QUANTIFYING DRIVER RESPONSE TIMES BASED UPON RESEARCH AND REAL LIFE DATA

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Summary: The purpose of this paper was to build upon previous research, identify the variables that significantly influence driver response times, and to determine the amplitude (constant) of that influence. The goal is that this research will explain why seemingly analogous published studies have come to very different driver response time results. An analogous driver response situation is defined as being in one of four groups: (1) lead vehicles that were stopped or moving slowly, (2) being cut off (when a vehicle changes lanes into the path of the responding driver), (3) path intrusions, or (4) known lights, icons or sounds. It was found that research that measured response times in analogous situations can be used to estimate the mean response time for a particular situation if adjustments are made to account for methodological differences between the studies. Non-analogous studies are poor predictors of driver response (An anticipated light stimulus response cannot accurately predict the response time to a path intrusion or lead vehicle). Mean driver response times can be predicted within 400 ms without accounting for individual difference. Therefore, external validity can be obtained regardless of the testing method (closed course, simulator or road), as long as the subject is unaware of either the stimulus or the appropriate response. Having a subject respond to multiple events does not (by itself) suggest that drivers will respond significantly faster.

INTRODUCTION

Over 150 years ago, the chronoscope (stop watch) was invented for the primary purpose of measuring how reaction times differ under various circumstances. However, rule of thumb estimates for response times have frequently been cited by researchers without regard to the specific task. Also, studies that measure the influence of an in-vehicle device may measure the response to a light, icon or lead vehicle and then claim that the results generalize to all response situations. Researchers may rely upon rule of thumb estimates due to the fact that there is little, if any, research to tell us what variables have a significant influence on response time and to what extent (its amplitude).

This research will address several substantive and methodology variables and their influence on driver response times. First, substantive and methodology variables were analyzed using ANOVA to determine if they significantly influence the change in driver response times (Muttart, 2001). Levels of each variable were also determined to ensure that each variable was objectively defined numerically, either ordinally or as a ratio term. In the second step, the variables that reached significance were analyzed using stepwise multiple linear regression (SMLR) from 145 previously published and unpublished driver response time studies (Muttart

2003a, 2003b). In the third step, the equations that were developed using SMLR were compared to the response times of 161 drivers, who were involved in actual crashes or near crashes that were video recorded in the U.S. and Europe (Muttart, 2004a, 2004b). The SMLR equations were found to predict mean response times within 400 ms (100% of the time) and individual response times within 600 ms 75% of the time. Step four involved the development of a parallel assessment method that is referred to as "Adjustment to Baseline" (A2B). A2B assessments involve making adjustments to analogous studies (Muttart, 2003b). The A2B method of estimating driver response also provides a parallel assessment to evaluate the reliability of the SMLR equations.

Each step along the way involved an examination of a greater number of variables and a comparison to a greater number of real-life responses. Now with a larger database of real life responses, this paper will once again look back at the influence of the individual variables.

For each of the four scenario groups, SMLR was used to identify the variables that were most significant when included with other variables. The ANOVA with linear regression analysis gives the slope of the individual variable-response timeline when that variable is considered individually. Although SMLR assumed orthogonal relationships, there will usually be some interaction among variables. For instance, at night, a driver may have smaller average eccentricities due to a smaller field being illuminated; there is no significant correlation between nighttime response time and visual eccentricity. To account for the manner in which the variables work together, a comparison was made of the regression constant (slope) for the variables selected in the SMLR analysis and the regression constant for those variables when considered alone. The regression constant was approximately half when considered with other variables, compared to when it was evaluated alone.

Therefore, a series of "adjustments" were developed that can be applied to analogous driver response time results and may also be used to estimate the influence of a distracter upon a driver's response time.

On the basis of the research by Muttart (2003a), driver response times must be grouped based upon the direction from which the hazard emerges. In earlier research, response times could not be predicted if results from non-analogous driver response times were grouped together. However, if response research was grouped based upon where the hazard emerged (an analogous situation), response times could be predicted with reasonable accuracy. Responses to (1) lead vehicles, (2) being cut off, (3) known sounds and lights, and (4) path intrusions must be grouped in separate databases. Therefore, a response to a known light will not be useful in predicting a path intrusion and a response to a lead vehicle will not be useful in predicting the response to a path intrusion (Muttart, 2003a, 2004a).

