Title

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Abstract

The need for a drivers' model that integrates a wider range of natural driver activities is important to the traffic engineering and human factors communities. Integration of real traffic behaviors into micro-simulations increases the accuracy and explanatory power of these models. For human factors engineers, improvements to driver modeling efforts provide a useful framework by which Intelligent Transportation Systems (ITS) can be evaluated for safety and mobility. This project includes a means to consider normal lane changing maneuver, driver support for emergency management and impaired driving. The overall objective is increasing the potential of the driver model by using three principle methods: modeling, experimental, and verification. Specifically, this portion of the project focus on the adaptation of the current implemented architecture for the simulation of impaired driving and address the simulation of emergency handling. The outcomes of this project are an improved simulation tool that can recreate many highway-driving situations with human behavior accurately integrated. It will also support Caltrans goal of vehicle safety by providing a better tool to simulate driver behavior and developing the body of knowledge about driver impairment and emergency driving.

Keywords: Cognitive driver model, distraction, lane change

Executive Summary

The presented research aims at providing a drivers model that integrates a wider range of natural driver activities is important to the traffic engineering and human factors communities. Integration of real traffic behaviors into micro-simulations will increase the accuracy and explanatory power of these models. For human factors engineers, improvements to driver modeling efforts will provide a useful framework by which Intelligent Transportation Systems (ITS) can be evaluated for safety and mobility. The proposed extensions include a means to consider normal lane changing maneuver, driver support emergency management and impaired driving. Where warning or taking control from the driver becomes necessary understanding how the cognitive mechanisms operate and when to provide an aid to the driver will be critical to the research effort required.

The basis of a naturalistic driver model, PADRIC, have been established by PATH through two projects (Caltrans Memorandum Of Understanding 369 – Human Driver Models for SmartAHS and Caltrans Task Order 4222 – Human Driver Model Development). These projects led to the definition of the structure of the model and the implementation of the basic vehicle control procedures. In this project, we propose to pursue the development of the model by increasing the scope of simulation capabilities to lane-change maneuvers and emergency or impaired driving. The capability to detect and avoid collisions is integral to safe driving. Determining the structure and pattern of these driver activities under emergency and impaired conditions is central to the extension of the naturalistic driver model.

This report is constituted of two parts, the first part is a literature review conducted by Jeff Caird and his team at the University of Calgary on the factors of distraction, driver impairment and emergency management. Concerning the factors of distraction, a list of 11 categories of distraction is proposed. A simplistic analysis of these 11 categories allows to distinguish between categories where the “eyes are taken off the road” and categories where the “mind is taken off driving”. A good example of “mind taken off” driving is a cell phone conversation, for which the reaction times found in the literature have been investigated in more details. Regarding driver impairment and emergency maneuvers, the literature review allowed deriving an effect of alcohol on drivers’ reaction time. Although the effect of drugs is documented, it is difficult to integrate because drugs act on different brain operations and the model would have to become too detailed.

The second part illustrates the methodology developed at PATH in order to process the data gathered during TO 4222 for developing and integrating to the model the lane change maneuver. These two efforts will be reconciled in the future in order to integrate the factors investigated by the Calgary team to the control of the lane change maneuver.

General Introduction

The need for a drivers' model that integrates a wider range of natural driver activities is important to the traffic engineering and human factors communities. Integration of real traffic behaviors into micro-simulations will increase the accuracy and explanatory power of these models. For human factors engineers, improvements to driver modeling efforts will provide a useful framework by which Intelligent Transportation Systems (ITS) can be evaluated for safety and mobility. The proposed extensions include a means to consider normal lane changing maneuver, driver support emergency management and impaired driving. Where warning or taking control from the driver becomes necessary understanding how the cognitive mechanisms operate and when to provide an aid to the driver will be critical to the research effort required.

The basis of a naturalistic driver model, PADRIC, have been established by PATH through two projects (Caltrans Memorandum Of Understanding 369 – Human Driver Models for SmartAHS and Caltrans Task Order 4222 – Human Driver Model Development). These projects led to the definition of the structure of the model and the implementation of the basic vehicle control procedures. In this project, we propose to pursue the development of the model by increasing the scope of simulation capabilities to lane-change maneuvers and emergency or impaired driving. The capability to detect and avoid collisions is integral to safe driving. Determining the structure and pattern of these driver activities under emergency and impaired conditions is central to the extension of the naturalistic driver model.

We propose to address the objective of increasing the potential of the driver model by using three principle methods, namely, modeling, experimental, and verification. In the process of modeling, we propose to integrate strategic, tactical and operational information processing levels within one model. The model will be able to simulate many driving maneuvers such as car-following, lane-changing, emergency maneuvers and impaired drivers. To achieve this objective, we will incorporate reactive and anticipative primary operative modes, using the ACT-R cognitive architecture. The "human-like" information processing produced by this architecture will result in commands which affect the control of a vehicle within SmartAHS.

To adequately understand and have data to verify the efficacy of extensions of the driver model, experimental investigations of lane-changing, emergency and impaired conditions are essential research activities. The goal of these experimentations is to provide support for the model design and calibration as well as data to validate the model. We plan to conduct complementary (and convergent) naturalistic data collection with the PATH instrumented Taurus for lane changing. A state-of the-art driving simulator will be used to investigate the effects of impaired driving and emergency management. Driving simulation mitigates risks associated with testing drivers in impaired emergency situations where crashes may result. The outcomes of this project will be an improved simulation tool that can recreate many highway-driving situations with human behavior accurately integrated.

This report is constituted of two parts, the first part is a literature review conducted by Jeff Caird and his team at the University of Calgary on the factors of distraction, driver impairment and emergency management. The second part illustrates the methodology developed at PATH in order to process the data gathered during TO 4222 for developing and integrating to the model the lane change maneuver. These two efforts will be reconciled in the future in order to integrate the factors investigated by the Calgary team to the control of the lane change maneuver.

1. INTRODUCTION TO A REVIEW OF DISTRACTION, IMPAIRMENT AND EMERGENCY FACTORS

1.1 Project Overview

The purpose of this project is to review the literature on driver distraction, impairment and emergency response that supports the development of the Naturalistic Driver Model. Driver models that are based on high-quality empirical research are more likely to serve as a useful and valid tool to professionals and researchers.

1.2 Project Objectives

The objectives of this review were to:

1. Generate an extensive literature review that identifies the extent that driver distraction and impairment affects reaction time, lateral and longitudinal vehicle control and other variables.

2. Review emergency responses in a variety of situations and determine their implications for lane change, car following and merging.

3. Synthesize the results on reaction time so that a range of values that can be incorporated into a driver model.

1.3 Project Scope

This technical report is structured into sections on driver distraction, driver impairment and emergency response. Within each section, prior literature reviews and recent empirical research is reviewed. Each of these areas has large bodies of literature. A certain proportion of it is methodologically and/or statistically flawed. Limitations of interpretation of the research are presented. Appendices A through C provide extensive details about each of the studies that were selected and reviewed in each area. Values for inclusion in a driver model and conclusions are set forth in the final section.

2. DRIVER DISTRACTION

2.1 Introduction

Concern about the contribution of driver distraction to crashes is not new. In one of the most comprehensive crash investigations ever conducted, Treat (1980) identified inattention and internal distraction as driver error causal factors. These factors are highlighted in Table 1 and represent errors associated with driver distraction. Inattention is defined as "a non-compelled diversion of attention from the driving task", whereas an internal distraction was defined as a "diversion of attention from the driving task that is compelled by an activity or event inside the vehicle" (Treat, 1980, p. 9). For example, Treat (1980) mentioned that during the data collection, from 1972 to 1975, there was an increase in accidents caused, in part, by 8-track and cassette players which represent a distraction within the vehicle. Historically, some activities such as adjusting the radio are well known to be distracting (cf., Goodman et al., 1997).

Table 1. Driver error causal factors in crashes (from Treat, 1980, Figure 4, p. 9).

