 1980). Although of limited use in descriptive terms, it is worth noting that discriminative reaction times to a range of signs using verbal or symbolic presentation for regulatory or warning purposes vary from about 500 ms up to about 1200 ms depending on the conditions (Dewar, Ells and Mundy, 1976; Ells and Dewar, 1979). The values are likely to be very much influenced by the nature of the task, and the response required of the subject.

In laboratory experiments relevant to the distracting visual environment of driving, Crawford (1962) obtained reaction times to the occurrence of a relevant light among a number of irrelevant lights. For the case of a steady signal against a flashing background of 21 irrelevant lights, a reaction time of 2.2 sec was obtained for an observer one standard deviation above the mean (i.e., approximately at the 85 percentile favoured by traffic engineers). Further work by Crawford (1963) using mixed flashing and steady background lights yielded very similar reaction time data. Further study of the effect of visual distraction, on the reaction time to a STOP road sign has been carried out by Holahan, Culler and Wilcox (1978). This study followed the demonstration by Johnston and Cole (1976) that environmental background distractors hinder driving performance under high information load conditions. Holahan et al found that reaction time was influenced by the number and colour of distractors, and the proximity of the distractors to the STOP sign. However, in absolute terms, the range of mean reaction times was relatively narrow (between 550 and 630 ms). As such, caution needs to be exercised in using such distraction estimates in design standards. Not only are the estimates from controlled laboratory experiments typically low, but also the variability of the responses and the effect of independent variables are likely to be much less than one would expect when one evaluated the effect of distractors in the real roadway environment.

Smith (1963) studied the speeded reactions to road features in slides of driving scenes presented in a laboratory situation, while the subject performed a subsidiary tracking task. He found an overall average reaction time of 2.14 s, and noted that a wide range of reaction times were obtained. From this observation he argued that there should be more than a single reaction time design value so as to be suitable for a range of conditions.

One laboratory experiment relevant to motor vehicle braking involved the making of foot responses to occasional visual stimuli while making more frequent responses to other signals with the hands (Westerlund and Tuttle, 1931, cited in Woodworth, 1938). The hand responses to the more frequent stimuli were slowed by the requirement to perform an additional arithmetical task. However, the foot response to the occasional stimulus was speeded up on average from 1040 ms without the arithmetic task to 910 ms when it was included. It appeared that the subject's attention was more broadly based with the additional task, thus making him more able rapidly to respond to the infrequent stimulus.

The effect of alcohol relating to reaction times in driving has received detailed attention. Moskowitz (1973) reviewed the available evidence and concluded that alcohol affected reaction time increasingly as the information processing demands become greater, such as when division of attention is required or when the overall level of uncertainty is high. Verhaegen, van Keer, and Gambart (1974) found that small doses of alcohol caused drivers to become slower particularly for situations where response choices were changing rapidly. Overall, it appears to be the skill of the driver in searching out new information in his driving environment and responding appropriately that is most influenced by alcohol (Moskowitz, 1973).

It is interesting to note that the design response time standard of 2.5 s has also been cited as the suitable time in aviation as a result of laboratory study. Stereo threshold response times (Diamond, 1959) indicate that pilots can be expected to start an evasive action in about 2.5 s.

SIMULATION STUDIES

The use of a simulator or closed-tracks allows the investigator to simulate part, and on occasion much, of the driving environment. As such, the studies conducted in such situations may have greater face validity than purely laboratory-based studies. In higher fidelity simulators, it is possible to have relatively exact control of highway variables and of the presence and path of the vehicles. Environmental variables can also be controlled, along with the occurrence of sudden emergencies. In general, simulation has the advantage that more complete control can be exerted over the independent and dependent variables of the experimental design. Very importantly, a car simulator allows research to be conducted that would be judged unsafe in the real world (Fox, 1960).

One study that has given particular emphasis to the reaction times of drivers to sudden emergencies caused by the presence of a pedestrian was conducted by Barrett, Kobayashi, and Fox (1968). A situation was established in the simulator so that the emergence of the pedestrian into the path of the vehicle would be completely unsuspected. The 11 driver subjects were each made quite familiar with the driving route before the emergency. Detailed records of driving performance were made as drivers tried to avoid the pedestrian. Interestingly, there appeared to be a tendency for drivers to give preference to a braking response rather than trying to steer around the pedestrian. The subjects were divided into two groups: those yielding faster reaction times (a mean of 829 ms) would have avoided hitting the pedestrian while those with longer reaction times (a mean of 1131 ms) did not stop in time. Although one could expect that these reactions are speeded, nevertheless the subjects were in an experimental setting, and for that reason can be classified as having a reasonable level of alertness. Nevertheless, this study is representative of what can be obtained from closed-loop simulator experimentation. While sophisticated research simulators are infrequently encountered, they could constitute a valuable tool for this type of investigation, particularly if data for a wide range of subjects are obtained.

Reaction times have been used as a measure to evaluate the effect of fixed roadway lighting on the ability to detect changes in vehicle headway (Fisher and Hall, 1978; Hoffmann, 1976). In headway measurement experiments on closed test tracks, research has shown that the figure of 2 s headway represents a good "rule of thumb" that drivers appear to adhere to when car following (Rockwell, 1972; Colburn, Brown and Copeman, 1978). Under slow speed conditions, however, the mean headway in the Colburn et al study on a closed track was found to be 1.77 s. Nevertheless, in all experimental conditions, the headways adopted were sufficient to allow safe braking when the vehicle ahead stopped abruptly. From the braking distances obtained, it was estimated that drivers' reaction times were between 500 and 1500 ms. Subjects could be regarded as highly alerted in this situation, as they were fully briefed, and were quite aware of what would happen. As such, this situation was much simpler than that normally found on the road although it is known that in car following the driver tends to fixate the car ahead. Despite this simplicity, approximately 40% of the initial headway was lost even in heavy braking under conditions of good road surfaces and vehicle performance.

Simple reaction times in a driving simulator have been found to increase reliably with age of the driver (American Automobile Association, 1958). The age group 15-19 years had a mean reaction time of 438 ms; and the value increased steadily to a mean value of 522 ms for the 65-69 year old group. Case, Hulbert and Moskowitz (1971) reported that peripheral visual reaction times increased under the effects of alcohol.

IN-VEHICLE MEASURES

Both on closed-tracks and on public-roads, a number of attempts have been made to measure the reaction times of drivers to a variety of stimuli. Some early reaction time data reported by the Massachusetts Institute of Technology (M.I.T.) (1934) are often referred to in traffic accident and engineering literature (e.g., Farmer and Chambers, 1939; Matson, Smith and Hurd, 1955). These results suggested that the reaction times obtained depended on the original position of the driver's foot (brake or accelerator), whether the car was moving or stationary, and whether the signal was expected or not. The type of stimulus to which the drivers had to react influenced the reaction time. Reaction times were generally longer when the vehicle was moving. They tended to be shorter for audible signals than for leading vehicle stop lights, and much longer when the driver had to respond on the basis of judged headway. In the situation where the following driver responded to the brake lights of the leading vehicle, and where expectancy was high, the overall mean reaction time was 640 ms, and 5 percent of the observations exceeded 1.0 s. A noteworthy result was that one driver in five had response times exceeding 1 s on occasion. A comparison of laboratory and field data showed that an individual's reaction time on the road can be as high as seven times the reaction time under laboratory conditions. This M.I.T. (1934) experiment reported mean values ranging from 240 ms to 1650 ms depending on the condition studied. Experimental subjects were used in the research vehicle, which implies that they were at least partially alerted and briefed.

De Silva and Forbes (1937) reviewed the earlier evidence and suggested that the brake reaction time is between 500 ms and 700 ms for the majority of drivers. A number of older studies conducted to evaluate driver reaction times obtained either in the laboratory or in a stationary vehicle were also briefly reviewed by Lister (1950), and yielded mean values between 440 ms and 640 ms. Very little attention has been given in these reports to the variability of reaction times across subjects. Lister (1950) obtained reaction times for drivers in both moving and stationary vehicles in closed track conditions that were somewhat less than those values reported in the studies he reviewed. He found that the total reaction time to a discrete visual or auditory signal was increased from a mean value of 350 ms when stationary to 450 ms when moving, when a movement from accelerator to brake was required. This latter value did not, however, appear to depend on the speed of the vehicle up to the maximum of 59 km/h (35 mph) used. The time taken to begin to lift the foot off the accelerator was about 260 ms, and the foot transfer time to the brake was about 170 ms. Lister suggests that because of the preparedness of his subjects the values he obtained would tend to be minimum reaction times. The earlier studies yielded values of about 500 ms in a stationary vehicle and about 650 ms when moving. These values are generally supported by Konz and Daccarett (1967) and Nagler and Nagler (1973).

In a study using experimental vehicles on a test track to determine stopping capability, Normann (1953) found that 95 percent of the subjects had a reaction time of less than 1 sec. Subjects were alerted and young, and were required to react as quickly as possible to a pneumatic tube lying across the path of their vehicle. This meant that the reaction could be fully alerted with the response required to an event involving only minimal temporal uncertainty. This form of response has been taken to represent the "reaction time" component of the "perceptual-reaction time" used in geometric road design by traffic engineers (AASHO, 1940, 1954, 1965, 1971; AASHTO, 1966, 1973). Typically the value adopted for the "reaction time" figure is 1.0 sec, corresponding closely to the longer times obtained by Normann, although the overall perception-reaction times recommended by AASHO (1940) did depend on vehicle speed. In this policy document the perception-reaction time chosen was 3.0 s at 51 km/h (30 mph) and 2.0 s at 118 km/h (70 mph). This differential, was dropped from the 1954 policy statement and an overall value of 2.5 s selected.

Laurell and Lisper (1978) required subjects in an experimental vehicle on a closed track to respond to randomly presented in-vehicle auditory signals. The subjects responded by pressing a switch on which the left foot continuously rested. Subjects were also asked to respond to obstacles placed in the vehicle's path by depressing the brake. The mean reaction time to the auditory signal was just over 450 ms early in the driving session but increased to about 500 ms after 3 hours of continuous driving. The distance to the obstacles when the brake response occurred decreased over this period. The two measures were significantly correlated, thereby providing support for the validity of subsidiary reaction time measures as a means of measuring changes in a driver's capacity to perform the driving task. In prior research, the same research group had found that generally the subsidiary reaction time increases with time spent in driving (Lisper, Dureman, Ericsson and Karlsson, 1971). Very inexperienced drivers showed greater reaction time increases with prolonged driving than those who had greater experience (Lisper, Laurell and Stening, 1973). Listening to a car-radio was found to reduce this increase in reaction time resulting from prolonged driving (Fagerström and Lisper, 1977). This may occur because the radio assists the driver in broadening his attention as discussed earlier (Westerlund and Tuttle, 1931). Furthermore, the increase in reaction time has been found to be associated with the actual driving task rather than presence in the vehicle over the period of time. Laurell and Lisper (1976) found that performance on the subsidiary RT task degraded with time when the subject was driving, but not when travelling as a passenger or when the vehicle was stationary. Furthermore, the degradation in subsidiary reaction time could not be attributed to changes associated with the driver's biological rhythm (Lisper, Eriksson, Fagerström and Lindholm, 1979).

The time taken to respond to the direction indicator of a vehicle ahead has been studied by Moore, Crawford and Odescalchi (1956). An average reaction time of about 1.5 sec was obtained, with about 20% of responses being less than 1 s and about 20% above 2 s. These data suggest a relatively symmetrical distribution which raises the question of whether the responses were highly speeded.

For responses to traffic lights in a controlled environment on an experimental track, Blackman (1960) found a minimum braking reaction time of about 800 ms to the occurrence of the amber light. About 200 ms of this duration represented the movement time from the accelerator to the brake, and the remaining 600 ms was the time before release of the accelerator. He found that the reaction time depended on the distance from the lights. At a long distance the delay before application of the brakes could be as high as 2 s. The shortest response times were found near the minimum distance at which it was possible to stop when the amber light appeared. One interesting observation was that, at a distance where about one half of the drivers elected to proceed rather than stop, about one third of those releasing the accelerator subsequently proceeded through the intersection. The hesitation time here was about 750 ms. Crawford and Taylor (1961) also reported a test track experiment where distributions of traffic light stopping data were obtained for vehicles having speeds of approach between 34 km/h (20 mph) and 102 km/h (60 mph) for a range of distances from the intersection. They found a minimum reaction time of 0.81 s. Webster and Ellson (1965) conducted a very similar experiment with almost identical results. Minimum reaction times were generally obtained when the drivers were in the vicinity of the "dilemma zone". It has been regarded as well established that drivers approaching a traffic signal at even moderate speeds sometimes find themselves in a dilemma if the signal changes to amber when they are within a certain distance of the intersection, where this distance is related to vehicle speed. In the location just before the dilemma zone, there is a need for a speeded response in order to stop before entering the intersection.

Again on closed-track, MacDonald (1978) showed that the response times to start depressing the automobile's accelerator following the start of the green was reduced to 300 ms when a red/amber period was introduced from the 700 ms value when no starting amber was used.