METHOD

A database was developed that consisted of coded entries for over 130 published and 6 non-published studies that reported driver response times. The reported driver response times from each study and codes for substantive and methodology variables were entered (see Table 1). If the study reported response times in two different scenarios, then two entries were placed into the database; if there were several hundred subjects but only one scenario, then one entry was placed into the database. This method was used so the influence of each variable could be examined. Added to the database were the 195 real-life response times objectively coded as indicated in Table 1.

Table 1. Codes for substantive and methodology variables

Age	Years
Anticipation	1-Known stimulus & Response Multiple responses, 2-Known stimulus and response – single event, 3- Known stimulus OR response, multiple, 4-Known stimulus or response-single, 5-Unknown stimulus and response.
Brake versus Steer	1-Brake, 2-Steer right, 2-Steer left
Crash	0-No, 1-Yes
Driving Task	0-No, 1-Yes
Eccentricity	Degrees
Experiment Type	1-Laboratory, 2-Simulator (steering wheel & brake), 3-Closed course, 4-Road
Gender	1-Male, 2-Female
Headway	In seconds
Horn	0-No horn used, 1-Horn used in avoidance
Km/h	Velocity
Lane	0-Center, 1-Right, 2-Left
Lanes Crossed	1-From the next, 2-Multiple
Left/Right	1-Right, 2-Left
Lighting	0-Day, 1-Dawn or dusk, 2-Night
Movement	0-Stationary or starting from a stop, 1-Moving without stopping
NASA TLX	Score on subjective stress quesytionaire
Response	1-Verbal or press button, 2-Brake or steer was only option, 3-Brake or steer, Brake & Steer
Road	0-Rural, 1-Suburban/Residential, 2-Arterial, 3-Urban, 4-Highway
Road Condition	1-Dry, 2-Wet, 3-Debris, 4-Snow
Stimuli	1-Mentally responding to one object, 2-Mentally responding to two spatially separate objects
Topography	1-Straight, 2-Curves, cues or intersections
Transition	1-First driver reaction, 2-First driver response (touch the brake), 3-First vehicle response
TTC	Time to contact in seconds from perception point
Turning	Destination of the responder, 0-Straight, 1-Right, 2-Left
Weather	1-Sunny, 2-Clear, 3-Rain, 4-Fog or snow

The database included 1,813 cases that account for over 10,000 driver responses, the dependent variable and 25 independent variables. There were 167 lead-vehicle response entries, 349 cut-off entries, 341 path-intrusion entries, 184 entries involving responses to known lights, sounds or icons, 141 entries for responses to traffic controls, 67 entries for gaps in traffic, and the remaining were miscellaneous responses.

Linear regression analysis and one-way analysis of variance (ANOVA) was conducted on each variable. The purpose was to identify the regression constant (slope) for each variable and compare that to the regression constant for the same variable (if found significant in the SMLR analysis). The relationship between the two constants was used to modify the regression constants obtained from the one-way ANOVA along with standard MLR so an adjustment could be obtained for each variable (even those that were not selected during the SMLR analysis). Every variable combination was examined in an attempt to find interactions. The adjustments that were developed were applied to several studies to determine if the differences in the reported results of each study could be accounted for using the adjustment variables.

RESULTS

As demonstrated in Table 2, studies that measure the response to a known light, sound or icon are influenced by different variables and are not similar to a typical real-life response to a traffic hazard. Furthermore, when examining the terms that best predict response time to a known light, sound or icon, the variables selected by SMLR were all methodology variables (Anticipation,

Table 2. The calculated statistical probabilities using one-way ANOVA for 25 of the variables evaluated relative to the influence upon driver response times*

	Lead vehicle	Cut off	Path Intrusion	Known Lts./Icons/Sounds
Age	0.35	ND	0.43	**0.04**
Anticipation	**0.01**	**0.00**	0.66	**0.00**
Brake v Steer	ND	0.50	0.84	**0.02**
Crash	ND	0.49	0.39	ND
Driving	0.12	**0.00**	**0.00**	0.16
Eccentricity	**0.00**	**0.00**	**0.00**	**0.00**
Experiment Type	0.08	**0.00**	**0.00**	**0.44**
Gender	0.87	ND	0.08	0.43
Headway	**0.00**	ND	ND	ND
Horn	ND	0.44	0.26	ND
KM/h	0.03	0.70	0.15	0.09
Lane	0.31	**0.02**	0.64	ND
Lanes Crossed	ND	**0.00**	0.13	ND
Left/Right	ND	0.38	0.70	0.18
Lighting	**0.00**	**0.00**	**0.00**	0.14
Movement	ND	ND	**0.08**	**0.00**
NASA TLX	0.09	ND	ND	0.32
Response	0.32	ND	**0.02**	0.84
Road	ND	0.90	0.60	**0.00**
Stimuli	**0.00**	0.75	**0.40**	0.10
Topography	**0.01**	**0.00**	**0.61**	0.14
Transition	**0.01**	ND	**0.00**	0.19
TTC	0.95	ND	**0.00**	0.67
Turning	ND	0.92	**0.00**	0.56
Weather	ND	0.18	0.86	ND