Causal Factor	**Definite**	**Probable**
Improper Lookout	17.6	23.1
Excessive Speed	7.9	16.9
Inattention	**9.8**	**15.0**
Improper Evasive Action	4.8	13.3
Internal Distraction	**5.7**	**9.0**
Improper Driving Technique	6.0	9.0
Inadequate Defensive Driving Technique	2.4	8.8
False Assumption	4.5	8.3
Improper Manoeuvre	5.0	6.2
Overcompensation	3.3	6.0

The importance of the volumes of analysis produced by Treat et al. (1979) is that they established the relative contribution of the driver, vehicle and environment to crashes. Various factors were classified as "definite" (95% confidence) or "probable" (80% confidence) causes (see Table 1), where a causal factor indicates that the crash would not have occurred had the factor not been present. A primary conclusion was that human errors (70.7%) contributed significantly more to traffic accidents than did environmental (12.4%) and vehicle (4.5%) factors. (In 20% of cases, a definitive causal classification into driver, environment and vehicle could not be made.) The in-depth analyses revealed that human causal factors contributed from 70.7 to 92.6 percent (definite - probable) of crashes. Typically, 90 percent of crash causes are attributed to the driver as driver error without reference to the source.

In a study that emphasized visual distractions, Wierwille and Tijerena (1996) used a key word search of the North Carolina accident database for 1989 and one third of 1992 (also see Goodman et al., 1997). A set of object words was used to search accident narratives for instances where attention was drawn inside the vehicle, outside or in an unspecified manner. To be included in the classification scheme, two criteria were used. First, vision was directed in some way by the object from the forward view and second, visual allocation of attention was the primary cause of the accident. Overall, more cellular phone and fewer CB radio accidents occurred in 1992 than 1989, which is in accord with expected usage patterns. Radio, two-way radio (CB), HVAC, instrument, seat-belt, mirrors, reading in the vehicle, visual occlusion, and interaction with a person or animal formed the primary categories of attention errors. Those objects that required immediate attention, such as waving away a wasp or getting a guinea pig from underneath the accelerator, were particularly distracting.

Using a similar means to describe the degree to which driver distraction contributes to crashes, Stutts et al., (2001) used data from the National Accident Sampling Sytem (NASS) Crashworthiness Data System (CDS) for the years 1995 to 1999. Further, they defined driver distraction as “…when the driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object, or person within or outside the vehicle compels or induces the driver’s shifting attention away from the driving task” (Stutts et al., 2003, pg. 3). They found that at the time of a crash 8.3% of drivers were distracted. The object(s) of distraction are shown in the category listings of Table 2. The re-direction of attention away from driving, to a large variety of objects within and outside of the vehicle, is evident.

Table 2. Driver distraction categories and overall percent (standard errors) for each category (based on Table 3, weighted CDS data, Stutts et al., 2001, pg. 11). To further illustrate the categories, narrative examples from Table 15 (pp. 26-27 of Stutts, et al.) are also included.

Driver Distraction	**Overall (N = 1,420K)**
Outside person, object, or event (e.g., vehicle, police, animal, novel events, people or objects in the road, etc.)	**29.4** (2.4)
Adjusting radio/cassette/CD	**11.4** (3.7)
Other occupant (e.g., talking, yelling, fighting, child, infant)	**10.9** (1.7)
Moving object in vehicle (e.g., insects, animals, objects)	**4.3** (1.6)
Other device/object (e.g., purse, water bottle, etc.)	**2.9** (0.8)
Adjusting vehicle/climate controls	**2.8** (0.6)
Eating/drinking (e.g., burger, tea, coffee, soda, alcohol, etc.)	**1.7** (0.3)
Talking/listening/dialing cell phone (e.g., answer, initiate call)	**1.5** (0.5)
Smoking related (e.g., reaching for, lighting, dropping, etc.)	**0.9** (0.2)
Other distraction (e.g., medical, other inside or outside events or objects, intoxicated, depressed, etc.)	**25.6** (3.1)
Unknown distraction	**8.6** (2.7)

2.2 Distraction from Cellular or Mobile Phones

Although cellular or mobile phones are not the largest contributor to distraction-related crashes (see Table 2, highlighted category), cell phone use by drivers has attracted considerable media attention. In addition, a modest body of research has emerged. Research that addresses the performance impact of cellular phone use while driving provides some insight into the biomechanical, visual and cognitive sources of distraction that other categories may share. A general introduction to this literature is given prior to an in-depth critique of driver performance research.

In general, the safety of using cellular, wireless or mobile telephones while driving has become a concern of individuals, governments, and corporations around the world. In North America, most of us have had to compensate for drivers engrossed in mobile phone conversations who appear to be oblivious to the movement of other vehicles around them. Hand-held mobile phones have been banned in a number of countries world-wide including U.K., Japan and Australia (Goodman et al., 1997), but they have not been in most Canadian provinces (except New Foundland) and U.S. states (except New York). Most state legislatures have debated the merits of legislation aimed at addressing cell phone use while driving (e.g., Sundeen, 2003).

The relative crash risk of a driver was found to increase if cell phones are used while driving (Redelmeier & Tibshirani, 1997), and more so as the frequency of phone use increases (Laberge-Nadeau et al., 2003). Additional epidemiological studies, that are immune to a number of methodological and statistical flaws, are needed to provide convergent evidence about crash risk (cf., Maclure & Mittleman, 1997; Redelmeier & Tibshirani, 2001).

At a driver performance level of analysis, a number of specific tasks; namely, answering a phone (e.g., retrieving it from a purse), dialing, talking and hanging up, have been implicated in crashes (Goodman et al., 1997; Redlmeier & Tibshirani, 1997). Banning hand-held phones while driving is based, in part, on epidemiological (Goodman et al., 1997) and performance (Stein et al., 1987; Zwalen et al., 1988) research that indicates dialing numbers while driving may take the eyes off the road. The crash potential of taking the eyes off the road to answer the phone or dial a number is somewhat self-evident. However, the effect that either hand-held or hands-free phone *conversation* has on driver performance is not as well understood and has been the focus of more recent human factors research activity (Ålm, & Nilsson, 1995; Cooper et al., 2003; Laberge et al., in press; Recarte & Nunes, 2003; Strayer et al., 2003). Cognitive distraction, or mind off the road, is more difficult to explain to legislators and also to adequately operationalize in an experimental context.

An important meta-analysis on conversation effects of cell phones was recently released by Horrey and Wickens (2004). To determine whether conversation affected reaction time (RT) and lane keeping (or tracking) performance, they did a meta-analysis of 16 studies. They examined whether using a cell phone, when compared to driving alone, degraded driving performance, and whether performance decrements were moderated by hands-free or hand-held phone use, conversation versus cognitive tasks (e.g., digit addition), conversation over hands-free versus with a passenger, or simulator versus on-road studies. Their conclusions were:

1. Reaction time tasks showed significant costs for both hands-free and hand-held phones.
2. Lane keeping and tracking measures had small or non-significant effect sizes.
3. Conversation tasks produced higher performance decrements than did experimental cognitive tasks.
4. Conversation task effects with either a passenger or over a cell phone were about the same.
5. Driving simulator and field study effects were roughly similar, with the latter being somewhat more variable.

A second meta-analysis of the studies used by Wickens and Horrey (2004) plus others reconfirmed their conclusions (Scialfa, Caird, Ho & Smiley, in preparation).

2.3 Literature Review Methods and Results

Up to 1997, Goodman et al. (1997) thoroughly reviews individual studies on driving and cell phones. Since 1997, several dozen studies or reasonable quality have been published. Here, studies of reasonable quality from both periods are examined in detail in Appendix A. The studies are presented chronologically. A number of studies are grouped together if they were published by the same authors in the same article, in different issues or different journals. The emphasis of each study, methods, participants, procedures, independent and dependent variables, results and notes are catalogued. The notes column lists study weaknesses, strengths and important considerations. Not all published studies were included in this review. Studies that lacked experimental or statistical detail, or did not include tasks related to cell phone use, or the constellation of tasks that compose driving, were excluded from consideration. A total of 40 separate experimental studies were examined in detail (see Appendix A). Three published studies had multiple experiments (Gugerty et al., 2003; Strayer, Drews & Johnson, 2003; Strayer & Johnson, 2001).