FOOT MOVEMENT TIMES BETWEEN ACCELERATOR AND BRAKE

Human factors recommendations exist concerning the desirable separation of the brake and accelerator pedals. Woodson and Conover (1966) specifically suggest that the separation should be sufficient to guard against the likelihood of catching the foot accidentally. For smaller vehicles, their recommended minimum separation was 5.08 cm and for larger vehicles a separation of 15.24 cm was preferred. Snyder (1976) argued that this difference is important because in the private car, the brake is higher off the floor than the accelerator pedal, whereas the two pedals are often coplanar in larger vehicles such as buses. In order to provide some experimental support to back up the recommendations of Woodson and Conover, Davies and Watts (1969, 1970) evaluated movement times for both elevated and coplanar brake pedal configuration with a constant lateral separation of 10.16 cm. They found mean movement time values of 149 ms for males and 194 ms for females for alerted subjects in the coplanar condition where this was the only task they performed. Lister (1950) had previously measured this transfer time to be about 170 ms. For the elevated brake condition, Davies and Watts found the overall mean movement time to be 309 ms. These results demonstrated that an elevated brake pedal causes significantly greater movements times. Snyder (1976) also found that the movement time was increased in the elevated brake condition. His results in the coplanar condition were very similar to those obtained by Davies and Watts at the same separation. In two older studies, Greenshields (1933, 1936) found that reduced elevations of the brake pedal significantly lowered brake reaction times both in actual cars and in a simulator. These movement times also approximated those found by Glencross and Anderson (1973) in a similar experiment. The data also showed that an increase in lateral separation in the coplanar condition had no significant effect on the movement time. Because of this insensitivity to lateral distance, and since evidence existed showing that accidents can be caused by misplacement of the foot on the wrong pedal, Snyder argued that separations of about 15 cm might be preferable provided the incidence of missing the brake pedal entirely is not high.

In order to evaluate the responses obtained using controls designed for handicapped drivers, Richter and Hyman (1974) obtained reaction times to a light signal presented at varying intervals in a simulated driving compartment in the laboratory using a normal pedal configuration and a hand control braking system. The foot responses yielded an average reaction time of 500 ms, and the hand control a mean time of 370 ms. The data for a hand control system not requiring the application of force yielded a mean reaction time of 200 ms, close to that for classical reaction time experiments. These hand control data related closely to those obtained by Konz, Wadhera, Sathave and Chawla (1971) who investigated the effectiveness of a combined brake-accelerator pedal. They also obtained faster reaction times than with conventional braking systems. On the other hand, Glencross and Anderson (1973) found that response times in braking were increased with the conventional system if both legs were involved in the braking sequence, such as using the left foot to depress the clutch at the same time as braking.

RELATIONSHIP BETWEEN REACTION TIME AND ACCIDENTS

Several studies have been published associating reaction time levels and patterns with the accident rates of drivers. Typically, these studies identify groups of drivers with different levels of accidents, and then evaluate the performance characteristics of each group. A caveat should be entered here that the existence of an association between accident rates (and sometimes traffic violations) and some laboratory-based measure of performance does not imply that some lack of basic performance capability is necessarily a causal factor in an individual's accident. For example, the association may just be a reflection of a relationship of both of these factors with a third variable. The relationships obtained may be somewhat tenuous, and some studies have specifically failed to associate reaction time and accident frequency, or found only a weak association (e.g., Harans, Peck and McBride, 1975; Edwards, Hahn and Fleischman, 1969).

In one interesting study, Babarik (1968) suggested that some drivers might be run into from behind because they react slowly to visual stimuli, so that the initiation of a response is slow, but that once begun, a strong response is emitted as in extreme braking. Babarik referred to this response type as "desynchronizing response pattern". In the car following driving situation, a strong braking action will naturally be required to avoid an accident if the initiation of braking is delayed. A number of taxi drivers were evaluated in a laboratory test in which Babarik measured both the time to respond to a stimulus, and the speed of the resulting movement. The types of accidents experienced by these drivers were compared with the reaction time patterns obtained. He found a strong relationship between the "run into from behind" accident frequency and the tendency to show the desynchronizing response pattern in the laboratory. The high rear end rate in such cases may result from the pattern of braking not conforming to the expectancies of the following driver. Huntley and Kirk (1972) found that even relatively low concentrations of alcohol caused the driver significantly to decrease brake depression time.

In a simulator experiment, Currie (1969) found that accident free drivers perceived danger more rapidly than drivers with a history of accident involvement. Fergenson (1971) measured decision time in the laboratory by recording the difference in reaction time between a three-choice and simple reaction time. Four groups of subjects (zero-accident, zero-violation; high-accident, zero-violations; zero-accident, high-violations; high-accident, high-violations) then also Bryant, 1969). The subjects were instructed to make a braking response when a single red light mounted on the car was presented. Each subject while driving received 50 presentations of the signal, which were randomly distributed over time at an average of about one every 2.4 minutes. A total of 2500 observations were obtained. Two observers were present in the car during the experimental period, and the equipment was visible to the subject who was fully aware of the purpose of the study. The reaction time obtained ranged from 0.47 s to 2.20 s. The overall mean time was 0.71 s, with a standard deviation of 0.16 s. The 85th percentile value was approximately 0.9 s.

In a study conducted on the Hume Highway, Smith (1964) attempted to obtain unalerted reaction times where drivers were confronted by an unexpected situation, and where no prior information was available. A rural road crest situation was selected where there was no roadside development, and a prominent but unfamiliar road-side sign was mounted just over the crest. This sign, which read SPEED CHECK AHEAD, was chosen in order to elicit a braking response from at least some of the drivers. The time was recorded from where vehicles passed the point where the sign could be read to the moment when the brake light appeared. Only lone vehicles isolated from other traffic were recorded. About a quarter of these vehicles responded by braking which perhaps raises a question concerning the representativeness of the sample. The braking response was observed to occur even for cars travelling relatively slowly as well as for speeding cars. For the 144 cars recorded, the mean reaction time was 3.4 s, and the 85th percentile was approximately 4.9 s. Smith argued that one should allow about one third of a second per word for reading, so that the above times should be corrected by subtracting one second from the above values, yielding a mean of 2.4 s and an 85th percentile value of 3.9 s. As discussed earlier, such a subtractive correction may be of questionable validity.

In a similar study conducted in Western Australia by the Main Roads Department, unalerted reaction times were obtained from drivers by placing a sign reading REDUCE SPEED across the road pavement just beyond a rural two-lane-road crest (NAASRA, 1965). As in the Smith study, about one-quarter of the eligible drivers responded by braking. The mean response time here was 1.8 s and the 85th percentile value was 2.3 s. The maximum braking response time obtained was 3.0 s and the minimum value 0.6 s. However, with these data, there was some question concerning what aspect of the situation elicited the braking response. The response time data quoted assumes that the driver needed to see the entire sign before any processing began. If it was the presence of a sign rather than the meaning or content that initiated the response, then approximately 0.2 s should be added to the above figures to allow for when the top of the sign began to come into view rather than initiating the response time from when the sign was fully visible. It was reported that in fact some drivers did appear to react to the sign appearing across their path. Reactions appeared to take place in the presence of oncoming traffic, and some of the reactions may have been in response to the traffic, or a combination of sign and traffic, rather than to the sign itself. It would be difficult to estimate the effect of this factor on the response time. These reservations introduce some uncertainty into these data.

Johannson and Rumar (1971) conducted a response time study on public roads for drivers in their own vehicles. The investigators measured the time from the occurrence of a loud auditory stimulus to the instant the brake light appeared. All drivers observed in one condition were expecting the presentation of the auditory stimulus and knew the appropriate braking response. Participants had been stopped by the police and instructed in the task and response required before the location where the signal was presented. The median response time was 660 ms, about one in seven of these drivers had a reaction time greater than 1 s, and a few drivers needed as much time as 2 s to respond. A sample of the same drivers were tested with response situations involving a reasonable degree of surprise, and the time to react increased by about 35 percent. For this surprise situation, 50 percent of the drivers took longer than approximately 730 ms compared with the median value of 540 ms for the same subjects when they had the opportunity of anticipating the signal. The authors supported the idea of using a multiplicative correction factor of 1.35 for values obtained where some anticipation was possible to estimate a realistic value where a response was required to an unexpected situation. While such a proposal is attractive, it would only be valid if the small sample of drivers evaluated in the "surprise" condition is representative of the population as a whole. This is questionable given that the median response time for this sample in the anticipation condition was somewhat less than the overall median. The assumption is also required that the same correction factor is suitable for drivers across the entire range of anticipation reaction time values. This would appear to be a strong assumption. Interestingly, in assessing minimum response distances for unexpected situations, the Texas Transportation Institute (1970) chose a perception-reaction time value of 5 s. This doubling of the 2.5 s standard was justified on the basis of the need to overcome strong driver expectancy effects.

Johannson and Rumar (1971) also noted that the subjects needed to become familiar with the signal and the required braking response. While the data from early presentations of the signal were neglected, the association or compatibility between signal and response may not have been high even after practice. If this was so, it would have the effect of increasing the response time.

RESPONSES WHEN CAR-FOLLOWING

Allen Corporation (1978) and Sivak, Post, Olson and Donohue (1981a) both reported experiments where the brake reaction times of unsuspecting drivers to the onset of brake lights of a leading vehicle were measured under normal traffic conditions. The prime purpose of these studies was to evaluate the effect of different tail light configurations mounted on the lead vehicle. Modelling of driver behaviour has predicted that small reductions in reaction times in car following may produce quite marked reductions in collision frequency (Brill, 1972). Sivak et al (1981a) describe in detail the moving base method of recording where a monitoring car following the driver under observation allowed his reactions to be recorded unobtrusively. Although the general pattern of results in these two studies was somewhat similar, and of great relevance to this report, there were some interesting differences. Allen Corporation (1978) reported a braking actuation response rate to the lead vehicle lights of 65% for conventional rear lighting systems and 84% for a high mounted system, while Sivak et al (1981a) found rates of 31% and 55% under somewhat similar conditions. Allen Corporation obtained a mean response time of 1.45 s for the conventional system, and 1.10 s for the high mounted condition. This difference was statistically significant. On the other hand, Sivak et al (1981a) did not obtain such a difference. Their mean response time values were 1.38 s (conventional) and 1.39 s (high-mounted). These differences in results for the two studies could have resulted because of the different detailed environmental conditions under which they were run. The Sivak et al (1981a) study was performed exclusively during daytime, while the Allen Corporation (1978) programme had a significant proportion of trials during the hours of darkness or dusk. Differences between the studies in terms of traffic pattern and roadway type may have influenced both the response rates and mean response times.

In a parallel study using alerted subjects in an experimental vehicle, Sivak, Post, Olson and Donohue (1981b) found that, for a range of lead car signal light configurations and steering-wheel mounted button response, the mean reaction times over twelve subjects were less than half the mean values obtained in the field trial experiment. Schmidt-Clauson (1977) in a study conducted in Germany obtained similar times to the Sivak et al (1981b) values when evaluating the performance of alerted subjects to different leading brake light configurations. If a correction factor approach was adopted to predict unalerted field response times from those of alerted subjects, the two Sivak et al studies (1981a, 1981b) suggest that the value would need to be greater than 2 in contrast with the Johannson and Rumar (1971) value of 1.35. This indicates that great caution should be exercised in using such correction factors, even when allowance is made for the different types of response used in the two Sivak et al studies. Johannson and Rumar used brake pedal responses for both the alerted and unalerted conditions.

The distance separating the lead and experimental vehicles had a highly significant effect on the braking reactions in the Sivak et al (1981b) study. For the short following distance, the mean reaction times for the various configurations ranged from 550 ms to 700 ms, and for the long following distance condition, the mean values lay between 670 ms to 830 ms. Overall, the mean values at the long following distance were about 15% above the shorter distance values. While this might be taken to suggest that the degree of urgency of a response might be influencing the reaction time, as the reaction time data to traffic signals suggest, this cannot be stated unequivocally since following distance in this experiment was confounded with speed. Traffic speeds were higher in the long distance condition.

All the data discussed so far have been for the situation where the brake lights of the lead car were presented. When they are not, it should be noted that the reaction time in response to the braking of the lead car is higher than in any of the other conditions, up to 1.65 s (Lobanov, 1978; M.I.T., 1934).

In an experiment conducted on public roads, the verbal response times of alerted driver subjects to coloured posts erected on the roadside at intervals along a test route were recorded (Armour, 1976). The reaction time was recorded from the moment that the post came into view around a horizontal or vertical curve to when the verbal response occurred. A mean verbal response time for the ten subjects was found to be 1.82 s with a standard deviation of 1.57 s. A physiological reaction time associated with the galvanic skin response was also recorded. The distribution of these measures had a mean 540 ms and standard deviation of 280 ms. An additional subsidiary serial response task while the subject was driving had no significant influence on the reaction times. The response distributions were negatively skewed. Thus, the responses may not have been made under a speed criterion.

STEERING WHEEL RESPONSE TIMES

The time taken by drivers to make steering responses to real world driving stimuli has been studied by Summala (1981a, 1981b). In the first study, a small lamp off the shoulder of the road was lit in order to induce an avoidance response of steering towards the centre of the road for real world drivers who were unaware of the experimental study and who received the signal unexpectedly. The displacement of the vehicle on average started at a latency of between 1 and 2 s, and reached its maximum extent in just over 3 s. Half of the maximum deviation had occurred by 2.5 s after the signal had been presented. This temporal pattern of responding appeared to be independent of the vehicle's distance from the lamp when the signal was presented. This response measure is an interesting alternative to the brake or subsidiary response. It should be remembered that with steering wheel response times, there is a delay component due to dynamic lags of the vehicle control system, and, it may be difficult precisely to identify the exact moment of lateral displacement commencing. On the other hand, this measure does not usually have a movement time component to the control such as the brake reaction time does. In the second study (Summala, 1981b), the steering manoeuvre was induced by the sudden opening of a car door parked just off the edge of the road. The results were similar to those in the earlier experiment. This displacement commenced on average at about 1.5 s after presentation of the signal, again reached its half way point at 2.5 s and had a maximum value at almost 4 s. The steering response exhibited appeared to be independent of the urgency of the situation. On the basis of this work, the author recommended that at least 3 s should be allowed for drivers to perform steering avoidance responses when changes in the roadway environment occur.

DECISION SIGHT DISTANCE ESTIMATES

Based on the assumption that processing stage estimates can be readily identified and estimated, McGee, Moore, Knapp and Sanders (1978) made predictions concerning the time requirements for the various stages based on the available literature, and then attempted validation of these times through field experimentation.