*The numbers in bold were significant in a one-way analysis and those in shaded cells were significant and accepted when using SMLR ($p < 0.05$))

Driving task, experiment type and movement). Therefore, when measuring the response to a known light, icon or sound, the study is likely measuring its own methodology, rather than any particular driving skill. Also, note that age reached significance only when responding to known lights, sounds or icons. Lights and sounds may not allow older driver to utilize their conditioned responses and recognition of traffic patterns.

Other variables that were examined included alcohol (BAC %), and THC ingestion. Although there may be a wealth of data for these drugs regarding their affects on a person's behavior, there is very little research into the effects of alcohol and THC on the performance of drivers when responding to lead vehicles, being cut off or path intrusions. Due to limited data, no significance was found.

There were four methodology variables: experiment type, transition time, anticipation and the driving task. All four reached significance in at least one response scenario. The influence of methodology variables may be a reason why several authors have performed analogous research yet arrived at different results.

In this research, there was no significant difference between the response times for those who were involved in a crash and those who were not. When evaluating an emergency response, all real-life responses involve urgency. Real-life driver response times were underestimated by studies that did not include the mental workload inherent in driving.

Response times increased when the drivers did not know the stimulus or appropriate response (the anticipation term), but then plateau. This suggests that exposing subjects to multiple events may still yield externally valid results, as long as the subjects do not know both the stimulus and appropriate response in subsequent exposures. This was not the case when examining the response to lead vehicles at long headways. In this case, the reason for a longer response time is due to the expectation that the lead vehicle will be traveling at normal highway speeds. Anticipation reached significance for responses to lead vehicles, but that is due to a confounding variable in the data. The confounding variable is the fact that many of the situations involving low anticipation were responses to lead vehicles at intersections that involved response times of approximately 1 second, while many of the long headway situations involved subjects who knew the stimulus and appropriate response.

Of the 161 emergency responses evaluated on video, 106 involved crashes. There was no difference between the responses of those involved in a crash versus those who avoided the crash. Most scenarios that we are examining involve a great deal of urgency. Based upon the research evaluated, there was no significance between time-to-contact (TTC) and driver response time up until TTCs of 5 seconds, after which time response times increased significantly in path intrusion situations. As expected, if TTC were not a significant influence on response time, speed would not be either. Only when responding to a lead vehicle was speed a significant influence on response time, and in that scenario response time increased at a rate of only 80 ms for every 10 km/h (6.2 mph). Therefore, speed, as a single variable is not an influence upon response time. However, in one of the two significant interactions found, when a driver was engaged in a distracting task, response times increased at a quadratic rate as speed increased (see Figure 1). The other interaction is headway versus topography, in that response time remains constant regardless of the headway at curves and intersections, yet increases dramatically at longer headways on straight roads.

The number of objects (stimuli) being mentally processed was a significant influence on response time. When being cut off, it was not significant suggesting that being cut off may involve greater intensity or notice than other stimuli. Also, when a driver in an outside lane was being cut off, particularly the left lane, response times were higher than when in the center lane. Overall, response time increased an average of 300 ms for eccentricities over 10 degrees in path intrusions and approximately ¼ second for every 10 degrees when responding to a lead vehicle. When being cut off, the number of lanes away that the intruding vehicle started reached significance, but number of lanes was not a significant influence in any other scenario. However, drivers responded nearly 1/5th of a second faster if a path intruding vehicle continued into the responder's path without starting from a stop (or being stationary). Please refer to Table 3 for the amplitude of the adjustments (regression constants).

When responding to illuminated lead vehicle daylight versus darkness had a significant but marginal effect upon driver response time. When responding to a path intrusion, response times increased an average of approximately ¼ second at night. There are several situations in which an object at night may need much greater time before perception is possible.