The scope of independent and dependent variables across studies is interesting. The independent variables manipulated or selected by researchers were:

- Study Type (i.e., Part Task, Driving Simulator, Test Track, On Road)
- Task Presence (i.e., With, Without Phone Task)
- Dialing
- Listening
- Conversation (e.g., PASAT, WMST, “Natural Conversation”, Word Games, Spatial and Verbal Tasks, Digit Addition)
- Phone Type (e.g., Hand-Held, Hands-Free)
- Road Geometry/Condition (e.g., Straight, Curved, Intersection, Wet, Dry, Light, Dark, Divided, Undivided, Rural, Urban, Traffic Density, Freeway, Posted Speed Changes)
- Frequent Event (e.g., Lead Vehicle Braking, Red/Green Square Appearance, LED Detection, Signs)
- Surprise Event (e.g., Pedestrian, Intersection Incursion, Obstacle)
- Other Device (e.g., Tune Radio, Read CRT, HUD, Instrument Panel, Manipulate Cassette)
- Participant Characteristics (e.g., Male/Female, Age, Truckers, Experienced/Inexperienced)

The dependent measures taken by researchers were:

- Collisions
- RT (e.g., BRT, RT, CRT, PRT)
- Lateral Control (e.g., Lane position, SDLP, RMS Error, Heading Errror)
- Longitudinal Control (e.g., Mean Speed, Circuit Time, Headway, SD Speed, Stopping Time)
- Detection (e.g., Gap, Signs, p(Miss))
- Eye Movements (e.g., Fixation Duration, Fixation Frequency, Pupil Diameter, Time Off Road, Proportion of Gazes to Mirrors and Speedometer)

- Workload (e.g., HR Variability, NASA-TLX, SWAT)
- Secondary Task Performance (e.g., RT, Errors)

The success of the multitude of manipulations and sensitively of measures chosen is not described here, but the results of individual studies are summarized in Appendix A. Instead, the focus is on a quantitative analysis of reaction time that can be used in driver modeling.

Reaction Time. In an effort to synthesize the average distraction potential of cell phone-related tasks on driving performance, studies that measured reaction time, and variants of it, are graphed in Figure 1 (next page). The best-fit linear regression line was $RT_{DISTRACTED} = 1.1623 \ RT_{NOT\ DISTRACTED} + 0.051$, which accounted for about 94 percent of variance. The grand mean for all studies was 0.25 seconds and the standard deviation of study means was 0.31 seconds. The quarter of a second represents a difference score between driving alone or with the listed tasks. The range of difference scores was from –0.11 to +1.46 seconds. Three of the 30 difference scores indicated a faster reaction time on the presence of a distractor task (Ålm & Nilsson, 1994, hard; Cooper et al., 2003, younger drivers; Strayer & Drews, 2003, with alcohol). These appear below the dotted line of Figure 1. Obviously, 27 difference scores indicated that in the presence of a distractor, drivers took longer to respond to a variety of stimuli and events, than without the distractor present.

An analysis of what response was required for different stimulus is indicative of the variability in methods and measures chosen by researchers. Thus, the context and constraints imposed on a response are important for understanding the range of response values graphed. The bulk of responses fell between 0.5 and 1.5 seconds, but the longer response times require some explanation. For the nearly 4 second value, Lamble et al. (1999) had participants brake when the lead vehicle that was slowing, without their brake lights, while they dialed or added 2-single digit numbers. In the next 2 highest values, Ålm and Nilsson (1995) had younger and older drivers, who were engaged in memory task, brake to a lead vehicle, which was decelerating at 4 m/s^2. BRT in Hancock et al. (1999; 2003) was to the change of a traffic light from green to red while remembering a phone number and comparing the first digit of it to a displayed number, then entering whether it was the same or different. In the series of studies produced by Strayer et al., the primary scenario required participants to brake to a lead vehicle while in the right-hand turn lane of a 4-lane roadway. On the fastest end of the response continuum, Irwin et al. (2000) and Consilio et al. (2003) had participants respond to red brake light, in the absence of a steering task, while they performed a number of secondary tasks.

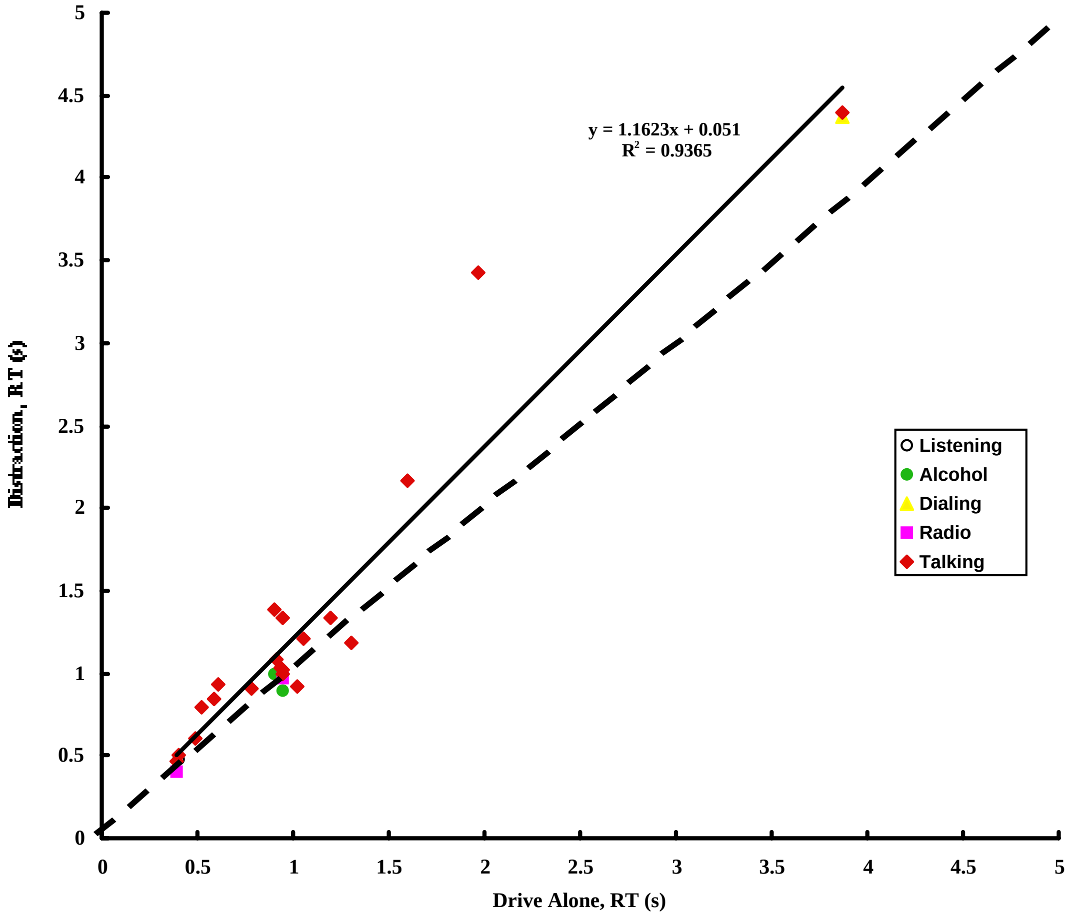

Figure 1. Reaction time to a variety of stimuli and events while driving alone, and while distracted by various tasks including talking, listening, radio tuning, dialing and impaired by alcohol. A total of 16 published studies and 30 mean differences are represented. See text for additional details.

Older Drivers. Older drivers had significantly higher performance decrements than younger participants in a number of studies (Ålm & Nilsson, 1995; Hancock et al., 2003; McKnight & McKnight, 1993; Strayer et al., 2003). The total mean latency for older drivers was 0.51 seconds (SD = 0.64) and 0.17 (SD = 0.29) for younger drivers. Studies that included older drivers as an age group did not include those over the age of 75 (Ålm & Nilsson, 1995, *M* = 67.6; Cooper et al., 2003, *M* = 60.0; Hancock et al., 2003, *M* = 60.2; Strayer et al. 2003b, *M* = 69.5).

2.4 Limitations and Future Research

1. Distraction from cell phones is likely to be heterogeneously distributed over driving context. The measures of mostly brake reaction time (BRT) are reasonable estimates of cell phone task decrements. The selection of context in which to test drivers is over-represented by car following scenarios (Ålm & Nilsson, 1995; Lamble et al., 1999; Strayer et al., 2003a; 2003b) and under-represented by other crash-likely configurations such as intersections (e.g., Hancock et al., 1999; 2003).