In determining geometric design criteria for highways, adequate sight distance (based in part on perception-reaction time criteria), has been of prime concern. While perception-reaction time estimates have been developed in the context of traffic engineering (hazard avoidance, responses to signals, etc.), the times obtained have been applied in the context of road geometric design. The adequacy of the values for geometric design has recently been questioned. Also, the design values assumed for driver eye height, obstacle height and vehicle speed directly influence the sight distance provided in addition to the perception-reaction time criterion. Different environmental circumstances determine the type of sight distance that is critical. Five different types of sight distance are frequently distinguished: Stopping sight distance, overtaking sight distance, intersection sight distance, headlight sight distance, and intermediate sight distance (the latter of relevance in Australia, but not in the U.S.). There has been considerable discussion of the adequacy of the design standards governing these various types in recent years (Louis, 1977). It has been suggested that the established sight distance standards are inadequate for situations where the critical stimulus is difficult to perceive, where the situation is complex, or where emergency braking might be inappropriate. Alexander and Lunenfeld (1975) proposed decision sight distance as a design concept so as to incorporate factors additional to those accounted for by stopping sight distance criteria. They defined decision sight distance as that at which drivers can detect a hazard (or a signal) in a cluttered roadway situation, recognise the hazard or its threat potential, select the appropriate speed and path, and carry out the required response sequence in a safe and timely fashion. The concept is intended to provide design standards that allow the driver sufficient distance to manoeuvre with a reasonable tolerance to errors.

The McGee et al study (1978) was an attempt to translate this general concept into operational terms. Their times associated with the pre-manoeuvre phase of a hazard avoidance model (Baker and Stebbins, 1961) is of most direct relevance to this report. This phase was taken to be the time involved in detection and recognition of a hazard, identification of alternative manoeuvres, selection of one of these, and the initiation of the associated response sequence. The time required for detection and recognition was assumed to be 1.5 s for lower speeds, and 2.0 s for higher speeds. For the decision and response initiation time, the worst case of a lane change manoeuvre was considered, and the time required was assumed to lie between 4.2 and 6.6 s for lower speeds, and between 4.7 and 7.1 s for higher speeds. In the validation phase, a subject driver was instructed to drive normally over a nominated route on public-roads and to respond to particular geometric characteristics which necessitated a change in path and/or speed. These features included lane drops and width transitions, for example. The responses required of each subject included the initial sighting of a geometric feature (indicated by pressing the horn button, and then identifying verbally), the moment of initiation of a vehicle path or speed change, and the time to complete the manoeuvre. The requirement to press the horn button would correspond in general terms to the procedure most frequently used to assess perception-reaction time. Nineteen subjects covering a wide range of ages performed in the evaluation. The recognition time values obtained had a mean of 5.7 s with a standard deviation of 4.6 s. These results led the investigators to expand the original detection and recognition estimate to include a range of values up to 3.0 s. The results for the decision and response phase had a mean of 4.8 s with a standard deviation of 4.7 s, which were regarded as supporting the initial range of times selected namely 4.2 to 7.1 s. Overall, the McGee et al study supports decision sight distance time values in the pre-manoeuvre phase of between 5.7 s and 9.1 s. These values are considerably in excess of the 2. 5 s perception-reaction time design value in the United States and Australia, the 2.0 s in parts of Europe and in the United Kingdom (HMSO, 1978), or even of the 3.0 s value occasionally proposed.

The question needs to be asked as to whether such large design time values can be justified. Certainly, a perception-reaction time value above 2.5 s has received reasonable support (e.g., Glennon, 1970; South Australian Highways Department, 1976). Gordon (1979) has suggested that the present 2.5 s value is widely recognised in the United States as a minimum value. The Texas Transportation Institute (1970) selected a value of 5.0 s. Some situations have been recognised as producing long decision latencies when multiple response alternatives are available or when the hazard or feature is difficult to discriminate. For example, apart from some already mentioned in this report, Crawford (1963) and Johansen (1977) both report hesitation times during the overtaking decision-making process as high as 4 s. One observational study in San Diego (Konecni, Ebbesen and Konecni, 1976) found that at a critical distance from a signalised intersection drivers who proceeded through the intersection tended initially to introduce a delay in the final response by slowing down initially on the amber before accelerating through the intersection. The Minnesota Highways Department has moved to introduce design values in excess of the AASHTO stopping sight distance criteria and is including values up to about 10 s. Forbes and Katz (1957) suggested that when a driver must make a judgement on the basis of a complex visual scene, the decision time may increase to 5 s or more. Warning signs are frequently placed 8 s or more in advance of a hazard.

Thus, given this background, the McGee et al (1978) estimates should not necessarily be regarded as very high. However, it should be noted that for the detection and recognition phase, although the subjects were instructed to respond "as soon as they recognized the hazard situation", the time estimates for the detection and recognition phase were much higher on average than those obtained in other comparable field studies of perception-reaction time (e.g., Armour, 1976). This may of course have been a function of the discriminability of critical stimuli. The requirement to give a verbal response may have had a significant effect on the times recorded for the later stages. In the discussion earlier on processing stages, caution was urged concerning the assumptions involved in assessing the durations of the stages. The duration of the decision and response phase may have not reflected any limitation of the driver's processing capacity, but rather the delay before it was reasonable or usual to commence a manoeuvre. Under stressed conditions, most drivers might be able to respond more rapidly and with relative safety. Although providing an interesting empirical manifestation of the decision sight distance concept, further detailed evaluation would be required before the procedure and results can be regarded as well established.

SUMMARY OF PREVIOUS DRIVER REACTION TIME RESEARCH

This review has highlighted the existence of a wide range of estimates of driver perception-reaction time. Most studies have assumed, if only implicitly, that the time estimates represent the results of speeded responses. Lower estimates tended to be obtained when briefed subjects were measured under experimental conditions. Except for the McGee et al (1978) study, the highest estimates were obtained for those studies conducted in rural environments using unobtrusive measures on normal car drivers. The two studies of this type that were designed to elicit braking responses used verbal signs which require interpretation and may not have been regarded as "urgent". Also, the braking response rate in these situations was not high, and this again raises some question concerning the saliency of the evoking road stimulus.

Usually, studies have provided only summary statistics concerning reaction time distributions, such as the mean and the standard deviation. Frequency distributions have not typically been presented.

In the past, it has been suggested or assumed that reaction times on the road will be related to vehicle speed (Mullin, 1972; AASHO, 1940), but data are lacking on this issue. On the one hand, it is argued that the more attention-demanding the situation, such as travelling on narrow roads, or car following at high speeds, the more aroused or alerted the driver will become. From this, one would predict a lowered response time. On the other hand, very demanding situations, such as in high-density traffic and where conflicts can occur, may lower the driver's available capacity to process additional information in a timely fashion, particularly if the stimulus was unexpected. In such circumstances, an increase in response time could result. It is conceivable that both factors may be operating at the same time, and which will dominate will depend on the particular road situation being considered. For the rural driving situation, however, it is not unlikely that higher speed travel will be associated with lower response times, but the amount of reduction is not known.

As the literature review showed, the data obtained in unalerted conditions on rural roads yielded much higher reaction time values than the estimates from laboratory studies or when subjects were alerted. However, the range of stimuli examined in field studies on rural roads to date has been limited, and a primary aim of this experimental programme was to obtain reaction times for stimuli of greater diversity. It can be argued that field data of this type have good face-validity and are more relevant for selecting and evaluating design standards than data that are more remote from the actual road situation.

THE EXPERIMENTAL PROGRAMME

PURPOSE OF THE STUDY

The experimental work in this project was designed to expand the range of relatively unalerted reaction time situations studied in rural or semi-rural environments. It was considered important that drivers be observed who were unaware that their performance was being recorded so that realistic and appropriate estimates of their response times could be obtained. Most attention was devoted to considering responses to stimuli from on the road, or relatively close to it. Situations were not examined that required wide visual search away from the road straight ahead, such as at busy intersections, or where frequent use of rear vision mirrors would be necessary. Response times can be expected to increase significantly in such environments (Robinson, Erickson, Thurston and Clark, 1972).

The measurement of braking responses was favoured by the investigators and the police. Concern was expressed by the authorities about using any stimuli that were aimed primarily at causing the driver urgently to displace the vehicle laterally towards the centre of the road. Braking responses also had the advantage of a very small delay between actuation of the brake and the appearance of the brake light. The possibility of using a change of vehicle engine noise was also investigated as a subsidiary type of response when the braking response rate was low (see Appendix A). However preliminary study showed that quite sophisticated techniques would be required to achieve reliable estimates of driver response based on changes in noise level.

The earlier discussion of characteristics of reaction time showed that reaction time is influenced by a range of stimulus and temporal variables. These variables may affect the discriminability of the stimulus, the nature of the decision-making process, and the expectancy or the preparatory state of the human. For example, it is possible to conceive of a continuum of possible alertness states under different road conditions. For these reasons, one should not expect that a range of eliciting stimuli of environmental conditions should yield similar reaction time estimates. In order to establish bounds on these estimates, it would be necessary to obtain measurements in more than a single situation. In fact, the notion of a single design reaction time might be questioned on this basis.

Data exist for drivers responding to road-based stimuli ahead of them on the highway (e.g., Smith, 1964). The situation of responding to the leading car when car-following has also been studied (e.g., Sivak, 1981). In car-following, it could be argued that the driver would be more alert in general, and more likely to be visually fixating the salient stimulus position (namely the rear of the leading vehicle) than lone vehicles. Comparisons of the response times in these two situations under similar environmental conditions and vehicle speeds would be of interest. This aspect was investigated in the study.

Both verbal and non-verbal eliciting stimuli were studied in the project in an attempt to evaluate a wide range of response situations. In reporting the data, the terms response time and reaction time will be used interchangeably, and refer to the total elapsed time between the appearance of the stimulus in the driver's view and brake light actuation.

STUDY METHOD USED

Suitable crests or horizontal curves of limited sight distances were selected for most situations. The site in each case was surveyed so as to identify the point on the road where the car driver could first observe the road stimulus provided. Only the reactions of car drivers were recorded in this study. A video camera was positioned so that a rear view of the vehicle was available over the travel distance in which brake responses might occur. The camera system was located and covered so as to be as unobtrusive as possible. Data were recorded on a video tape unit for subsequent analysis. A video time clock accurate to one hundredth of a second, was used to facilitate the analysis. Anyone data collecting session did not exceed several hours, so as to minimise repeat observations of the same vehicle, and to prevent any significant general familiarisation by the public with the eliciting stimulus. The permission and co-operation of the Victoria Police were obtained, and the Victorian Country Roads Board (CRB) supplied traffic signs and traffic cones.

Observations were also made of railway level crossing warning lights. In this situation, the eliciting stimulus was the actuation of the signal on the approach of the vehicle to the crossing and no intervening road crest or curve was involved. Episodes were only recorded where a vehicle was entering a critical zone on the approach so that a speeded response was required to the appearance of the warning lights (the distances varied between 130-160 m approximately). Level crossing data were obtained under both day and night conditions.

Usually only data for vehicles travelling singly and unperturbed by other traffic events were analysed. To obtain car-following reaction times, however, the braking latency of a following car after the appearance of the brake lights of the leading vehicle was recorded. The leading vehicle braking response was induced by a salient stimulus further along the highway that was not yet in the view of the following driver.

Data were only recorded for the various conditions in clear visibility conditions when the weather was fine.

SITUATIONS STUDIED

A range of static stimuli (as opposed to the occasional appearance of railway crossing lights) were studied, and the situations considered evolved as the study progressed. The aim was to select situations that might cause a significant proportion of drivers to make a braking response that could be regarded as a speeded reaction. The approach was a conservative one where the initial situations studied were selected so as to be most unlikely to result in an extreme braking manoeuvre or avoidance response. In fact, there were no extreme manoeuvres observed in the entire study.

For part of the data recording, a second video camera was set up well off the road and aimed at right angles to it. The scene was recorded on the video, tape unit so to allow vehicle speed to be estimated accurately. Vehicle speed was recorded during parts of the data collection on the approach to railway level crossings, and when using a police car or an amphometer (speed recording device using 2 black cables stretched across the road) as the eliciting stimulus.

A total of 18 different situations were examined as listed in Table 1.

Table 1 Eliciting Stimuli for Braking Response

1. Two red reflective triangles on road edge at night.
2. Motorcycle on shoulder of road in daytime.
3. CRB Sign: "Traffic Hazard Ahead".
4. CRB Sign: "Road Plant Ahead".
5. CRB Sign: "Roadworks Ahead".
6. Vehicle slightly protruding on road surface with tyre change in progress.
7. Vehicle with rear lights and 2 red reflectors at night.
8. Policeman using hand "stop" signal.
9. Police Car.
10. Amphometer: Dual Carriageway, semi-rural, moderate speed.
11. Amphometer: Two-lane, low flow, low speed.
12. Amphometer: Two-lane, low flow, high speed.
13. Amphometer : Two-lane, high flow, high speed.
14. Rail Crossing Signals: Night, general driving population.
15. Rail Crossing Signals: Night, special driving group.
16. Rail Crossing Signals: Day.
17. Car-following.
18. Pedestrian traffic signal lights.*

* Considered but omitted from experiments because of variable delays in signal actuation or undesirable traffic responses.

RESULTS AND DISCUSSION

Most attention was given to collecting data using the amphometer and at railway level crossings. Observations could be most easily collected using these response-eliciting environments. Some of the other situations particularly those involving vehicles stopped on the shoulder and receiving attention resulted in some passing motorists tending to stop, which was not desirable.