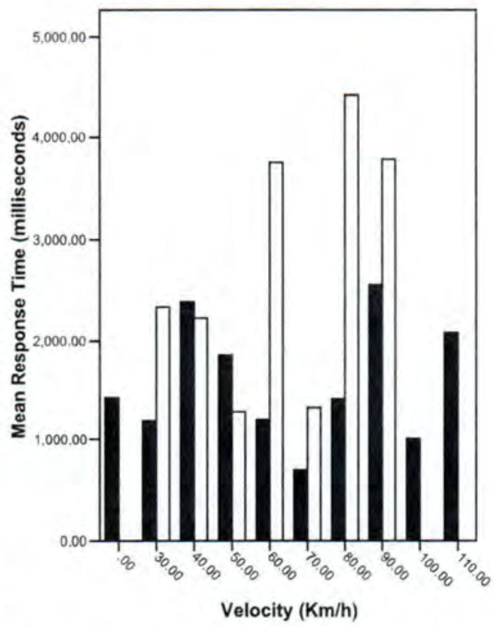

Figure 1. The relationship of speed and driver response time to a lead vehicle. The white bars represent multiple stimuli responses and the black bars single stimulus responses.

Topography could be referred to as a context term. Drivers tend to respond faster in response to lead vehicles or intruding objects when at an intersection or when approaching a curve, compared to when responding to a similar situation on a straight road.

In the second part of this study, the regression constants were used as adjustments to determine if the reported results of each study can be accounted for with substantive and methodology variable adjustments. In Table 4, you can see the adjustments calculated for path intrusions. "Mock" refers to the mock scenario we are attempting to predict response time for. The actual average perception-response time of all real-life drivers who were traveling straight through an intersection and responded to a path intrusion that started from a stop in daylight was 1.3 seconds. Barrett, Kobayashi and Fox (1968), Lechner & Malaterre (1991), Olson and Sivak (1986), Phelps and Dunn (2000), and SATAI (1999) refer to path intrusion studies. The second row from the bottom shows the reported result of that study and the total adjustments. The bottom row shows the adjusted response time for the mock scenario.

Table 3. The amplitude of the regression constants of the independent variables.

	Lead vehicle	Cut off	Path intrusion	Known Lts. /Icons/Sounds
Age				7.2
Anticipation	[redacted]	177		251
Driving Task	-740	-91	-350	-376
Eccentricity	23	11	30	32
Experiment Type	81	172	108	252
Headway	297			
KM/h	8			
Lane		64		
Lanes Crossed		393		
Lighting	98	213	125	
Movement			-164	-177
Response			109	
Road				-79
Stimuli	806		802	
Topography	-639		-692	
Transition	350	344	170	
TTC			103	
Turning			261	

Table 4. The results and methodology of five path intrusion studies in coded form with adjustments for several variables

	Path Intrusion	Mock	*Barrett*		*Lechner*		*Olson*		*Phelps*		*SATAI*	
Driving Task	350	1	1	0	1	0	1	0	0	350	1	0
Eccentricity	30	5	9	-120	5	0	5	0	5	0	5	0
Experiment Type	108	4	2	216	2	216	3	108	1	324	3	108
Lighting	125	1	1	0	1	0	1	0	1	0	1	0
Movement	-164	0	0	0	0	0	0	0	0	0	0	0
Response	109	3	3	0	3	0	3	0	1	218	3	0
Stimuli	802	1	1	0	1	0	1	0	1	0	1	0
Topography	-692	2	1	-692	2	0	2	0	1	-692	1	-692
Transition	170	3	1	340	1	340	2	170	1	340	3	0
TTC if < 5 sec	103	4	4	0	4	0	4	0	4	0	4	0
Turning	261	0	0	0	0	0	0	0	0	0	0	0
Result/Adjustment			1498	-256	850	556	1080	278	635	540	1901	-584
Adjusted RT	Actual =	**1.3**	1.2		1.4		1.4		1.2		1.3	

DISCUSSION

Some studies measured driver response time from perception up until first reaction (taking the foot off the throttle or first hand movement). Others measured response time to first response or brake reaction time (up until the foot touches the brake or when steering is accomplished). Still others measured response time up until full braking or first lateral movement (which accounts for the vehicle latency). Due to a poor vocabulary in the field, all three scenarios have been interchangeably referred to as perception-reaction, perception-response and brake-response time. For clarification, perception-reaction should be when the foot comes off the throttle because that is the driver's first reaction. Brake response time should be the time up to brake application and perception-response should be from perception as an immediate hazard up until first *vehicle* response.