2. Although grouped together, talking or conversation included a number of experimental tasks as well as more casual conversation. Naturalistic conversation was found to produce greater performance decrements than experimental tasks (Horrey & Wickens, 2004).

3. The impact of dialing and searching for a phone within the vehicle and holding cell phones to one side of the head with the hand or with the neck, on steering and execution of maneuvres has not been adequately researched. For example, does holding the cell phone with the head tilted restrict the drivers ability to detect threats on the same side?

4. How the intellectual or emotional content of a conversation varies over time and differentially affects driver performance has not been adequately measured or manipulated.

5. The face validity of some secondary tasks that are supposed to be representative of cell phone tasks stretches the human factors principle of task approximation (e.g., Strayer et al., 2001). Tasks that approximate those typically engaged in by drivers are

more likely to estimate the true impact on driving performance. For example, Horrey and Wickens (2004) found that conversations tasks produced higher performance decrements than information processing tasks.

6. The amount of cell phone experience has varied over time by market penetration of sampled participants. For example, Stein et al. (1987) described the difficulty of finding one cell phone user per cell, whereas recent studies report rates of cell phone use as high as 80 percent and of these 75 percent reported driving with them too, which is likely to be susceptible to social desirability effects. Many studies fail to ask or report cell phone experience. None of the studies that were reviewed examined differential performance based on experience using cell phones while driving.

7. The precise coincidence of driving and distraction tasks is usually not adequately described. Despite clear variations in primary and secondary task demands, the assumption was that they were essentially concurrent.

8. Secondary task performance is frequently not collected or analyzed (e.g., Strayer et al., 2003). Analysis of linguistic variation, if the secondary task is conversation-like, requires effort and domain knowledge. LaBerge et al. (in press), for example, examines a number of linquistic variables that may vary as a function of a conversation task such as speech rate, linquistic frequency and word errors. Overall, 14 of the 40 studies reported secondary task performance. How drivers trade-off driving performance, if at all, for other task demands, is a fundamental question that needs to be addressed by each study. The degree to which either drivers or protocol allocate effort to either task is rarely reported.

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3. IMPAIRMENT

3.1 Introduction

While drinking and driving has substantially declined in the last decade, it continues to be the leading cause of road accidents resulting in serious injury or death. In the year 2000, alcohol was involved in approximately 40% of all fatal crashes occurring in the United States (Fatality Analysis Reporting System, 2000). In an effort to reduce the impact, countries have identified certain blood alcohol concentration (BAC) levels when operating a motor vehicle is prohibited (c.f., Pedan et al., 2004). However, BAC limits vary between 0.05 and 0.10% depending on the country. In the Unites States, limits of 0.08 to 0.10 have been adopted, whereas in Canada limits of 0.05 to 0.08 have been implemented, depending on the state or province.

The effects of alcohol on driver performance have a vast corpus of literature on it. However, the quality of the research is highly variable and requires that filters or criteria are applied to separate the wheat from the chaff. The purpose of this review on alcohol impairment is to:

1. Summarize studies that examine the impact of alcohol on driving performance.
2. Contrast studies that have been carried out on road or in driving simulators with laboratory only based tasks.
3. Analyze the impact of BAC on reaction time in laboratory, driving simulation and on road studies.
4. Summarize the relevant reaction time results into a form that can be used for input into driver models.
5. Describe the limitations of existing research and identify gaps in the literature.

3.2 Driver Performance Reviews of Drinking and Driving

In 1968 Greenburg stated, “all of the scientific evidence indicates that above 0.05% alcohol in the blood many individual functions may suffer some impairment, that experimental driving performance depreciates, and that the probability of traffic accident causation increases with rising blood alcohol levels" (p. 262). In the years since, a number of researchers have reviewed research on alcohol and driving-related skills in an effort to quantify when deficits in performance first appear and in what context.

Moskowitz and Fiorentino (2000) reviewed 112 studies published during the years 1981 to 1998 that investigated how driving related skills were affected by low-doses of alcohol. Based on 109 studies, 27% of these studies found that blood alcohol concentrations as low as 0.039% caused decrements in performance. Incorporating all studies with blood alcohol concentrations of less than or equal to 0.079%, the number of studies reporting decrements in performance increased to 92%. The results were highly dependent on the sensitivity of the measures used, with some measures showing impairment at BACs as low as 0.009%. Sixty-one studies examined alcohol effects and either a divided attention, tracking, perception, information processing or reaction time task. The results of divided attention, tracking, perception and information processing and reaction time are highlighted because this is where the 61 of the studies focused.

1. *Divided attention.* Moskowitz and Fiorentino (2000) reviewed 18 studies investigating the effects of alcohol on divided attention using 52 behavioral tests. Thirteen out of 15 studies indicated a decrease in the ability to divide attention was first detected when blood alcohol concentrations of between 0.03-0.10% occurred. When asked to carry out two tasks simultaneously, which commonly involves performing a tracking task in conjunction with a peripheral search task; impairments could be detected at BACs as low as 0.05%. The research on divided attention also suggests that when asked to divide their attention between two tasks, participants tend to focus on one task at the expense of the other (Kerr & Hindmarch, 1998; Moskowitz and Burns, 1990).

2. *Tracking performance.* Eleven of the studies reviewed by Moskowitz and Fiorentino (2000) examined how alcohol affected the ability to perform tracking tasks. When using adaptive tracking, which gets incrementally harder as participants perform better, performance deteriorated at levels as low as 0.018%

BAC. Studies investigating the effect of alcohol on the ability to carry out pursuit tracking found decrements in performance starting at 0.054%. When compensatory tracking was tested decrements in performance varied depending on the study tasks. Four of the studies indicated an impairment in performance for BACs between 0.06 and 0.10%, whereas five of the studies found no impairment when investigating BACs ranging from 0.021 to 0.079%. Finally studies using a critical tracking task found performance deteriorated for BACs between 0.03% and 0.07%.

3. *Perception.* Twelve articles reviewed by Moskowitz and Fiorentino (2000) involved a perception related task, including but not limited to a signal detection task, visual search tasks and a traffic hazard perception task. The authors concluded that most of these tasks failed to show significant impairment below a blood alcohol concentration of 0.08%.

4. *Visual Function*. When they reviewed 19 articles pertaining to visual functions they found that visual acuity was quite resistant to the effects of alcohol, with significant impairment occurring only at a BAC of 0.07% or higher. However, contrast sensitivity and oculomoter control were affected at BACs as low as 0.03%.

5. *Eye Movements*. Moskowitz and Burns (1990) reported that as BAC increases there is the tendency for the eyes to fixate on the central visual field, while making fewer eye movements to the peripheral view. When presented with a complex environment requiring the ability to rapidly process information being presented from a complex source, the interpretation of the information may be negatively affected by the presence of alcohol in the system. The authors remark that when under the influence of alcohol the driver uses fewer sources in the visual field to obtain information about the environment, they take longer to "recognize and respond" to aspects that present vital information about their environment (i.e. street signs) and they focus their attention on aspects occurring

in their central field of vision often to the detriment of peripheral information (p.13).

6. *Reaction time.* Moskowitz and Fiorentino (2000) examined 15 studies and 37 behavioural indicators of choice reaction time and 5 studies and 20 behavioural test results of simple reaction time measures. In the choice reaction time tasks, impairment was first consistently observed at a BAC of 0.06%. The authors concluded that simple reaction time tasks are resilient to alcohol effects due to their simplistic and predictable nature.

7. *Information Processing.* Moskowitz and Burns (1990) indicated that the rate in which people can process information is hindered by the presence of alcohol in the system. As the number of stimuli present and the number of possible responses available to react to stimuli increases, so does the time it takes to make a response.

Kruger grouped tasks used in alcohol impairment studies into two categories (as cited by Holloway, 1995). First, automatic behaviors (i.e. easy tracking, simple reaction time, choice reaction time, etc.) which entail extensive practice and are often improved upon when attention is focused on performing the task in question. Second, controlled behaviors (i.e. difficult tracking, divided attention, information processing tasks etc.) that require performing multiple tasks concurrently. Holloway concluded, after reviewing 48 studies, that on average performance decrements of tasks requiring automatic behaviors were first impaired at BACs of 0.04 to 0.05%. Thirty-five studies investigating tasks classified as controlled behaviors were also reviewed, and these studies indicated that decrements in performance often first appear at a BAC of 0.03% or less. When looking at the research carried out using laboratory-based tasks it becomes apparent that as task complexity increases the probability that the task will be compromised at lower level of alcohol also increases (Kerr & Hindmarch, 1998).