RESPONSE TO SIGNS, EMERGENCY SITUATIONS AND POLICE PRESENCE

Interestingly, the traffic signs used tended to generate a very low braking response rate from vehicles. "Traffic Hazard Ahead" and "Road Plant Ahead" caused only about 3% and 4% of drivers to respond respectively. The rate was slightly higher at 6% with the sign "Roadworks Ahead", and the response times had a mean of 1.64 s and a standard deviation of 1.26 s. The two Australian studies discussed earlier (see NAASRA, 1965) produced about 25% response rates but the mean braking response times were higher. For the sign "Speed Check Ahead" in this earlier work, the mean response time corrected for the sign reading time was approximately 2.4 s and for the sign "Reduce Speed", the mean time was approximately 1.8 s. The mean value for the "Speed Check Ahead" sign was statistically significantly higher 1::han the "Roadworks Ahead" result obtained in this study ($z = 2.48$, $p < .02$). It is perhaps not surprising that those signs dealing specifically with speed and relating directly to the driver should generate a higher response rate than signs describing environmental conditions. One of these signs, "Speed Check Ahead", would also have been relatively unfamiliar to drivers. However, the higher response rate was not accompanied by a faster reaction time value. Drivers may have responded with a generally smaller emphasis on speed because of the expectation that such information would be provided on an advanced basis. Some braking responses in this situation may thus have been of a relatively unspeeded precautionary or anticipatory type.

The erecting of two red reflective triangles spaced 5 m apart on the shoulder of the road at night elicited a negligible braking response from drivers. On the other hand, the motorcycle lying on its side on the highway shoulder in daytime caused about one in three drivers to brake. A response rate of 44% was obtained using a vehicle on the road shoulder with a tyre change in progress. This "tyre-change" situation yielded a response time of 0.97 s with a standard deviation of 0.45 s. A vehicle under repair at night with reflective triangles erected generated a 64% braking response rate with a mean reaction time of 1.02 s and a standard deviation of 0.36 s. These "emergency" situations generated relatively good response rates, and the reaction times were significantly lower than those obtained using signs. However, the disadvantages to the use of such eliciting stimuli were that drivers tended to slow down considerably in the vicinity of the vehicle and not infrequently to offer assistance. This interfered significantly with the data collection process.

A different problem emerged with using a policeman to stop vehicles as; they came over a crest. While vehicles invariably responded to such a signal by braking, some vehicles travelling in the opposite direction flashed their lights to attract the attention of motorists approaching the crest. This had the effect of slowing the vehicle streams and alerting subjects to forthcoming activity. In any event, the data gathering process with this approach would have been very time consuming given the police checking process that followed the stopping of each vehicle, and this method was not pursued after initial evaluation.

A white police vehicle parked on the road shoulder over the crest of a hill generated a 22% braking rate for eligible vehicles, that is those who were travelling singly and not in a platoon. Under these conditions, the response times had a mean of 2.37 s and a standard deviation of 0.69 s. There were essentially no cases where drivers in on-coming vehicles, having passed the police car, flashed their lights to attract the attention of approaching motorists. However, the speed distribution of the oncoming vehicles was significantly slower l00 metres after passing the police car near the crest of the hill compared with vehicles proceeding in the direction towards the police car, although the two distributions were similar when the police car was not present. This may have served as another alerting cue for the drivers approaching the police car. The vehicles that braked when the police car came into view tended be those of higher speed as shown in Figure 1. The mean speed of those who braked was 102.7 km/h and the mean for all vehicles was 94.4 km/h. Given this observation, it is perhaps interesting that the response times obtained to the presence of the police vehicle were not lower. However, during the period these observations were made, police were not permitted to use radar to observe the speed of motorists and only the amphometer was officially sanctioned in Victoria for roadside speed observations. In the absence of amphometer cables across the road, there may have been only moderate perceived urgency in responding.

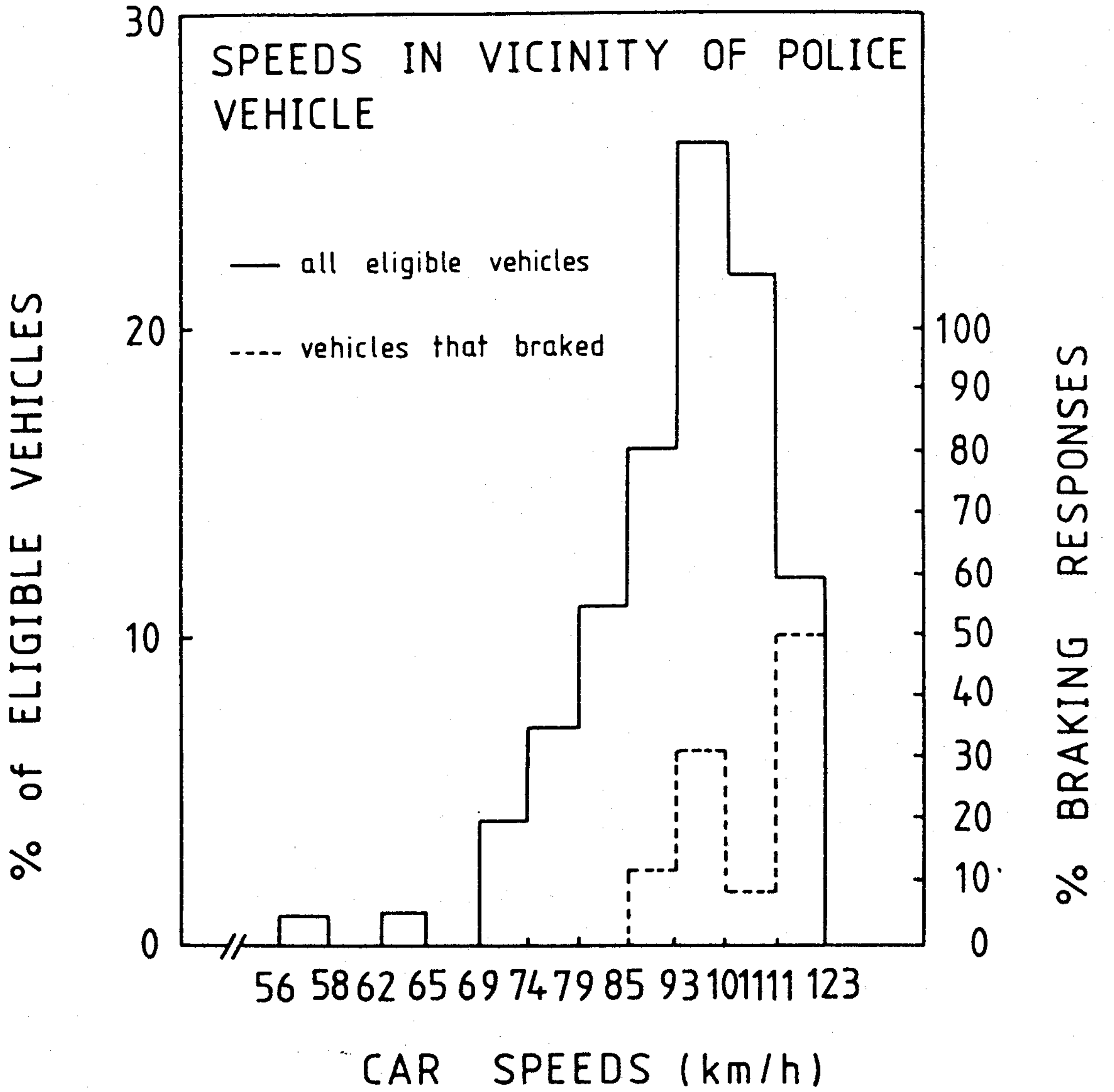

Figure 1 Distribution of automobile speeds (km/h) approaching a police vehicle for all vehicles and those that braked at the Princes Highway site

RESPONSES TO AMPHOMETERS

The amphometer is a device used by the Victoria Police to record the speed of vehicles on public roads. It consists of two black cables stretched across the left hand roadway pavement separated by a distance of 25 metres. Such devices have been used for years throughout the State by the Police, and are to be seen frequently on Victorian roads, so that the driving public are highly aware of their purpose. The cables and the characteristic spacing are relatively easy to detect and perceive, so much so that sites were frequently chosen in practice in order to limit their detection to just before crossing the cables.

Four different locations were studied using the amphometer as a device to elicit braking from the general motoring public. The cables were placed such that they came into view only at a relatively short distance before being crossed (between about 2.5 s and 4.0 s of travel time at the prevailing speed at the site). It was possible to determine accurately the point at which the cables could be first seen by the car driver. The four sites were located at Beaconsfield (mean vehicle speed 85-90 km/h, speed limit 75 km/h, dual carriageway), Dandenong North (mean speed 70-75 km/h, speed limit 60 km/h, two lane, semi-rural road), Gisborne (mean speed 90-95 km/h speed limit 100 km/h, two lane, moderate vehicle flow-rate), and Tynong (mean speed 105-110 km/h, speed limit 100 km/h, two lane, moderate to high vehicle flow-rate). All sites were selected so that if drivers were to respond before crossing the cables an immediate brake reaction would be required. Across sites, there appeared to be no marked difference in the ease with which the cables could be detected. The contrast between the cable and the road surface was similar for the various sites, and the speed of oncoming vehicles did not noticeably change after passing by the amphometer cables (these did not intrude into the opposing lane of travel).

Data were not analysed for vehicles involved in car following even at a long distance or followed closely by later vehicles. The response rates for eligible cars varied between 12% and 30% approximately. Table 2 indicates the summary results, and the cumulative response time distributions are presented in Figures2a, 2b, 2c, and 2d.

Table 2 Amphometer Reaction Time Results

Site	Response Rate	Number of Responses	Mean	Standard Deviation	Skewness
Beaconsfield	30%	35	2.46s	1.04s	+.250
Dandenong North	24%	100	2.45s	0.92s	-.027
Gisborne	12%	85	2.54s	0.66s	+.340
Tynong	31%	485	1.75s	0.70s	+.637

The sites selected also allowed the following planned comparisons for the response time data using the method of unweighted means. First, the response time data initially collected at the Beaconsfield and Dandenong North sites were compared so as to assess the effect of different speed limits at relatively low speeds. This contrast controlled for the semirural environment and actual speeds in relation to the speed limit. The mean values for these two sites were essentially identical, and it was considered that the data for these two sites could then be combined for comparison with other sites. The composite distribution for these two sites had a mean of 2.45 s and a standard deviation of 0.95 s.

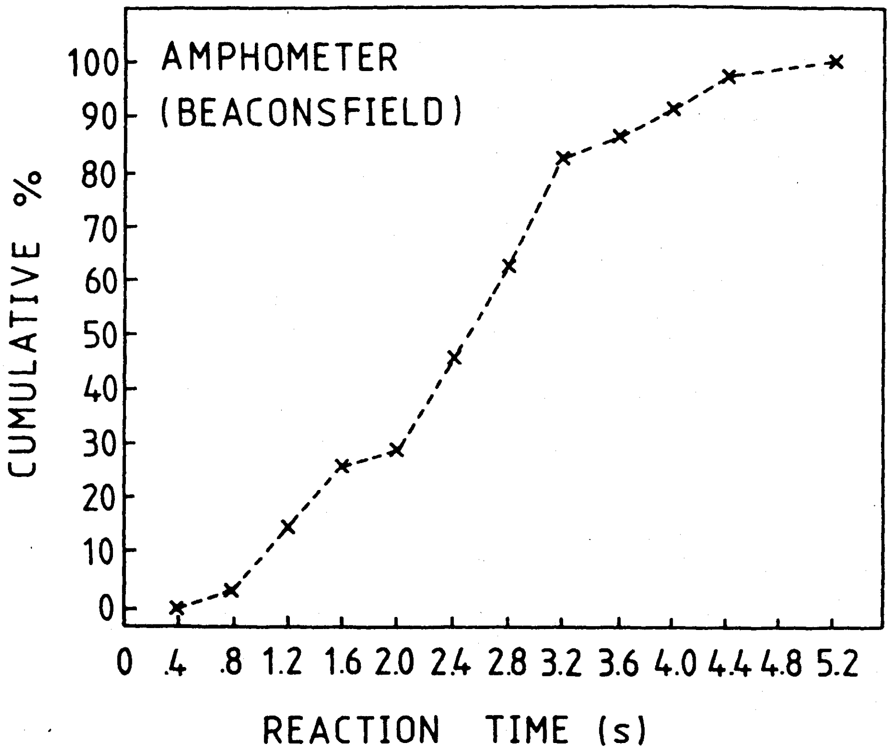

Figure 2a Amphometer braking response times at Beaconsfield site (n=35, mean – 2.46 s, standard deviation = 1.04 s, skewness = +0.25)

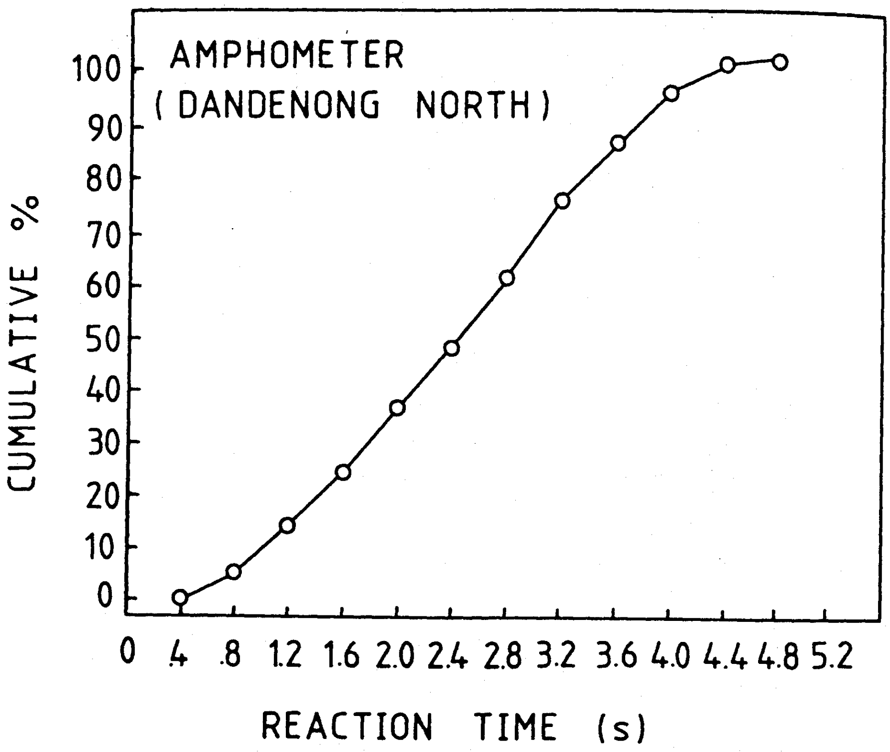

Figure 2b Amphometer braking response times at Dandenong North site (n=100, mean = 2.45 s, standard deviation = 0.92 s, skewness = -0.03)