A change in the stimulus not only brings about a likely different response, but the variables that influence a driver's response have various influences in the various driver response scenarios as well. Mean driver response times may be estimated with a reasonable degree of accuray without accounting for individual characteristics if the direction from which the hazard emerged can be accounted for. This research was based upon how drivers have performed in various research settings and in real-life situations. The results are limited to situations involving an easily identifiable and immediate hazard.

There were four experiment types (laboratory, simulator, closed course and road). A simulator was defined as any response that offered a steering wheel and brake. Therefore, there is a huge disparity in what is considered a "simulator." Subsequent examination of the data has shown that high fidelity simulators such as those at the University of Iowa, GE and others of similar complexity produce results that are very consistent with a "road" study, which is consistent with the findings of McGehee, Mazzae & Baldwin (2000).

These driver response times did not have a significantly skewed distribution if analogous responses were compared and the methodology of the test is not overly simplified so as to involve a human response time limitation. For those situations when the average response time is near 1 second or less, there will likely be a skew in the distribution because we start to approach a human response limitation.

Drivers' response times are approximately 200 ms faster when the intruder moves into the responder's path without stopping. Essentially, this means that drivers are recognizing the hazard when the intruder is approximately 200 ms before the stop line. Speed of the intruder did not influence the response time, which supports a contention that drivers did not calculate stopping distances of an intruder, but most likely judge safety by proximity of other traffic.

When evaluating the response of a driver, we are usually examining the performance of drivers when exposed to one of the most stressful events they will ever face. Urgency may play a role in the response of drivers in less threatening situations, but time-to-contact (TTC)was not significant in this research until TTC in path intrusion situations is greater than 5 seconds. When TTC is greater than 5 seconds, the hazard is becoming less and less of an immediate emergency. This research is examining emergency response times.

Eccentricity had a lesser amplitude when responding to lead vehicles then when responding to path intrusions. This is consistent with a premise that if drivers are mentally occupied by a distraction, they are more likely to fixate in the area of the lead vehicle. It is also noteworthy that steering and braking response times were not significantly different. A steering response does not involve leg movement, but apparently there is a greater cognitive component when steering.

There is still much we do not know and cannot predict based upon the current data. More research should be done regarding the use of alcohol and distracting stimuli. There is also interest in further examination of the types of eccentricities (up and down, etc.), and separating out the influence of horizontal and vertical curves from warnings. There also appears to be evidence that short following headways may adversely affect response times to path intrusions. There is still a great deal of research required to identify the factors that influence search patterns and driver attention in various situations.

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REFERENCES

Barrett, G., Kobayashi, M., & Fox, B. H. (1968). Feasibility of studying driver reaction to sudden pedestrian emergencies in an automobile simulator. *Human Factors, 10*, 19-26.

Lechner, D., & Malaterre, G. (1991). *Emergency maneuver experimentation using a driving simulator* (SAE Paper No. 910016). Warrendale, PA: Society of Automotive Engineers.

McGehee, D. V., Mazzae, E. N., & Baldwin, G. H. S. (2000). Driver reaction time in crash avoidance research: validation of a driving simulator study on a test track. *Proceedings of the International Ergonomics Association 2000 Conference.*

Muttart, J. W. (2001). Evaluation of the influence of several variables upon driver perception response times. York, England: *Proceedings of the 5th International Conference of the Institute of Traffic Accident Investigators,* 116-129.

Muttart, J. W. (2003). *Development and Evaluation of Driver Response Time Predictors Based upon Meta Analysis* (SAE paper No. 2003-01-0885). Warrendale, PA: Society of Automotive Engineers.

Muttart, J. W. (2003). Evaluation of Methods for Estimating Driver Response Times. *Proceedings of the 6th International Conference of the Institute of Traffic Accident Investigators*, Stratford-upon-Avon, England.

Muttart, J. W. (2004). DRIVE3: A simplified method for estimating driver response. Auckland, NZ: *Australasian and South Pacific Association of Crash Investigators 2004 Conference Proceedings.*

Muttart, J. W. (2004). Estimating driver response times. In *Handbook for Forensic Human Factors in Litigation* (Ch.14). Boca Raton, FL: Taylor & Francis.

Olson, P. L., & Sivak, M. (1986). Perception-response time to unexpected roadway hazards. *Human Factors, 28*, 91-96.