3.3 Drugs and Driving

Illicit and licit drugs can have a detrimental effect on skills related to driving especially when used in conjunction with alcohol. A major impediment to understanding the relationship between drugs and driving behavior is that not all drugs have the same physiological or psychological properties or effects (Moskowitz 1999; 2002; Smiley & Brookhuis, 1987). Properties specific to the drug including the duration of effects, peak levels, when the drug is metabolized or excreted from the body and behavioral implications may differentially affect driving behavior. This is further complicated when several drugs are combined or used with alcohol, which may amplify the effects of the drug and/or the alcohol.

In contrast, alcohol is a distinctive drug that disperses equally throughout the body when water is present (Moskowitz 1999; 2002; Smiley & Brookhuis, 1987). Accurate measures of the blood alcohol concentration in the body at a given time can be obtained through blood, urine, or breath samples. Other drugs rarely share this feature and subsequently may target different parts of the brain, affecting different behaviors from person to person. Many drugs also remain detectable long after they exhibit any behavioral effects, making it difficult to obtain a clear understanding of a dose-response relationship and what specific concentration of the drug will affect driving performance.

While several epidemiological studies have attempted to establish the role drugs play in collisions, the following difficulties have limited widespread testing for drugs (Moskowitz 1999; 2002; Smiley & Brookhuis, 1987):

1. Few studies incorporated a control group making it difficult to compare drug presence in those that had a collision and those that did not based on the same roadway type at similar times of days in similar conditions.

2. Limitations in determining when drugs were taken causes drugs to be classified as either present or absent. When a drug was categorized as being present, it only indicated the driver had used drugs within a given period of time, but failed to determine whether the drug was a contributing factor to the accident.

3. In a large proportion of collisions drugs were combined with alcohol, making it hard to determine whether it was the drug, the alcohol, the combination of both or other factors (i.e. weather, other drivers, distraction, etc.) that contributed to the crash.

Due to these and other limitations, we have limited this review to studies concerning the relationship between alcohol and decrements to driving performance.

3.4 Literature Review Method and Results

Database searches were conducted using the keywords: drinking, driving and alcohol, BAC, intoxication, revealing 1674 article abstracts. Other articles were obtained through backwards referencing. In total 116 articles were retrieved; from this 27 were selected for review and these reviews appear in Appendix B.

The following criteria were used to limit the number of articles:

- The study was available for retrieval.
- The study was published in English.
- The study investigated driving related measures.
- The study was conducted on-road or used a simulator.
- Those that were not carried out using simulators or instrumented vehicles, used measures in which a direct relationship could be derived to indicate driver behavior or perception.
- If the study also investigated drugs, only those studies that had a clearly defined placebo group and an isolated alcohol group were reviewed.

Drivers must be able to successfully carry out a number of inter-related tasks based on information that is constantly changing. The driver is required to seek out, filter, and prioritize information presented to them from “multiple sources” (Moskowitz & Burns, 1990, pg. 14). Based on relevant information, drivers must be able to make accurate judgments concerning when or if a reaction is necessary. Perception, divided attention, tracking and lane position, information processing and reaction time are each fundamental processes involved in the task of driving. Rather than being isolated mechanisms, all of these factors come together when a person undertakes operating a motor vehicle. Accidents occur when the ability to carry out any of these components or to integrate information from multiple sources is broken down. The individual impact of each component will be briefly reviewed here.

1. *Divided attention.* While on route, the driver is continuously confronted with competing demands. A proficient driver is able to monitor their environment and their performance while carrying out multiple tasks at the same time. Based on constantly changing information they must determine what situation requires their immediate attention and anticipate future requirements.

To understand the impact of alcohol on multi-tasking several researchers had participants track or maintain lane position while responding to intermittent stimuli presented in their peripheral or central view. At blood alcohol concentrations of 0.03 and above, reaction time increased, tracking was negatively affected and departure from the road becomes more frequent (Finnigan, Hammersley & Millar, 1985; Loomis & West, 1958; Roehrs et al., 1989). Finnigan et al. (1985) determined that the detrimental effects of alcohol on tracking can persist for up to 130 minutes, while the effect upon reaction time can last up to 70 minutes.

2. *Tracking and lane position.* The ability to avoid an accident is dependent on the drivers ability to monitor and adjust the position of their vehicle in their lane, to other vehicles, roadside markers and other hazards. When alcohol is consumed, participants had greater lane variability and tracking performance than without. They also adopted a position closer to the left edge of the road and made more steering errors. Dott & Mckelvey (1977) indicated high velocities and driver inexperience augment alcohols impact on steering errors. The above decrements in performance were reported at blood alcohol concentrations as low as 0.05% (Arnedt et al., 2001; Brookhuis & De Waard, 1993; Dawson & Reid, 1997; Lenne, Triggs, & Redman, 1999; Louwerens et al., 1987; Rimm et al., 1982, Roehrs et al., 1989; Roehrs et al., 1994).

3. *Eye Movements.* A competent driver continuously scans their surroundings, fixate on vital aspects, and from this derive necessary information that subserves action. At blood alcohol concentrations of 0.07% and higher, the total number of eye movements decreases, the duration in which the eye was closed increases, the

frequency of long to short saccades begins to diminish and fewer fixations are made on objects lying in the peripheral view (Beideman & Stern, 1977; Schroeder, Ewing & Allen, 1974). Buikhuisen and Jongman (1972) determined that while under the influence drivers made fewer saccades and adopted a less flexible search strategy. This resulted in them observing fewer traffic aspects, and also taking a longer period of time to perceive an event. Due to the tendency to focus mainly on the roadway they subsequently ignored aspects occurring on the left and right of the road. Intoxicated drivers often overlooked stationary hazards while retaining their ability to identify moving hazards.

4. *Perception and Pattern Recognition.* Participants with a BAC of 0.025% to 0.05% took longer to indicate that a situation presented in a movie taken from the driver’s perspective was a hazard (West, et al., 1993). At blood alcohol concentrations as low as 0.04% the ability to exhibit detection accuracy and decision caution when performing signal detection task was impaired (Mongrain & Standing, 1989).

5. *Information processing and reaction time.* The driver must filter all of the information that is presented to them in a way that allows them to anticipate and react to future events. At blood alcohol concentrations as low as 0.03% participants took longer to react to red and amber lights or other hazards presented to them (Dennis, 1995; Horne, Gibbons, 1991; Loomis & West, 1958). Brookhuis and DeWaard (1993) indicated that although statistical significance was not reached, at blood alcohol concentration below or equal to 0.05% there was a trend towards a longer perception and response time to speed variation in a lead vehicle.