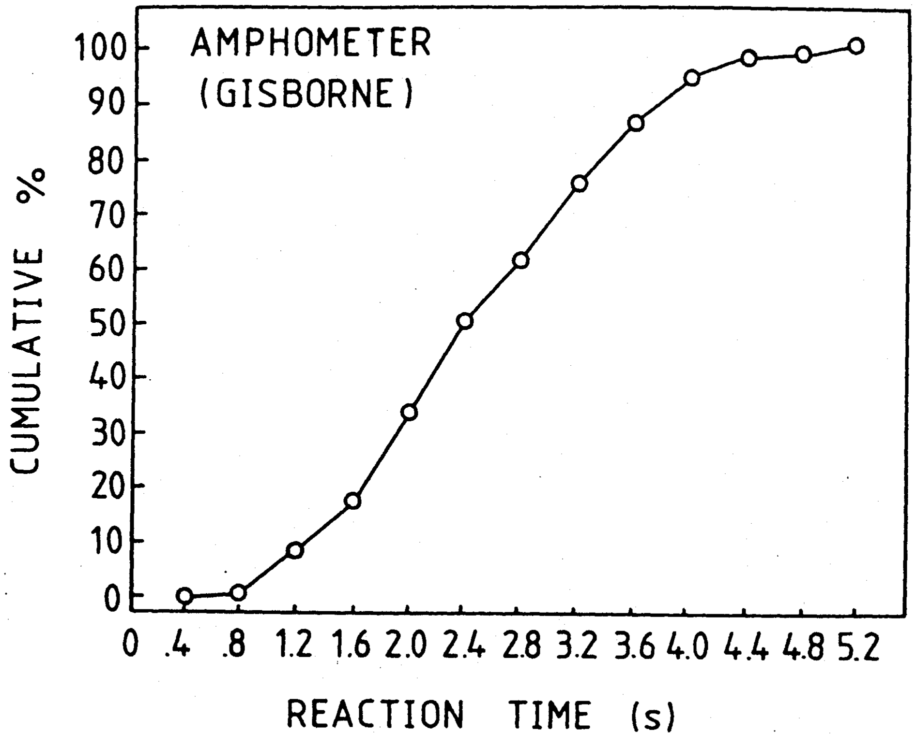

Figure 2c Amphometer braking response times at Gisborne site (n=85, mean = 2.54 s, standard deviation = 0.66 s, skewness = +0.34)

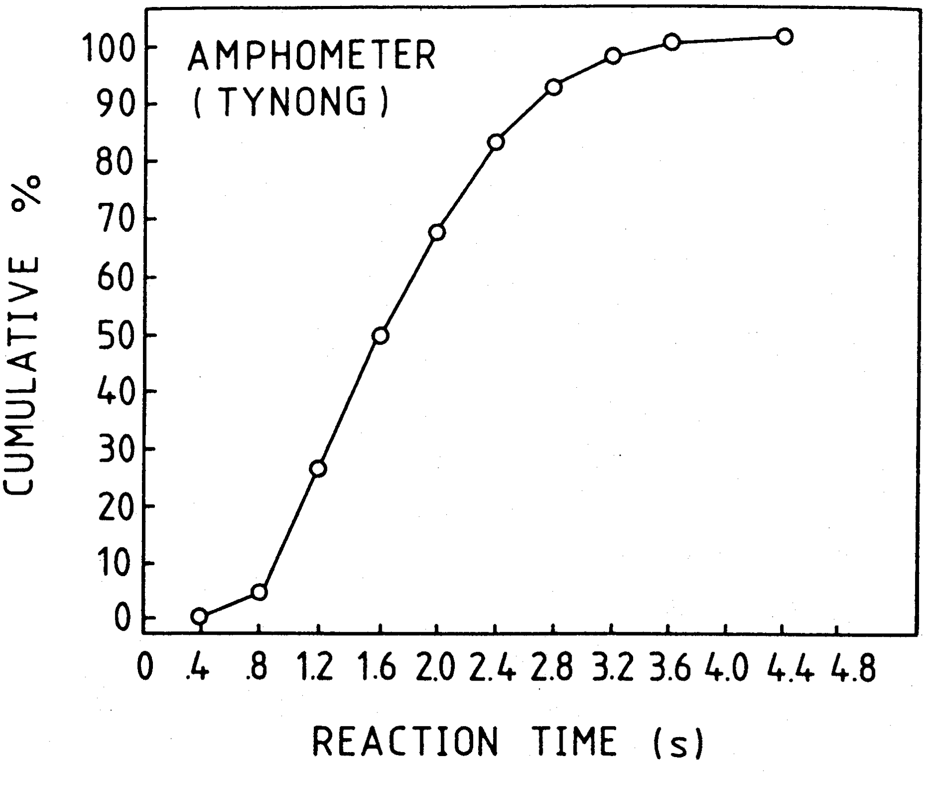

Figure 2d Amphometer braking response times at Tynong site (n=485, mean = 1.75 s, standard deviation = 0.70 s, skewness = +0.64)

Second, the absolute speed limit in the State of Victoria was 100 km/h at the time of data collection. The response times for the situation where vehicles travelled well below this limit (Beaconsfield and Dandenong North) were compared with the values obtained at the site where the speeds were well above this value (Tynong). This comparison controls for the relationship between the mean traffic speed and the speed limit at the site, as the mean speeds at all three of these sites were 5-10 kph above the speed limit. Third, the response times for the traffic generally above the speed limit were compared with those obtained for traffic travelling under this limit. The contrast of the Gisborne and Tynong sites allowed for control of the type of site and speed limit value.

Three of the sites yielded very similar mean response times with an overall mean of just under 2.5 s. The reaction times at the Tynong site were significantly shorter than those at Gisborne ($F(1,702) = 78.49$, $p < .001$). They 'were also significantly shorter at speeds above the absolute State limit ($F(1,702) = 61.62$, $p < .001$). The finding of significance shows overall that reaction times to the presence of amphometers were not homogeneous across all sites.

The response distribution was most positively skewed for the Tynong site. It can be argued that the Tynong data may reflect either reactions made with greater emphasis on response speed because fast reactions are perceived to be more necessary at higher speeds, or greater driver alertness at the significantly higher speed at this site.

The response rate at Gisborne was significantly different from the next lowest response rate ($X^2(1) = 26.7$, $p < .001$), but there was no significant difference between the remaining three sites. It should be noted that the speeds at the Gisborne site were in fact below the posted speed limit (and the "design speed" of the road), while for the remaining sites the mean speed was higher by about 10 km/h than the sign-posted legal level (Table 2). Thus, it is not unreasonable that the response rate would be lower at the Gisborne site. If exceeding the speed limit (and the associated need to reduce speed rapidly in the presence of speed control devices) was responsible for the faster reactions at the Tynong site, then one would predict that the reaction times at the Beaconsfield and Dandenong North sites would be shorter than those at Gisborne. In fact, the response times were very similar. This supports the proposition that the reduced reaction times at Tynong results from the raised level of alertness or arousal in drivers caused by the high speeds adopted in the presence of significant levels of traffic.

SPEED OF VEHICLES BRAKING AT AMPHOMETERS

Detailed vehicle speed information was recorded for some observation periods at the Tynong and Gisborne amphometer sites. Most data were obtained at the Tynong site. The distributions of speeds for eligible cars that braked and those that did not brake at Tynong are shown in Figure 3a. The mean speed for those that braked at Tynong was 116 km/h, and those that did not brake was 107 km/h. The difference between these distributions was highly statistically significant ($z = 8.27$, $p < .001$). This result is riot surprising given the legal implications of higher speed when crossing the cables. However, a similar pattern of data was found for the Gisborne site (Figure 3b) where the speeds were largely below the speed limit.

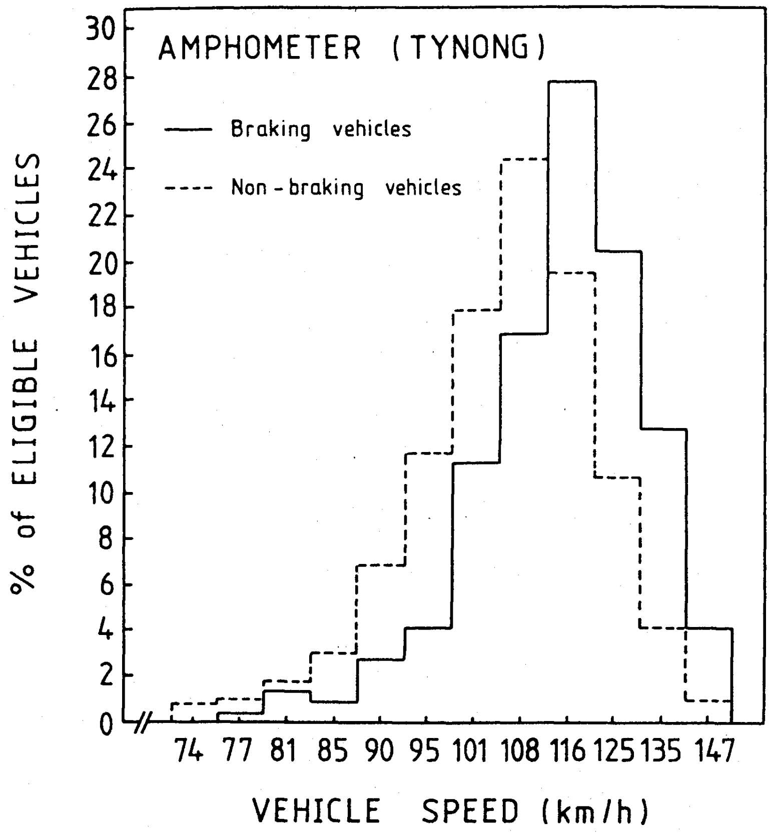

Figure 3a Speed distributions for vehicles that braked and did not brake at the Tynong site (Braking vehicles: n=226, mean = 116.0 km/h, standard deviation = 14.2 km/h; Non-braking vehicles: n = 511, mean = 107.0 km/h, standard deviation = 13.5 km/h)

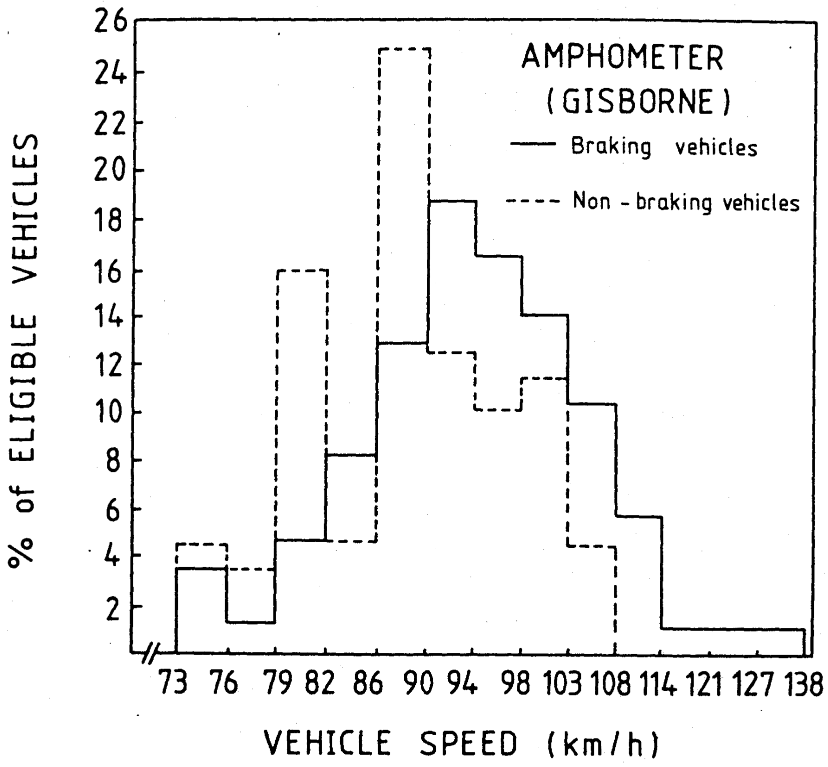

Figure 3b Speed distributions for vehicles that braked and did not brake at the Gisborne site (Braking vehicles: n = 85, mean = 95.0 km/h, standard deviation = 10.4 km/h; Non-braking vehicles: n = 638, mean = 87.6 km/h, standard deviation = 9.7 km/h)

For the vehicles that braked at Tynong, reaction time was significantly negatively correlated with vehicle speed (r = -.26 p. < .01). Reaction time as a function of grouped speed data is shown in Figure 4a. Those in the higher range of speeds had faster response times than those in the lower range of speeds. For the vehicles with speeds greater than 120 km/h, the mean response time was 1.49 s, and for those with speeds below 112 km/h the mean response time was 1.91 s. The two distributions are shown in Figure 4b. These response times were highly significantly different (z > 3.5, p < .001) and are of practical interest given the magnitude of the difference (0.42 s). The response times of the faster drivers were also more positively skewed than the slower drivers. This pattern of results might be taken as an indication of differences between the driving groups that adopt high and low highway speeds. Young males for example are frequently cited as high risk takers on public-roads. It is conceivable that those who drive faster also have a basic ability to respond faster. However, the simple response times of various groups are known to be similar. For example, the differences between young and old subjects, or male and female subjects, that are found in experimental situations tend to be quite small (Woodworth, 1938). This suggests that the basic performance characteristics of the higher and lower speed groups may not be primarily responsible for the differences in reaction times. The observed variation in reaction time as a function of speed probably results largely from the higher speed drivers being more alerted, and in a higher state of preparedness to respond. This suggestion is consistent with the conclusion based on the pattern of reaction time data over the four amphometer sites. As mentioned earlier, it is also possible that lower speed drivers had a different criterion for responding rapidly than higher speed drivers. When seeing an unexpected stimulus on the road, slower drivers may have chose-a to brake in a 'precautionary' way where these responses would have been made with a reduced emphasis on speed. However, the data for the various sites suggest that the driver's speed in relation to the speed limit may primarily influence the probability of a response being emitted, rather than the criterion adopted when making the response.