Phelps N.R. and Dunne M.C.M. (2000). Static or kinetic tests, which are influenced most by age? *Investigative Ophthalmology and Visual Science, 41*(4) S433.

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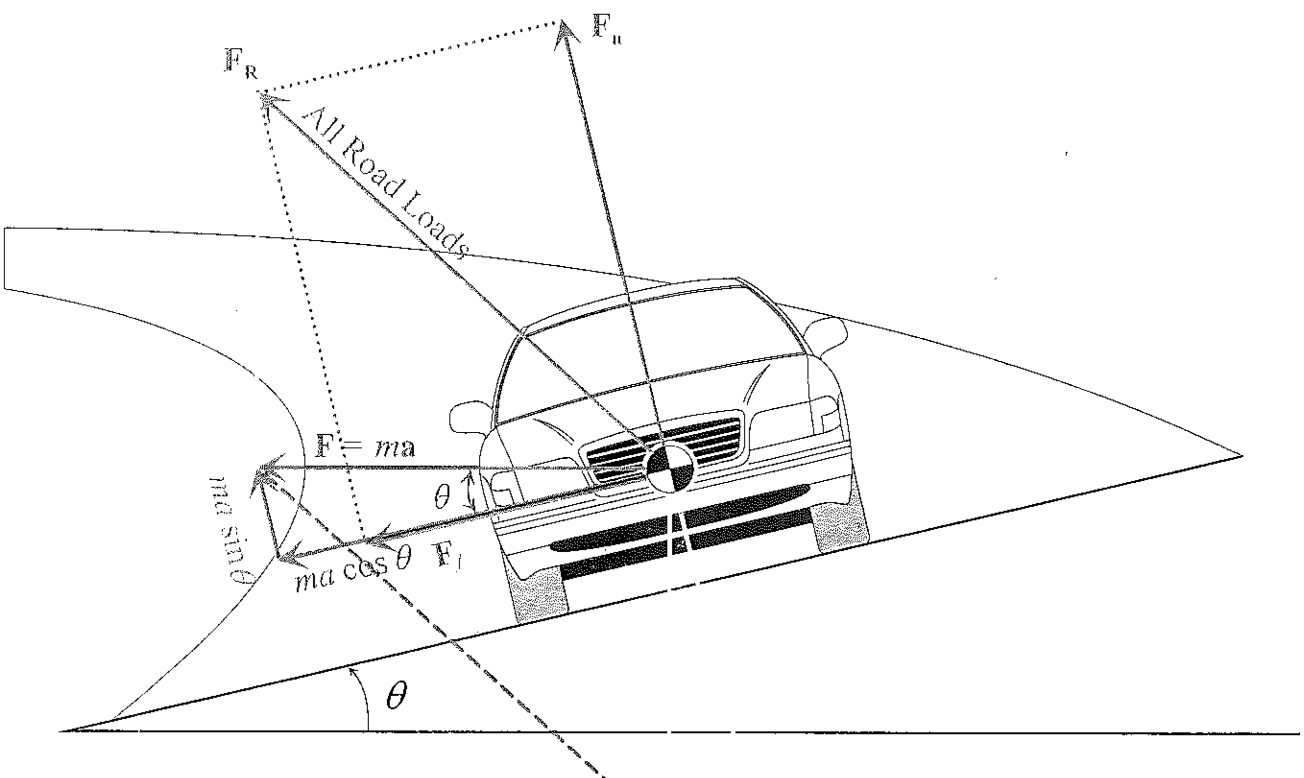

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US	SI
$a = 0.049$	$a = 0.00579$
$b = 2.345$	$b = 0.4444$
$c = -236.96$	$c = -72.18$
$S = \frac{-2.345 \pm \sqrt{2.345^2 - 4(0.049)(-236.96)}}{2(0.049)}$	$S = \frac{-0.4444 \pm \sqrt{0.4444^2 - 4(0.00579)(-72.18)}}{2(0.00579)}$
$S = -23.92 \pm 73.54$	$S = -38.37 \pm 118.04$

Notice that two answers exist for speed. Although a quadratic equation yields two mathematically correct answers, only a positive answer makes physical sense in this example, so our answer is:

US	SI
$S = 49.61\,\text{mph}$	$S = 79.67\,\text{kph}$

12.8 Perception–Response Time

The perception–response time (PRT) is also commonly referred to as the driver response time (DRT). At face value it is simply the time that is expended from when a driver senses a hazard to when the vehicle first responds to the driver's input. Further examination reveals that the influencing factors that dictate the actual value of the time are, at the very least, uncertain and may not be quantifiable. Therefore, using a single value for a PRT for all situations is inappropriate, and the particular circumstances of the crash must be considered in order to determine an appropriate value.