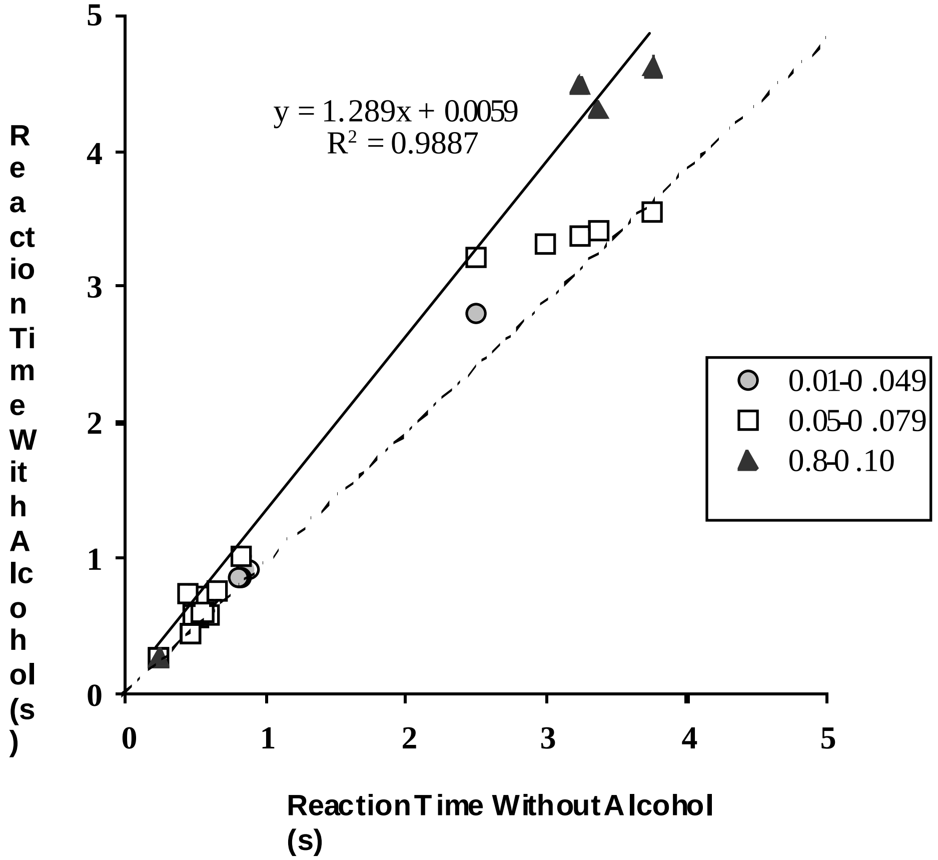

Figure 3. Reaction time with and without alcohol for 3 levels of BAC.

A clear linear relationship between alcohol and reaction time is shown. As BAC increases so does the time it takes for a person to react to a stimulus. The best fitting equation for this relationship was $RT_{ALCHOHOL} = 1.28\ RT_{NO\ ALCOHOL} + 0.0059$. The fit of the equation accounts for 98.87% of variance in the data included in Figure 2. Maylor and Rabbitt (1993) when reviewing the effect of alsohol on RT, carried out a meta-analysis based on 8 studies (that they had conducted). The best fitting equation for their data was $RT_{ALCHOHOL} = 1.12\ RT_{NO\ ALCOHOL} - 17.87$, which accounted for 99.8% of the variance. While the slopes of these equations are similar, the intercept is not. The range restriction imposed by a limited range of BAC used by Maylor and Rabbitt (1993) may account for this difference. A more thorough meta-analysis that encompasses RT data from laboratory-based, driving simulation and on-road studies should be conducted to test the significance of these collective effects.

The research on the ability to maintain and determine a safe velocity is equivocal. Some of the research suggests that participants who consume alcohol were able to maintain a constant speed (Dott, McKelvey, 1977; Kearney & Guppy, 1988; Louwerens et al., 1987; Mongrain & Standing, 1989; West et al., 1993). Others suggest that at blood alcohol concentrations of 0.05 to 0.08%, drivers increased their variance in speed through pressure applied to the gas pedal (Arnedt et al., 2001; Cox et al., 1995; Lenne, Triggs, & Redman, 1999). Sutton (1983) reported that participants who had a blood alcohol concentration of 0.06% drove slower in order to compensate for the effects of alcohol. Participants who consumed four units of alcohol also increased their following distance but experienced difficulty in maintaining a steady headway (Horne & Baubmer, 1991).

The ability to carry out maneuvers such as skid control and t-turns were impaired at BACs as low as 0.03% (Dennis, 1995; Sutton, 1983). Participants who consumed alcohol spent more time off the road and hit more hazards (Arnedt et al., 2001; Flanagan et al., 1983; Loomis & West, 1958). Rimm et al. (1982) found that at 0.064% participants made more breaking errors. Laurell (1977) indicated that at a BAC of 0.052 to 0.06% participants hit more pylons and took longer to stop, experienced difficulty when trying to align their car to a proper position and made more false actions. At higher BACs, drivers may not always be able to determine the correct course of action or to be able to effectively carry out the maneuvers required to avoid a potentially dangerous situation.

3.5 Limitations and Future Research

The interpretation and generalizability of the effects of alcohol on driver performance is limited by a number of experimental, paradigmatic, measurement precision and design limitations. The implications of these factors on future research is also introduced.

1. Many articles have investigated the impact of alcohol on experimental tasks related to driving, yet few have been done so using simulation or instrumented

vehicles on-road. Studies performed with laboratory-based tasks indicate the impact alcohol has on individual task performance. Laboratory studies are assumed to generalize to actual driving. However, driving involves a constellation of overlapping tasks or activities that vary as the traffic context changes. A meta-analysis that contrasts the effect sizes of laboratory, simulation and on-road studies is required to determine if each of these methodological approaches yields similar or different results.

2. A number of studies reviewed did not explain how the task was indicative of driving. Brookhuis, De Waard and Fairclough (2003) list a number of measures that are more likely to indicate driver impairment. These measures included: vehicle control, headway distance, overtaking with oncoming traffic, overtaking at a junction, abrupt lane change, weaving between lanes and excessive speed. The authors suggest that time headway, time-to-collision, speed, lateral position, time-to-line crossing and steering position can be used to determine performance decrements related to alcohol use. The inclusion of these and other variables, using a multivariate approach, may uncover a number of interesting causal relationships among and between variables.

3. Laboratory studies indicate that at even low BAC levels, alcohol may negatively impact task performance related to driving. Many of the studies that investigated the relationship between alcohol and driving ability, failed to explore the effects of more than one level of BAC. Future research needs to define and implement low, moderate and high levels of BAC which would help to determine how performance is affected by different levels of alcohol, when decrements first appear, and how they fade as alcohol is metabolized.

4. A number of investigations did not control for participant consumption of caffeine, food, nicotine, or alcohol prior to entering the study. These foodstuffs can affect the rate at which alcohol is absorbed into the body. A common set of restrictions should be implemented to inform participants of what substances to abstain from and how long they should do so in the hours prior to an experimental

session. Time-of-day effects must also be considered as performance differences have been found between afternoon and evening consumption (Maylor & Rabbitt, 1993).

5. The time allotted for participants to consume and absorb alcohol is highly inconsistent across studies. Greenburg (1968) stated that as the amount of alcohol consumed increased, so did the time the body required to absorb it into the blood stream. When alcohol is consumed over a short period of time the peak alcohol level will be higher and achieved faster than if alcohol consumption is spaced over a longer period of time. The timing of experimental trials relative to the peak and decline is at issue.

6. In a number of the studies reviewed, a large variation in the BAC levels was obtained between participants and over the time-course of the study. Subsequently a reliable calculation should be used to determine the amount of alcohol to administer, such as the weight approximation method. BAC levels should be continuously monitored.

7. A number of investigators failed to report important participant information such as driving history, drinking experience, age, and sex which may lead to performance variability. Large variations in these factors can limit the comparison of decrements across studies. When participant samples are considered, researchers should ask the following questions: What is the normal drinking pattern of those most affected? Is the sample indicative of those involved in accidents where alcohol was a contributing factor? Is the sample representative of the population we are interested in examining (also see Maylor & Rabbitt, 1993)?

8. The vast majority of the studies used a repeated measures design. Using this design, participants take part in all the conditions thereby allowing the researcher to control for individual differences that might influence performance measures (Heiman, 1995). This design allows participant variables to be held constant, reduce error variance and increase “statistical power for detecting differences due

to the influence" of the independent variables (pg. 217). At the same time, repeated exposure, expectancy effects, loss of subjects and order effects can affect performance and confound results. Studies that use repeated-measures designs need to be counterbalanced to minimize the influence of these factors. Many had small sample sizes, with only a few studies employing more than 20 participants. Future research needs to increase the number of participants in order to adequately measure between-subject effects (Maylor & Rabbitt, 1993).

9. Most studies used only men, while a few used only women, fewer still have a balance of men and women. When women and men both participate in a study, it is important that alcohol quantities are adjusted to obtain similar BAC levels. A common, but imperfect method to equalize intake levels between men and women, is to use a smaller dosage for females (e.g., 92% of male dosage).

10. Many of the studies failed to report all of their data, or insignificant results, making it difficult to combine statistical information into a meta-analysis. As a matter of review and publication, studies should make all data available and report both significant and insignificant effects (cf., Maylor & Rabbitt, 1993).