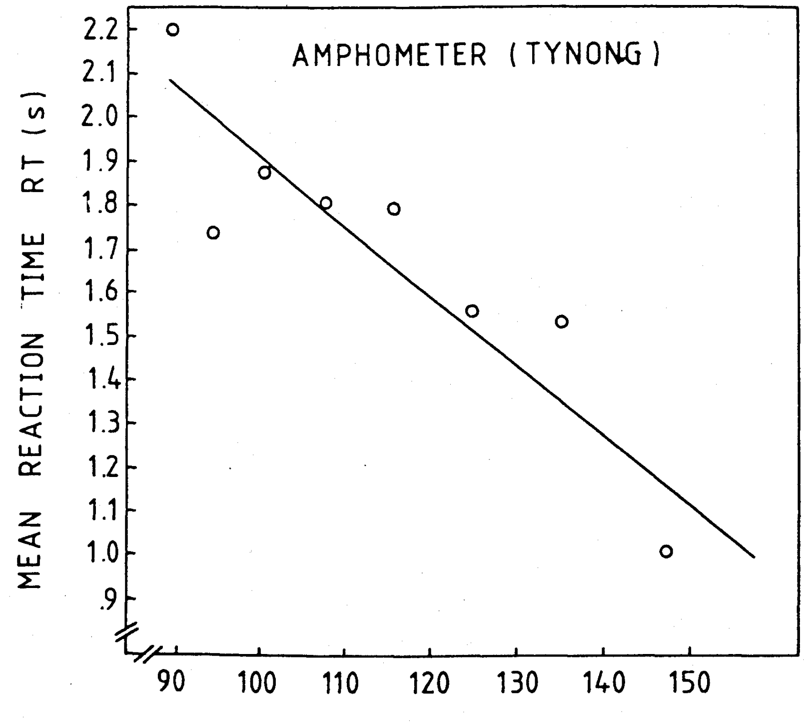

Figure 4a Mean reaction time as a function of vehicle speed group at the Tynong site (Regression line: RT = 3.537-.016n)

At the Gisborne site, again the speed distribution for those that braked was significantly different from those that did not (z = 6.6, p < .001, Figure 3b). The mean speed for those that braked was 95.0 km/h, and those that did not brake had a mean of 87.6 km/h. The overall correlation between vehicle speed and reaction time was -.167, which was not significant (p = .13). It should be noted that the vehicle speeds at this site were more uniform than those at Tynong. Thus, the failure to find a significance correlation is perhaps not surprising.

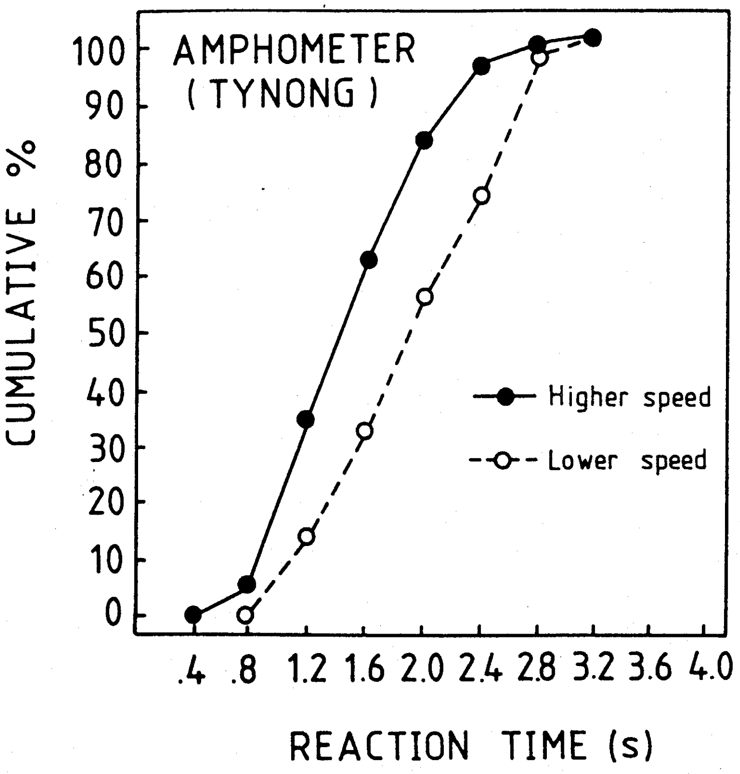

Figure 4b Cumulative reaction time distributions for higher speed (> 120 km/h) and lower speed (<112 km/h) vehicles (Higher speed: n = 86, mean = 1.49 s, standard deviation = 0.35 s, skewness = +0.91; Lower speed: n = 73, mean = 1.91 s, standard deviation = 0.69 s, skewness = +0.28)

As vehicles were generally below the speed limit at the Gisborne site, the fact that higher speed vehicles were those that braked is noteworthy. Several possible explanations are possible. First, drivers may not monitor their speedometer very closely, and it is known that drivers are not able to estimate their speed very accurately from environmental cues only (Triggs and Berenyi, 1982). Nevertheless, drivers who are close to the speed limit will have some general knowledge of this and may brake to reduce the probability of being detected for exceeding the speed limit. Second, the higher speed drivers observed may be those who are more likely generally to drive above the speed limit. Because of this, they may be better prepared to respond selectively to speed-related stimuli whatever the situation than the lower speed drivers. Third, faster drivers may be more generally alert and more primed to respond to any salient stimulus.

RESPONSES TO RAILWAY LEVEL CROSSING SIGNALS

Seven railway level crossing sites were selected that were all in rural derestricted speed areas. There were no bends in the vicinity of the crossing at any site and the road on the approach and departure side was sealed, straight and level for a reasonable distance. The condition of the roadway surface was good in each case. The sites were located around the state of Victoria at Bairnsdale, Cranbourne, Swan Hill, Hamilton, Glenalbyn, Baxter, and Merton. Although the measures obtained were unobtrusive, it seemed desirable to obtain data at widely separated sites.

Observations were made under both day and night conditions for the general driving population, and at night for a specialist rally driver group. At night, the braking response rate obtained was very high. All but a few drivers responded to the stimulus presentation, and the rate of responding was about 98% overall. Data were only recorded for vehicles travelling along without following or approaching traffic.

The response rate for daytime level (70%) crossing observations was significantly smaller than for night observations ($X^2(1) = 31.9$, $p < .001$), although still high compared with the other response eliciting situations considered in this study.

The summary results for these rail crossing conditions are shown in Table 3, and the cumulative reaction time distributions are shown in Figures 5a, 5b, and 5c.

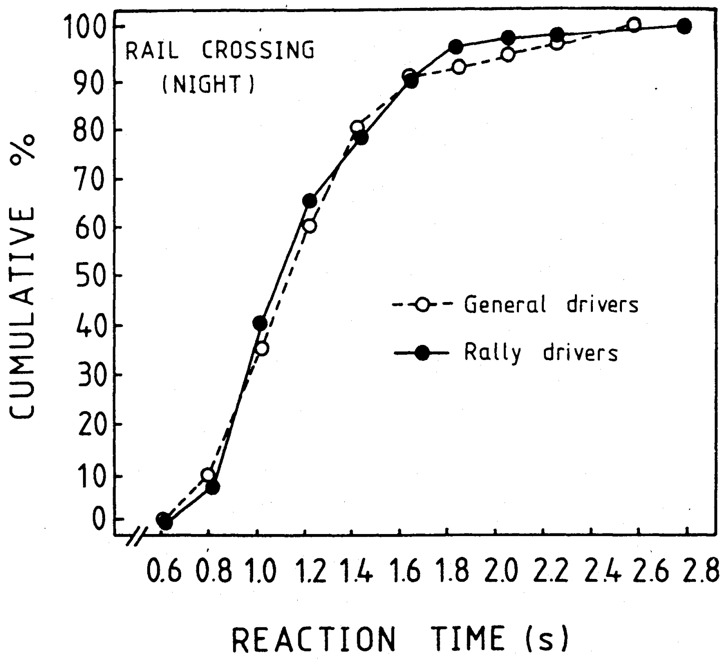

Figure 5a Cumulative reaction time distributions for railway level crossing signals for both the general driving population (n=171, mean = 1.18 s, standard deviation = 0.36 s, skewness = +1.36) and a rally driver group (n = 91, mean = 1.14 s, standard deviation = 0.34 s, skewness = +1.80)

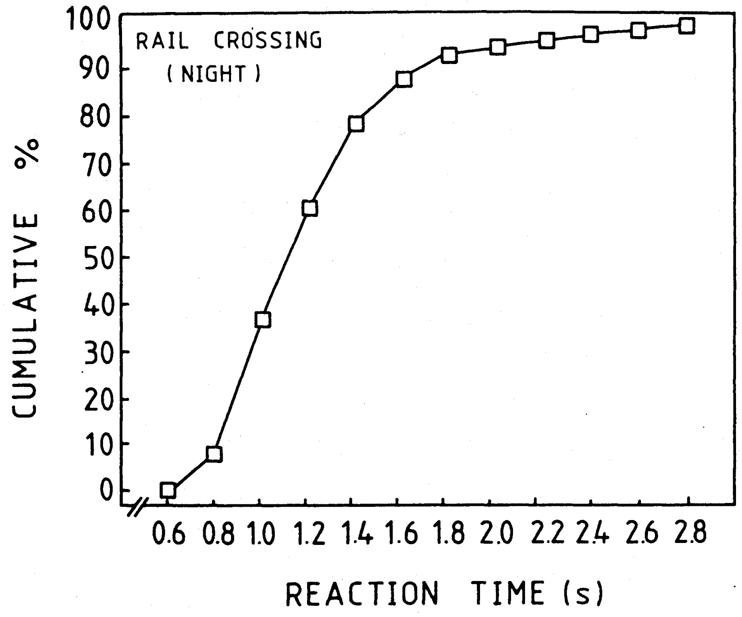

Figure 5b Cumulative reaction time distribution for railway level crossing signals at night for combined rally and general drivers (n=262, mean = 1.16 s, standard deviation = 0.35s, skewness = +1.44)

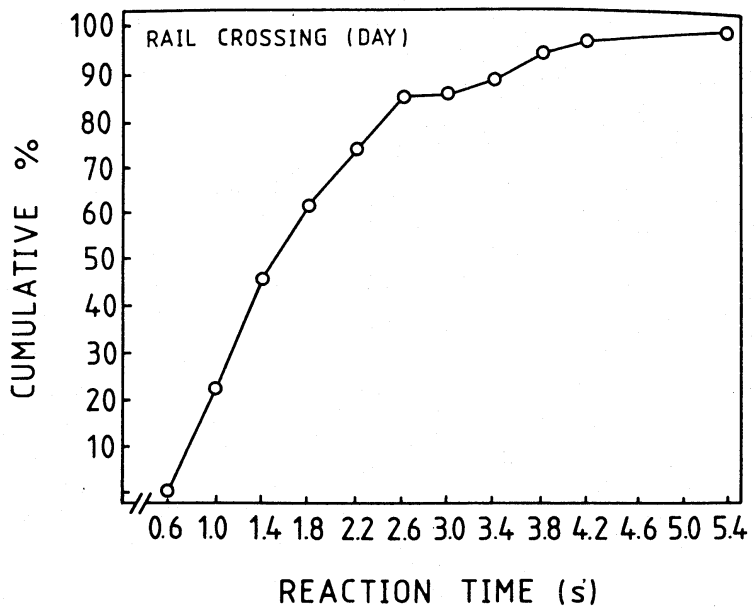

Figure 5c Cumulative reaction time distribution for railway level crossing signals during daytime for the general driving population (n=104, mean = 1.77 s, standard deviation = 0.84 s, skewness = +1.22)

Table 3 Railway Level Crossing Reaction Time Results

Condition	Response Rate	Number of Responses	Mean	Standard Deviation	Skewness
Night (normal drivers) }	98%	171	1.18s	0.36s	+1.36
Night (rally drivers) }		91	1.14s	0.34s	+1.80
Night (composite) }		262	1.16s	0.35s	+1.44
Day (normal drivers)	70%	104	1.77s	0.84s	+1.22

The mean day level-crossing reaction time was 600 ms longer than the mean for the night events. This 50% increase was statistically significant ($z = 76.0$ $p < .001$). This difference can be attributed largely to the differences in discriminability of the flashing lights under day and night conditions. It is unlikely that drivers paused under daytime conditions before responding in order, for example, to attempt to gain additional information by searching the environment for the presence of a train. Such search would take much longer than the reaction time increase in daytime conditions (Robinson et al, 1972). Moreover, the most reasonable strategy would be to slow down first, then gain additional information.