The purpose of this section is to provide the investigator an introduction to some of the concepts used to describe the phenomena of human performance in avoidance maneuvers.

12.8.1 Events of an Evasive Maneuver

Distinct events comprise an evasive or avoidance maneuver. These event intervals are in the following (possibly overlapping) order:

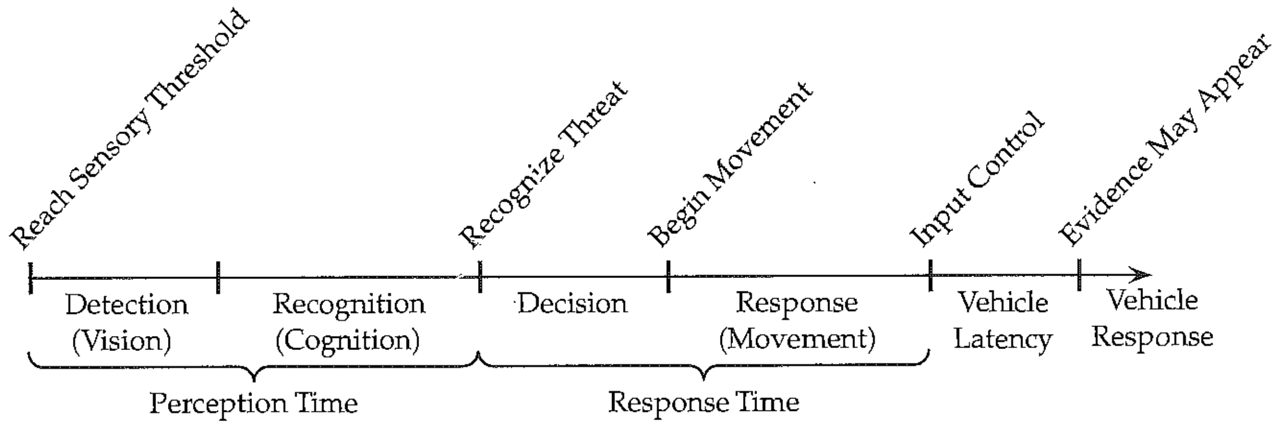

Figure 12.5: *A time line representing a typical avoidance maneuver. The intervals are not necessarily spaced as shown and may overlap. (Figure revised in 2007).*

1. Detection– The period of time between being able to see an item and coming to the realization that you are seeing it. In other words, this is the time from the point where the absolute visual threshold is reached to when the driver realizes that an object actually exists. The point of absolute threshold is when the photons strike the eye in enough concentration to excite the eye and visual cortex of the brain. This point of detection may be different for different people. Things that are not well illuminated, camouflaged, or otherwise difficult to see may never be detected.

2. Recognition– The process of deciding what an object represents. In avoidance maneuvers, the object is recognized as an immediate hazard, whether it be a child chasing a ball or a stationary dump truck on the side of the road. The key word here is *immediate* because hazards that are far enough away (either time or distance) can be dealt with using normal defensive driving techniques. For example, if a dump truck is 1/4 mile away, it may not be an immediate threat, and an uneventful maneuver can be executed. However, once an object is recognized as an immediate hazard, it is perceived to be an immediate threat and the driver must decide what action to take. A driver can detect something without recognizing it for some time.

3. Decision– The time it takes to decide the response to the situation. A driver may use the horn, brake, steer, and/or brace during an avoidance maneuver. The decision may not always be the most appropriate, but some time must elapse for the decision to be made, even for responses that are conditioned or "automatic". A *reaction* time in some literature is strictly the time that it takes to initiate the driver's first movement (i.e., take the foot off the accelerator).

4. Response– The time it takes for the driver to implement the decision. The response time

involves the foot movement for braking and the hand movement for steering. This is a measure of the driver's muscular response and may be longer for elderly drivers.

5. Vehicle Latency– The time that it takes for the driver's input to propagate to the mechanical system of the vehicle and leave evidence at the scene. For a braking maneuver, this would be the amount of time that it takes for the wheels to spin down to where they leave marks. Vehicle responses to steering can be relatively short in most cases that do not involve a great deal of confusion. However, the latency for an air-braked commercial vehicle can be relatively long. Often a driver will continually update the response and brake harder and harder as the sequence of events unfolds. This action blurs the distinction between driver response and vehicle latency.