3.6 References

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4. EMERGENCY RESPONSES

4.1 Introduction

Experimental psychology has lent to driving a methodological framework to investigate the speed that a driver can respond to various stimuli. However, like many paradigms, it is not immune to measurement and interpretive difficulties. It is generally accepted that a number of processes may contribute to the time it takes to respond to an event that requires braking or steering. In Figure 3, reaction time is fractionated into the psychological processes that contribute to a response. The various stages of information processing indicated are ranges of values for each stage. Perception-response time (PRT) corresponds to the time required by the following driver to detect, orient, recognize, decide, move, and engage the brake.

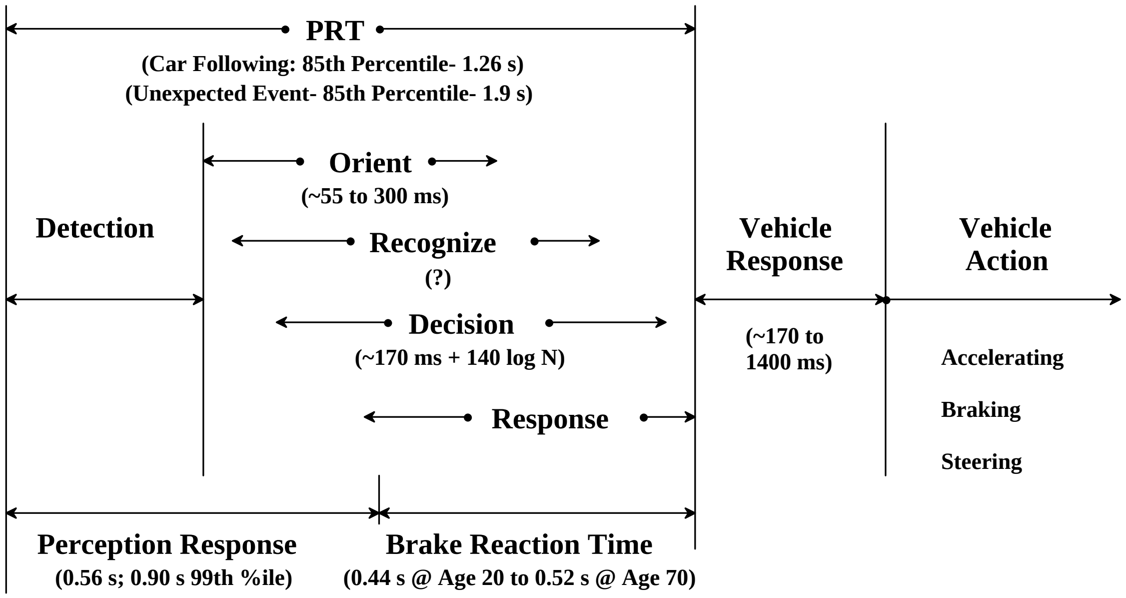

Figure 3. Perception reaction time (PRT), associated stages of processing and data from a number of sources. See text for additional details.

PRT is roughly equivalent to choice RT within experimental psychology. Practically, drivers lift their right foot from the accelerator and place it on the brake. The perception component is measured by the onset of a stimulus or event until the foot leaves the accelerator, whereas brake reaction time is measured from the point the foot leaves the accelerator until it contacts the brake. The capability of driving simulators and instrumented vehicles makes this definition somewhat confining, but it allows for comparison across studies.

Measurement of these two components does not necessarily indicate what information processing is achieved. For example, detection, decision and response elements may be contained in the perceptual component. In practical terms, unless circumstances demand a quick response, initiation of a response may be reflected in easing up on the accelerator. If the foot remains on the accelerator, in this situation, the true RT would not be necessarily be known. A differential application of pressure to the accelerator may reflect one headway regulation strategy that is not captured by the perception-reaction time paradigm. Thus, not all ongoing driver behavior is necessarily captured by PRT measures. Anticipation based on context, learned perceptual cues and other experience is the hallmark of defensive driving.

4.2 Processing Stages

The various processing stages from Figure 3 are further elucidated. The progression from one information processing stage to another implies a number of assumptions about processing, irrespective of driving context. What is not known is the degree of overlap, interaction, and separability of the processing stages specific to the task of driving (e.g., see Wickens & Hollands, 2000, pp. 361–373). For example, which stages are serial or parallel and where facilitation or interference effects exist, is not necessarily amenable to conclusive empirical investigation. For these reasons, attempts to sum individual processes may under- or over- estimate the true response time.

In addition, as the number of decision alternatives increases, overall response time increases linearly with the log of the number of choices. The continuum of choices available to the driver may include; to continue to move forward at the same velocity, to speed-up and pass, to reduce the action on the accelerator, to take the foot off the accelerator, to move it to the brake in preparation to brake, to differentially depress the brake, and perhaps down shift the car if it has a manual transmission. Each of these "decisions" may have differential degrees of automaticity associated with them, which in turn affects the time necessary to execute a response. This is supported by the finding that drivers with more driving experience reacted faster to changes in headway than less experienced drivers (Colbourn, Brown, & Copman, 1978). However, the processing stage that is automated, whether perceptual, decisional or motor, presents an empirical challenge.

Brake Reaction Time (BRT) is a measure of the time taken to move the foot from the accelerator to the brake. BRT is one component of PRT, however, in some papers is synonymous with it (e.g., Taoka, 1982). Care to precisely define measures and place results into a greater referential context is a common problem. The vertical and horizontal planes the foot moves in from the accelerator to the brake, the distance moved, and size of brake pedal affect BRT. A mean BRT value of 0.496 seconds was obtained for 1,461 subjects and varies upward with age as indicated in Figure 3. In simulators, test track, and on-road tests, BRT's and PRT's rise to between three-quarters to two full seconds (Triggs & Harris, 1982; Olson & Farber, 2003) depending on the complexity of the environment, and the disposition of the driver (fatigue, drugs, age). While stimulus complexity and number of decision choices tend to be minimized in laboratory-based studies, within real traffic environments, PR times can vary depending on the driving context (Triggs & Harris, 1982) and necessity for response (Caird & Hancock, 1994). The discrepancies between PRT values from real traffic environments and laboratory based experiments have troubled highway engineers and accident reconstructionists, because they must use these findings for design standards and determination of probable crash causes, respectively.

4.3 PRT Measures of Unexpected Traffic Events

A number of difficulties of real-world and laboratory measures have been noted. One of the primary difficulties that laboratory studies have is they indicate the fastest that a driver may respond. Participants are alerted and poised to respond as quickly as they can, they can do so in about a quarter of a second. Clearly, values of reaction time (RT) and choice reaction time (CRT) in the laboratory represent near optimal conditions, whereas, responses in a traffic environment are more complex. Traffic engineers, however, must base their design criteria on the slowest end of the RT distribution, that is, the slowest responses of the driving population. Differences between laboratory and on-the-road studies have produced discrepancies of 0.5 to a full second (Olson, 1989; Toaka, 1982; Triggs & Harris, 1982). As a result, a number of studies have sought to determine drivers' responses *in situ*, that is, on-the-road. Many of these studies are collated in Appendix C. Critical independent variables include the manipulation of the traffic environment (e.g. Summala, 1981a, 1981b; Triggs & Harris, 1982), sampling of older populations (Lerner, 1993, 1994), and introduction of unexpected events (e.g., Johansson & Rumar, 1971; Olson & Sivak, 1986). Studies included in Appendix C highlight the emphasis of transportation researchers to discover ecologically valid PRT measures.

Perhaps the most striking difference between experimental and real-world traffic events is the increase in PRT values of 0.2 to 0.5 s to being alerted or surprised (see Johansson & Rumar, 1971; Sivak & Olson, 1986). Clearly being ready to respond, contributes to the discrepancy between on-road and laboratory measurement. However, given this known and relatively consistent difference between the two settings, adjustments to data collected in the laboratory may suffice (see Johansson & Rumar, 1971), that is, it makes little sense to discard a corpus of research. On-road experiments or descriptive studies leave many variables uncontrolled and are expensive to conduct. A logical alternative is low-cost driving simulation.

On-road and laboratory reaction times are not normally distributed. Distributions are skewed to the left, that is, towards faster RT values (Olson, 1989; Olson & Farber, 2003; Taoka, 1982, 1989; Triggs & Harris, 1982). Thus, means and standard deviations do not necessarily reflect the upper regions of PRT distributions. In addition, researchers have failed to sample from populations that are functionally slower; namely older drivers. Lerner (1993, 1994) examined stopping sight distance (SSD) and intersection sight distances for older and younger drivers (see Appendix C). His results for the 85th percentile do not exceed the design recommendation of 2.5 and 2.0 s for either traffic geometry respectively.