The mean response times for the general driving population and the rally drivers were very similar, and the 0.04 s difference did not approach significance. This result is of interest given that the rally drivers were in the younger age group with a mean age in the mid to late twenties, and 95% male. They encountered the level crossing being observed after about 2 hours of continuous driving, following a one-hour rest and an earlier 4-hour driving session. Such a period of driving may cause a small increase in a subsidiary task reaction time, but the increase in absolute terms will be very small (Laurell and Lisper, 1976). One would predict that for a group of highly motivated drivers that within limits the change in reaction time to environmental events with time on task would be small. Thus, the similarity of the data for the normal drivers and the rally group is noteworthy. The mean vehicle speed for both groups was the same at approximately 95 km/h. While laboratory data have shown essentially no change in reaction time between the late teenage years and into the sixties (Woodworth, 1938), field data have been lacking on this topic. Although the average age of the general driving group would have been higher than the rally club drivers, no difference in reaction time was found for the two groups.

The approach to a level crossing may provide some degree of pre-alerting before the presentation of the critical stimulus because of the standard fixed signs and rail crossing fixtures at all sites. While rail crossings tend to be blocked by trains only a small proportion of the time and observations showed that mean vehicle speed did not change significantly on the approach to crossings equipped with flashing lights when they were not activated, pre-alerting may account in part for the lower reaction times in the daytime rail crossing condition compared with the police car data, and the amphometer data for lower speed vehicles. Nevertheless, it is reasonable to attribute a significant proportion of the difference in these situations to the greater perceived urgency in responding to the flashing lights at the railway crossing.

RELATION BETWEEN VEHICLE SPEED AND RESPONSE TIME TO FLASHING SIGNAL

The reaction times and vehicle speeds were correlated for those sites and dates for which speed data were collected. For night rail crossings with the general driving public, the two sites evaluated had statistically significant negative correlations for data obtained within an observation period (Glenalbyn: r = .-542, p < .02; Bairnsdale: r = -.512, p < .01). During daytime observations of the general driving public, however, reaction time and speed had a correlation of close to zero (Cranbourne: r = -.048; Merton: r = -.023). The significant correlations at night substantiate the relationship found with the Tynong amphometer data. Faster vehicles respond more rapidly. The absence of a relationship during the day could have resulted from the lowered discriminability of the crossing flashing lights which increased the scatter of response times in this condition. The response time may have depended significantly in this situation on the driver's visual scanning pattern immediately after the signal was presented.

The correlation between vehicle speed and reaction time for rally drivers at night for the railway level crossing observed was also calculated. While the mean speed of the rally drivers (95.5 km/h) was similar to the mean for the general driving public, the speeds showed much less dispersion (Standard deviation: for rally drivers, 7.9 km/h; for general drivers, 13.6 km/h. This relative uniformity in speeds would militate against the obtaining of a high correlation, and in fact the actual value was not significant (r = -.150, p = .12).

CAR FOLLOWING REACTION TIMES

Using the method described previously for the Tynong amphometer site, car following reaction times were obtained on a relatively high speed two-lane highway. Individual reaction times under relatively constant environmental conditions were obtained. The mean of the braking response times to the brake lights appearing on the leading vehicle was 0.92s, the standard deviation was 0.28 s and the skewness value was 0.62. The distribution of reaction time data is given in Figure 6. The brake lights of the leading vehicle generally appeared for just over 1 s, and the decrease in vehicle speed was usually small. If leading drivers had continued braking for longer periods, more following drivers would have been expected to brake.

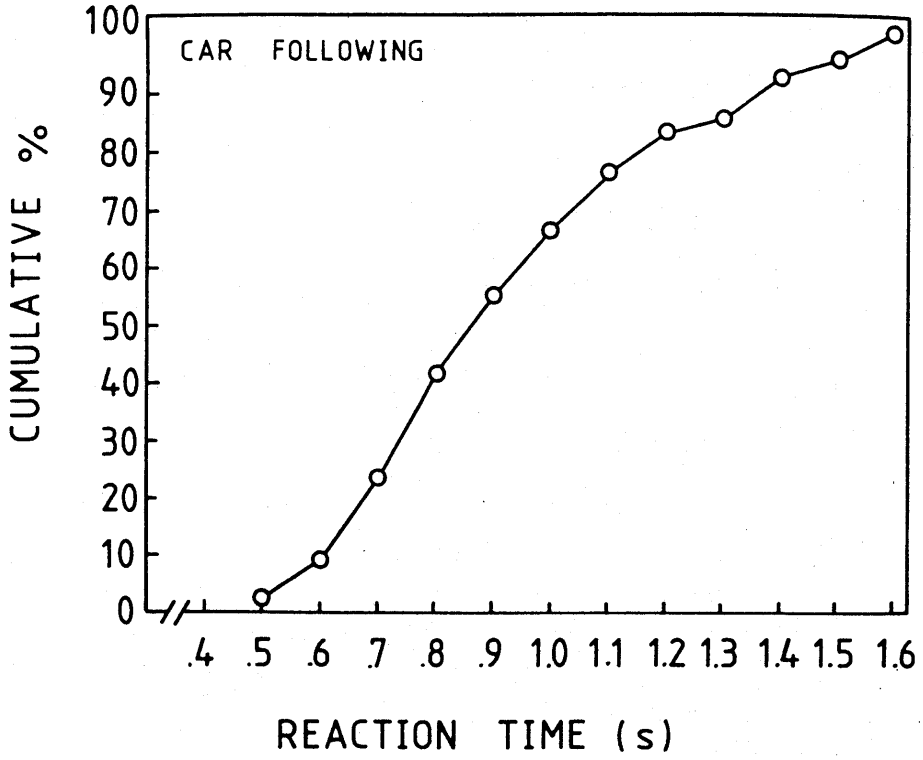

Figure 6 Cumulative reaction time distributions for brake light signals on leading vehicles when car following (n=42, mean = 0.92 s, standard deviation = 0.28 s, skewness = +0.62)

Examination of vehicle time headways showed that if less than 1.0 s separated the leading and trailing vehicles, all following drivers in the sample responded by braking when the brake lights of the leading vehicle appeared. The smallest vehicle headway observed was 0.3 s. For a headway separation of greater than 1.4 s, there were almost no braking events. Braking at longer headways would have been predicted if leading vehicles had reduced speed for a longer period of time. The cumulative distribution of headway times for those following cars that braked is shown in Figure 7. It should be noted that the mean headway for those that braked was 0.91 s, essentially the same value as the mean reaction time. Figures 8a and 8b show that there was very little overlap in the headway distributions for those that responded with a braking response and those that did not. In this situation, it was not very meaningful to report a braking response rate as was done by Sivak et al (1981a) and Allen Corporation (1978). The mean response time obtained here was 0.53 s and 0.46 s smaller than the values reported by Sivak et al and Allen Corporation respectively.

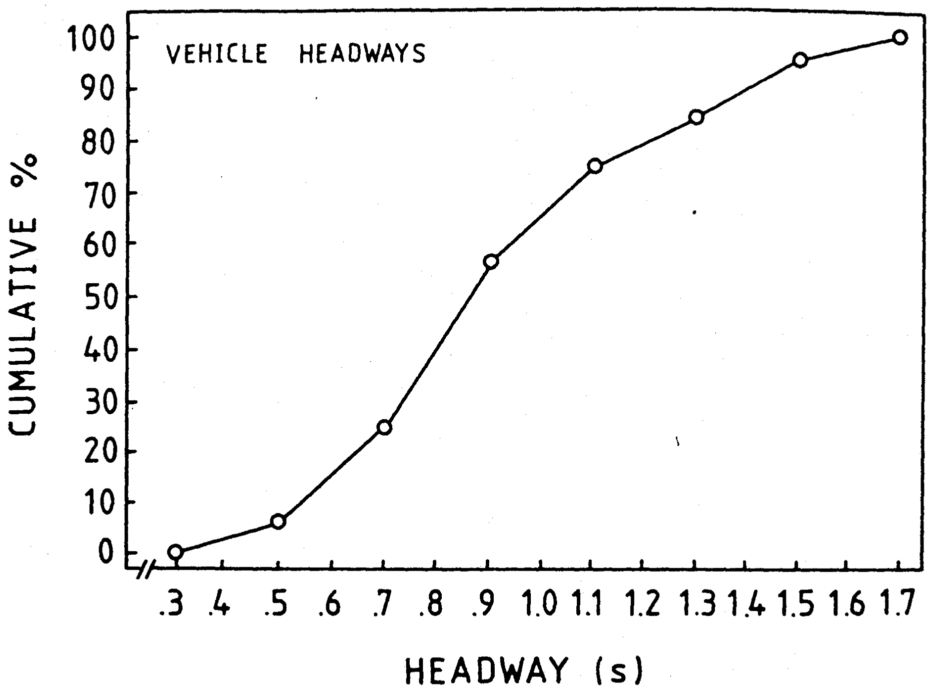

Figure 7 Cumulative time headway distribution for drivers responding to leading vehicle brake lights (n=42, mean = 0.91 s, standard deviation = 0.30 s, skewness = +0.48)

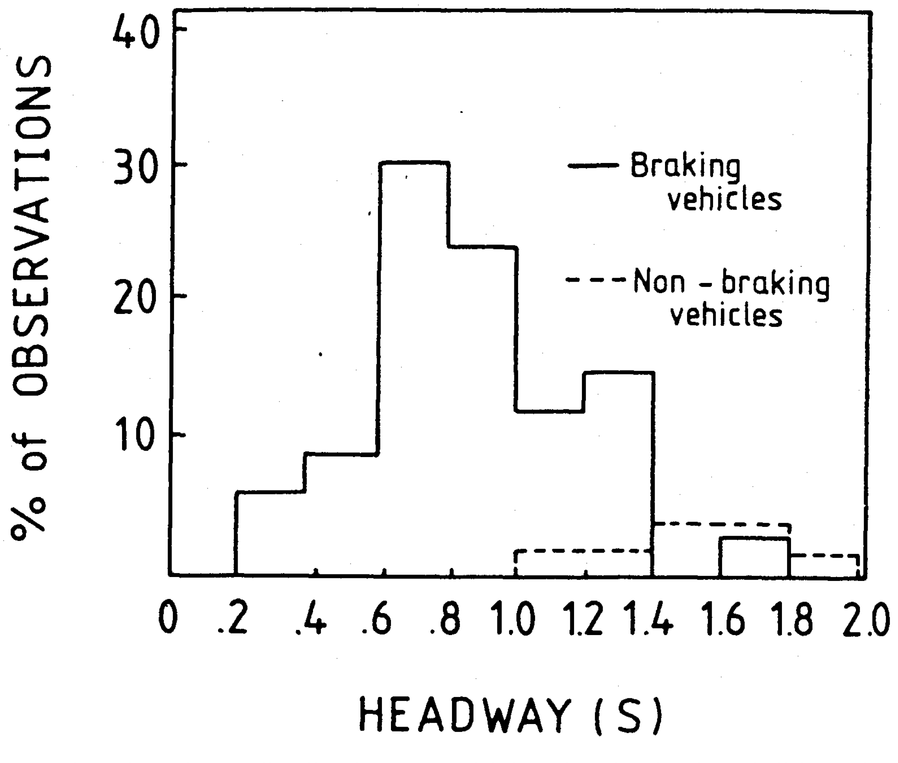

Figure 8a Time headway distribution for vehicles that braked and did not brake for headways between 0 and 2 s

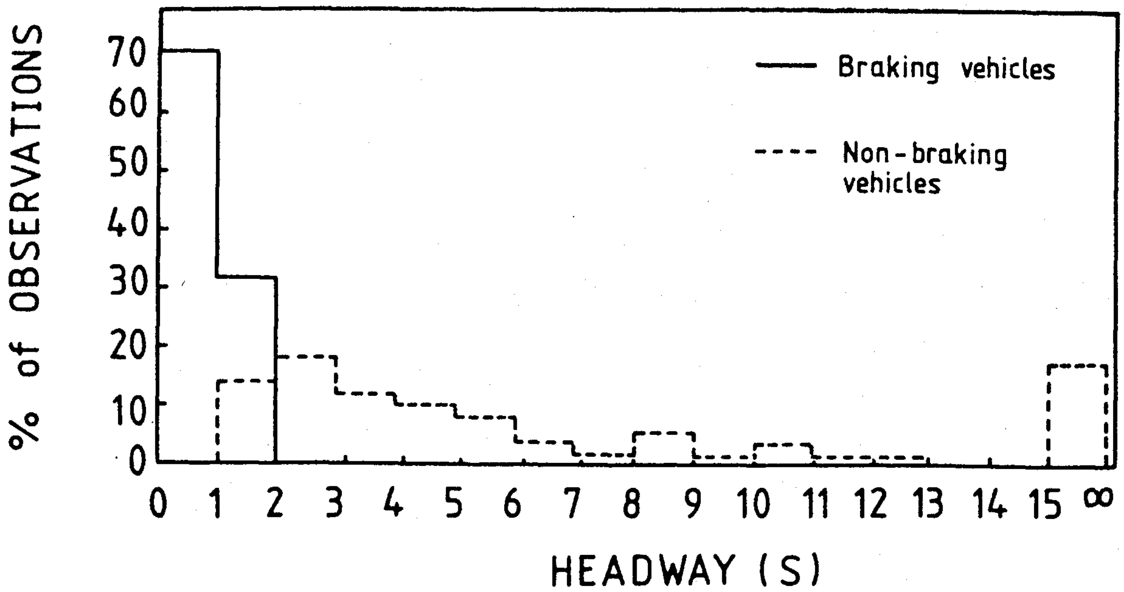

Figure 8b Time headway distribution for vehicles that braked and did not brake for all time headways

It was judged to be most unlikely that the response times in this study were reduced as a result of the amphometer cables being perceived by the following driver before the brake lights of the leading vehicle appeared. The smaller the headway difference, the less the view the following driver had of the lane ahead as his vehicle came over the crest and the road ahead fell away visually. Geometric analysis of the situation showed that only with very narrow leading vehicles, extreme differences in lateral position for the two vehicles, and long time headway was any glimpse of the amphometer possible for the driver of the following vehicle. Observations at the site verified that view of the amphometer cables in the single lane was occluded by the leading vehicle for the driver of the following vehicle over a wide range of vehicle separation distances and leading car widths. It is concluded that the response of the following driver would not have been influenced to any degree by visual sighting of the amphometer by the driver of the following vehicle. Additionally, it is known that the driver of a closely-following vehicle focuses his attention primarily on the leading vehicle rather than on other road features. It is also unlikely that following drivers could have received any early cue of a change in vehicle speed. Any speed change would have been negligible in the time between lifting off the accelerator and actuating the brake light. Earlier discussion of foot transfer times indicated that this duration should not exceed about a third of a second. Given that the vehicles were travelling at the crest of a vertical curve, essentially no change in speed should have occurred during this transfer period. There was also an absence of events where the following vehicle braked where the lead vehicle did not. Some cases of this would have been expected if the amphometer had been seen by the closely following driver or minor speed changes in the leading vehicle detected. The standard deviation of responses in car following (0.28 s) was much smaller than the standard deviation for the amphometer condition (0.77 s). This also supports the contention that the car following responses were of a distinctly different type.