6. Vehicle Response– By this time, evidence may be found, but the driver input may not be over. Determining driver response times usually does not take this interval into consideration.

Figure 12.5 shows a time line of a possible avoidance maneuver. The total driver response time is the time that passes from the point when the sensory threshold is reached to when control is applied to the vehicle. Additional time, vehicle latency, is needed for the vehicle to respond and leave evidence.

Some studies, however, define the perception-response time as the time that transpires until the driver's first movement (i.e., throttle release). These would be studying the perception-reaction time rather than the perception-response time. Other studies will measure the time the transpires until the brakes are applied. This is referred to as the brake-response time (BRT), which is the same as the total perception response time. To summarize:

Perception-Response Time is the time determined by adding the time it takes for a driver to make a decision, implement the decision by inputting a vehicle control. This is the most useful value to a crash investigator. However, there is still a finite amount of time that elapses from the end of the perception-response time to when the vehicle leaves evidence on the road.

Perception-Reaction Time is the time from when the driver recognizes an immediate threat to the point of first movement. This is the same as the decision interval on the time line and it will always be shorter than the perception-response time because it does not include driver movement.

Brake Response Time is the perception-reaction time plus the time of driver movement. This is the same as the total perception-response time.

12.8.2 Influencing Factors of PRT

The duration associated with driver response time is correlated with many things, including the event intervals seen in Figure 12.5. Both psychological and physiological factors influence a driver's ability to perceive and respond to events on the road. Some factors that are difficult (if not impossible) to represent in a mathematical form include: experience, attentiveness, stress, eye health, fatigue, and drugs—just to name a few.

There are a few measurable parameters that significantly influence the perception-response time. The detection and perception interval is highly correlated to the contrast of an item to its surroundings, the driver's anticipation, the strength of the stimulation, and the eccentricity of the object from the driver's line of sight. The mnemonic CASE-DR may be helpful in remembering some factors influencing drivers' ability to respond:

Contrast is the ability of an object to be distinguished from its background, and is concerned with lighting, patterns, and colors. Humans are most sensitive to the green-yellow colors. Under poor lighting, the contrast of an object is reduced, which will tend to increase the length of the detection interval.

Anticipation gages how a driver may be expecting some event. For example, a driver may anticipate a child in a residential neighborhood much more so than when driving on a freeway. Anticipation does not have to be conscious, as it refers to the psychological concept of "priming."

Stimulation factors include the strength of the stimulation, the quantity of stimuli, and the nature of stimulation. For example, an air horn is a different stimulant than a flashing light. When there are multiple of objects providing stimulation, such as on a crowded street, drivers typically will not detect hazards until they can discriminate the hazard from the non-hazards. This may not occur until they get closer to the object.

Eccentricity deals with where a driver is looking. As this measurable angular quantity increases, the perception-response time of drivers increases. A human must look directly at something to clearly see it.

Decision-making speed in adverse situations is primarily a function of experience or prior conditioning. A number of possible alternatives come into play in deciding what to do. Often drivers are conditioned to either stomp the brake or jerk the wheel when there is imminent danger ahead.

Response is the action a driver takes to provide input to the vehicle controls. The driving task, especially under stressful conditions, is complex, and response times measured for pushing a button (a simple response) may not be equivalent to response times for a complex response (braking and steering).

Undoubtedly, there are many other factors that influence a driver's perception-response time. The goal of presenting the CASE-DR list is to promote contemplation concerning the complexity of human performance.

12.8.3 Modeling PRT

When deciding what perception-response time to use, the best solution is to find a reputable study that examined an analogous situation to the one the driver in question experienced. This research may not exist or may be too time consuming to discover and interpret. In that case, a published regression equation may be used; see Muttart's work in references [13,14]. As a last resort, the values of PRT listed in tables can be used with an understanding of the limitations and complexity of human performance.

The human factors in traffic crashes are the subject of intense study. Data, methods, and tools are continually being improved and developed. Pioneering work and ongoing work by Olsen, Sivak, Hoffman, Mortimer, Summala, Muttart, McGehee, and many others have revealed the importance of understanding and investigating perception-response time.*

*See Refs. [15,16,17,18,19,20,21].