On the other hand, this difference in results compared with Allen Corporation (1978) and Sivak et al (1981a) could have resulted from drivers being more highly alerted by the car following at speeds generally above 105 km/h. The speeds in these two American field studies could be assumed to have been less, given prevailing speed limits and the situations studied. It is also possible that car following distances could have been shorter in this study than in the two comparable field studies, at least relative to the prevailing speeds. Sivak et al (1981b) found some evidence supporting a direct relationship between reaction time and following distance using briefed subjects driving an experimental vehicle. However, in that study, following distance and vehicle speed were confounded. For the data reported here, the correlation between reaction time and time headway was +0.32 ($p < .05$), the correlation between reaction time and vehicle speed was -0.40 ($p < .05$), and the correlation between vehicle speed and headway was -.021 ($p > .05$). Calculation of partial correlation coefficients showed that the correlation between reaction time and headway with the effect of speed removed was 0.34 ($t(35) = 2.1$, $p < .05$), while the correlation of reaction time and speed with the effect of headway eliminated was -0.41 ($t(35) = 2.68$, $p < .02$). These results suggest that both headway time and vehicle speed play a role in determining the response times of drivers in the car following situation. This study may have yielded smaller response times than the two American field studies, because the situation did not cause drivers at longer headways to brake. These response times would have been expected to be longer given the above relationship. The urgency of responding at longer headways would generally be less, and responses would not need to have such an emphasis on speed. Given that this experimental setting elicited responses from only closely following drivers who would have been set to respond speedily, the similarity of the mean headway for braking vehicles and the mean braking response time may be more than coincidence. It might not be an unreasonable strategy for drivers who follow closely to select a headway value close to their speeded reaction time value. It is most unlikely that any differences in vehicle design could have accounted for the relatively large difference in response time between the two American studies and these Australian data. Extension of data collection to a range of environments would be necessary to account further for the relative contribution of headway, highway speed, and traffic flow rates to the car-following brake reaction time. However, the value of response time in this situation is the lowest yet reported using unbriefed subjects. Such a result is reasonable given the alerting nature of the situation, the importance of immediate responses for those that braked to prevent collision when the vehicle ahead slows and the tendency of following drivers visually to fixate the leading vehicle rather than broadly sample the environment.

EIGHTY-FIFTH PERCENTILE REACTION TIME VALUES

Eighty-fifth percentiles are frequently of interest to traffic engineers for road design purposes. A wide range of 85th percentile values from the various reaction time distributions were obtained for the various situations studied for which a reasonable reaction time estimate was available. These values are listed in Table 4.

Table 4 85th Percentile Reaction Time Values

C.R.B. "Roadworks Ahead" Sign	3.0s
Protruding vehicle with tyre change	1.5s
Lit vehicle under repair at night	1.5s
Parked Police Vehicle	2.8s
Amphometer: Beaconsfield	3.4s
Amphometer: Dandenong North	3.6s
Amphometer: Gisborne	3.6s
Amphometer: Tynong	2.54s
Railway crossing: Night (General Population)	1.50s
Railway crossing: Night (Rally drivers)	1.50s
Railway crossing: Day	2.53s
Car following	1.26s

The results for car following relate only to gaining information from the vehicle immediately ahead. All other situations studied involved obtaining information from the roadway, a road signing system, or an object in the driving visual scene. Highly discriminable emergency signals (such as clearly visible broken-down vehicles close to the road pavement, and rail level crossing signals presented close to a critical decision position) yielded 85% reaction time values below 2.5 s. Parenthetically, it should be remembered that drivers may have been somewhat pre-alerted on the approach to railway level crossings. General hazard warning signs, signs relating to speed reductions, and non-emergency but salient information on the pavement surface yielded 85th percentile values above 2.5 s even for drivers with raised alertness levels from travelling at high speeds.

It is worth noting that all of the 85th percentile reaction time values obtained in this field study well exceed the perception-reaction value of 0.70 s assumed in the U.K. in order to calculate values for the shortest stopping distances as a function of speed under optimum conditions of visibility and driver alertness (HMSO, 1978).

CONCLUSIONS

Results show that any answer to a question concerning the basic response time of drivers on public roads must be qualified. The response time depends greatly on the type of situation, the degree of urgency, and the speed of the vehicle when the eliciting signal commences. In more urgent responding situations, most unalerted drivers have shown themselves capable of responding in less than 2.5 s. In the situations studied here yielding these relatively short response times, the stimulus has been clearly discriminable and unambiguous. The decision involving selection of the appropriate response should also have been relatively simple. With more difficult decisions associated with situations where either the critical stimulus is not as discriminable (such as daytime railway level crossing signals), is more complex in structure, or requires a greater change in cognitive set in order to be responded to, one could reliably predict a significant increase in response time. It should be noted that most eliciting stimuli used in this study subtended relatively large visual angles or could be reasonably easily detected.

On the basis of these experiments, however, driver response times can be expected to exceed the commonly accepted design value of 2.5 s relatively frequently. Excluding car following, seven of eleven response eliciting situations produced 85th percentile values above 2.5 s, and four of these had values of 3.0 s or more. These data, along with the results from previously reported field investigations, cast significant doubt on the appropriateness of the current standard. Upgrading of the 2.5 s value appears to be warranted, and a number of questions should be addressed in any revision of the design value.

In reviewing the issue of a design standard, road authorities should stipulate the degree of urgency of the stimulus governing the reaction time value to be selected. Design values covering several different types of situations might warrant consideration. There exists the associated question of whether unspeeded response times should be allowed for within the design standard. In other words, what range of emergencies or requirements to respond rapidly should the road designer cater for? This is a difficult decision deserving further consideration and debate.

A judgement is also required concerning inclusion of sign reading complexity and reading time considerations in any future road design reaction time standard. If some correction for sign reading time (such as that used by Smith (1964)) is opted for, a decision must also be made about how the correction factor should be selected. Alternatively, should responses to road signs be specifically excluded from a reaction time standard? If included, one can question what level of sign familiarity should be assumed.

As discriminability of a response-eliciting stimulus increases the reaction time decreases and vice versa. Should an assumed level of discriminability be explicitly nominated in any future design standard?

Reaction times to flashing railway level crossing signals were approximately 600 ms longer during the day than at night. This 50% increase in daytime reaction times was statistically significant. Although this result was not unexpected because of the higher detectability of these signals at night, these data plus the significantly lower response rate during the day question the adequacy of the current level-crossing signal conspicuity.

The amphometer and railway-crossing data demonstrate that, overall, drivers of higher speed vehicles respond faster than those at lower speed. This effect was attributed to greater alertness levels at higher vehicle speeds, although the adoption by faster drivers of a different criterion for the urgency of braking required may also have been a factor. Differences of up to 500 msec were found in this study for higher and lower speed groups under otherwise similar conditions. Caution would be required, however, in applying this observation generally in road design, as it has not been demonstrated to be a linear effect over the range of speeds of interest to road designers and the speed effect may interact with the type of eliciting stimulus. Furthermore, on roads designed for higher speeds, the critical stimulus or object will come into view at a greater distance, and will subtend a smaller visual angle. This may make the object more difficult to detect or discriminate in some circumstances, and hence increase the driver's reaction time. Such a visual angle consideration would not have been very relevant to the amphometer or rail crossing stimuli for which the correlations between reaction times and vehicle speeds were obtained.

The car-following reaction times were markedly lower than those observed in previously reported field experiments probably because the situation of this experiment tended to cause only those drivers at relatively short headways to brake. Time headway and vehicle speed independently influenced driver response times when car following.

Both response rate and the skewness value of the response time distribution have been found to be associated in this project with the urgency of the response situation. For example, for both the amphometer and the rail crossing stimuli, the highest response rate and skewness have been found for the shortest response times. However, there is insufficient evidence available to support these two criteria of urgency unequivocally. Nevertheless, the wide spread of reaction times obtained in this study emphasises the need to separate truly speeded responses from those that are merely precautionary.

Estimates of driver reaction times currently have relevance to several areas of road design and road safety. These are geometric road design, traffic engineering (placement of warnings, etc), recommendations to drivers concerning headways to be adopted in the vehicle-following situation, and driver education and mass media safety campaigns where reaction time values are used for illustrative purposes. The implications of the data from this study for geometric road design and traffic engineering have already been discussed, and the 2.5 s value commonly adopted has been questioned. In vehicle-following, a time-headway of at least 2 s is frequently recommended, and the data reported here suggest that such a time-headway may be longer than is necessary in terms of the reaction times obtained in such situations. It should be noted, of course, that the longer the headway the greater the margin of safety. Driver education programmes often cite 1 s as a typical driver reaction time. Based on the overall results of this study, this estimate is probably only a representative value for essentially ideal conditions where drivers have a relatively high expectancy that a speeded response will be required to a road-based stimulus that is clearly visible.

One other issue deserves mention. If a driver's eye height is lowered, the time available for braking or otherwise responding is reduced in the limited sight distance case. Sports cars, for instance, typically have driver eye heights below the design value. Eye height is effectively reduced for all drivers under night driving conditions on rural roads where objects on the road are illuminated by the vehicles headlamps. This is because headlights are mounted lower than the driver's eye height, and an object can only be seen for a vehicle approaching a crest when in the line of sight of the headlamp rather than that of the driver's eyes. Hence, application of the current design standard in Australia means that for many night driving situations there is less than 2.5 s available to the driver for responding to objects on the road, given that vehicle speeds at night differ little from those during the day.

In summary, the field reaction values obtained in this project were sufficiently large to allow the current road design value of 2.5 s to be challenged. A review of the current design practice is strongly recommended.

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APPENDIX A

POSSIBLE METHODS FOR OBTAINING TIME OF DRIVER RESPONSE IN THE MEASUREMENT OF UNALERTED RESPONSE TIME WHEN NO BRAKING RESPONSE IS MADE

It may be possible to determine the time at which a driver responded to an unexpected stimulus by the analysis of noise made by a vehicle. It is assumed that often the first response of a driver on perceiving what may be a hazard is to lift off the accelerator. This should generally result in a change of the intensity or spectral characteristics of the vehicle's noise, which may or may not be detectable.

There are likely to be a number of difficulties with the acoustic analysis approach. The intensity of noise emitted by vehicles may increase, decrease, or remain relatively unchanged, under trailing throttle. As such, it is not expected that intensity would provide a suitable signal for the automatic determination of an accelerator response. It is more likely that changes in spectral characteristics would be a reliable measure. However, for high speed vehicles on rural roads, the major component of noise made by the vehicle is -tyre noise which will largely mask the engine noise that is the noise source whose spectral characteristics change rapidly with accelerator response.

Data could be obtained by recording the noise made by vehicles as they pass the experimental area. The noise would be recorded on the audio channel of a video tape recorder (VTR). A simultaneous video recording would also be made. A time mark, synchronised with a video timer, would be mixed with the audio information.

The analysis of these records would be the difficult part of the technique. First, the records would be examined by ear and any responses determined to the nearest second. However, experience to date suggest that such detection is difficult, and so further examination of the record would need to be based on synchronising with the video record. The acoustic record could then be analysed in bursts for spectral content. These bursts would have to be of sufficient duration to allow for several cycles of the lowest useful frequency to be sampled. Assuming that engine revo1utions are in the range of 2000 to 4000 revolutions per minute, that is 33 to 66 Hz, for a four cylinder engine and thus two detonations per revolution the lowest useful frequencies are in the range of 60 Hz and 130 Hz. On this basis, bursts of approximately 100 ms would have to be analysed. This would thus give a timing resolution of 0.1 s to the technique. However, it is not expected that there is sufficient change in this fundamental detonation frequency at the moment of accelerator lift-off for this to be the most useful frequency range. It is more likely that the sensitive frequencies will be those in the higher range. The detonations should yield noise bursts whose spectral composition will change with throttle position, but it is considered that several cycles of detonation noise would need to be sampled for reliable results.

There are several methods by which this analysis could be achieved. A multi-channel spectral analyser could be used. The cost of such an instrument is in the order of $15,000. However, there are two low hardware-cost techniques that seem feasible that would utilise equipment more generally available.

The minimum hardware technique would be to digitise the audio record by means of the fast A/D facility currently planned for the Nova computer. This would allow use of numerical filtering and Fourier transform techniques to determine spectral characteristics. Such an approach, however, is a major programming exercise and would be likely to take at least six person-months of work.

The second technique would be to construct a simple multichannel , analyser of about 10 channels and interface this with the NOVA through the A/D facility. This would probably be slightly more economical of labour but would include additional, but not significant, hardware costs.

Although both of these techniques have promise, further analysis would be required before a definite statement could be made about their potential for yielding reliable and sensitive results. A first step would be to carry out a trial experiment and have the data analysed by a multichannel analyser to determine the sensitivity of the technique.

Two additional simple techniques could also be evaluated. First, the change in intensity suggested earlier, but using a computer plotted display of intensity with identification of the response being made manually. Second, using a radar to sample speed at a fairly high sample rate.