Another aspect of the design debate questions the generality of various design standards to all roadway scenarios. For example, Triggs and Harris (1982) cite numerous examples and add to the list from their own research scenarios that do not strictly adhere to design recommendations. Thus, design standards may not capture the interactions of traffic, weather, and individual differences such that all drivers are able to respond appropriately.

The fact that a percentile cutoff or criterion was used to describe acceptable regions of a distribution is somewhat troubling though. What should the percentile cutoff be? A portion of the distribution is accepted while a fraction, albeit small, is ignored. Any criterion implies that a small portion of drivers may exceed the criterion. A portion of the debate, surrounding SSD and other design values, centers on the degree that a standard captures the complete response distribution. If a study fails to sample drivers from the right tail of the distribution, the conclusions drawn from the results have little relevancy for scrutinizing a design standard. Only one study reviewed (Lerner, 1993), actively sought older drivers from a range of capabilities and backgrounds. If the proportion of the PRT values found in the right tip of the distribution is extrapolated to the greater driving population, how many people are represented that cannot function within the constraints of current highway design guidelines? It is precisely these questions that have been posed by researchers but remain unanswered.

4.4 An Example

Three experimental routes, each with a critical event, were developed for this study. Each route consisted of a series of intersections where a critical event occurred at one intersection in the series. The locations of the critical events changed in each series of intersections to prevent participants from anticipating an event. Critical events included the sudden appearance of a pedestrian during a right turn (Pedestrian), a last-second yellow light (Yellow Light), and a vehicle violating a red light while the participant had a green light (Vehicle Incursion). At each of the critical event intersections, other traffic, pedestrians and signs were present to increase the complexity of the visual field.

Table 3. PRT means and standard deviations (in seconds) for each event type and age group.

Event type	**Age Group PRTs (s) (SD)**	
	19 to 23	65 to 83
Pedestrian	0.97 (0.46)	1.44 (0.45)
Yellow Light	0.76 (0.18)	1.26 (0.29)
Vehicle Incursion	1.14 (0.31)	1.50 (0.28)

Table 4. Response types to critical events by age group.

Age group	**Response type**	**Event Type (%)**	
		Yellow Light	Vehicle Incursion
Young (19 to 22)	Braked	50	83.3
	Accelerated	50	-
	Braked but struck object	-	8.3
	Neither braked nor accelerated	-	8.3
Older (65 to 83)	Braked	25	41.7
	Accelerated	75	-
	Braked but struck object	-	25
	Neither braked nor accelerated	-	33.3

4.5 Summary

The processes that underlie the perception and response to traffic events were reviewed. Experiments that have used ecologically valid PRT measures are summarized in Appendix C. Primary differences between on-the-road and simulator or laboratory studies involve differences between prepared and unexpected responses to events. Issues that surround the use of PRT values for design standards were discussed. Finally, PRT values fail to capture other forms of adaptive responses to unexpected traffic scenarios. For example, drivers steer to avoid obstacles, brake to increase the time and distance between them and other vehicles, and when necessary brake and steer simultaneously.

5. DISCUSSION AND CONCLUSIONS

5.1 Summary

Driver distraction from technology in vehicles is not unique to mobile telephones (Stutts et al., 2003), although the largest collection research resides in this area. Talking, listening and dialing a cell phone is a relatively smaller category compared to even adjusting the radio/cassette/CD category which is nearly 10 times larger (i.e., if the the distances between numbers are, in fact, absolute) of the overall driver distraction problem (see Table 2).

To address the broad contribution of driver distraction to traffic crashes will require solutions from social policy, epidemiology, human factors, design, and engineering. Legislation and enforcement aimed at the broader problem of driver distraction, rather than just mobile phones, has the potential to reduce more overall crashes.

The distinction between inattention and distraction—especially when classifying a particular crash case with limited information—is not without semantic and operational difficulties. It is difficult to accurately infer that a driver is simply spaced out or intentionally absorbed by an object.

The effect of conversation on driver performance is to delay recognition and response to important traffic events. Hands-free phones produce similar performance decrements as hand-held phones. Legislation has not necessarily considered the impact that conversation has on driver performance.

The average performance of drivers in the presence of a distraction such as a cell phone probably underestimates the behaviour of drivers when not being observed and free to adopt typical habits of their own vehicles (cf., Evans, 2003).

Individual studies do not necessarily consider the overall pattern of research progress in an area and select measures and manipulations that satisfy more localized interest and potential knowledge generation goals.

Drivers who are alcohol impaired and distracted at the same time may additively or multiplicatively increase their crash risk. The reaction times associated with the interaction between these factors has not been investigated. Distraction by alcohol, alcohol by fatigue, and age by distraction are important interactions that require additional research.

5.2 Conclusions

Table 5. Summary of Mean Differences from a Driving Without Condition, Standard Deviation of Study Means, and Number of Studies Used to Calculate Means and SDs.

Condition	**Mean Difference from Driving Without Condition (seconds)**	**Standard Deviation**	**Number of Studies**
All Distraction Tasks	0.25	0.31	16
Talking Hands Free or Hand Held	0.25	0.31	12
Tuning Radio	0.41		2
Talking to Passenger	0.13		2
Younger Drivers	0.17	0.28	4
Older Drivers	0.51	0.64	4
BAC: 0.01 to 0.049	0.12		9
BAC: 0.05 to 0.079	0.13		20
BAC: 0.08 to 0.10	0.61		3

Table 6. Adapted from Peters, G.A., & Peters, B.J. (2002). *Automotive vehicle safety*. New York: Taylor and Francis. (pg. 95) Table 7.1, Human reaction times (highly variable)(seconds).

Activity	**Situation**	**Range**	**Commonly Utilized**	**Study**
Perception (detection and awareness)	Simple Complex	0.5 3.0 to 4.0	1.5	AASHTO (1973)
Reaction (braking)	Simple Complex	0.5 1.0	1.0	AASHTO (1973)
Swerve (avoidance)		0.9 to 2.0	1.5	Johansson & Rumar (1971), Hulbert (1984)
Maneuver (passing)		3.5 to 4.5	4.5	AASHTO (1973)
Preview (scene)	Look ahead Look back	2.0 to 2.5 0.8 to 1.0	2.5	Hulbert (1984), Robinson et al. (1972), AASHTO (1973)
Headway (distance)	60 mph (96 km/h)	1.0	1.0	Robinson et al. (1972)
Search (visual)	Lane change Enter crossroad	0.8 to 1.6 1.1 to 2.6	0.8 2.5	Robinson et al. (1972) Hulbert (1984)
Sight distance (hazard detection up to braking)	Legal assumption 95th percentile	1.6	0.75 2.5	Hulbert (1984) Olson & Sivak (1986)

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Analysis of data from TO 4222 for development of lane change schema

As was described in TO4222, some unexpected difficulties with the extraction of location of front and rear vehicles based on the radar data slow down the data processing and delayed the creation of a full data set that can be analyzed. The data analysis is currently ongoing; therefore, this report will focus on the illustration of the method that will be applied to the full set of data in order to integrate the lane change maneuver as a schema for the model. As exposed in TO 4222, we categorize driver behavior as a function of driver goals and distinguish two main situations:

- Situations where driver has to adjust the behavior primarily as a function of the infrastructure, for example, when entering a highway, the driver has to either merge or stop
- Situations where the driver adjust the behavior as a function of traffic. This is a situation that we usually call cruising.

We consider that driver goals and behavior vary as a function of these situations and therefore use them in order to categorize driver behavior. In this section, we will first discuss these two situations and how they impact lane change and then present examples.

Zone and lane change

We consider that drivers regulate their behavior based on three zones. A relative zone is a zone where the driver is controlling its behavior first as a function of traffic and second as a function of the infrastructure, there is no longitudinal physical constraint to the behavior. The best example of this situation is when a driver is cruising on a highway. An absolute zone is a situation where the driver has to integrate physical constraint to the behavior regulation, such as taking an exit or a merge or negotiating an entrance. A transition zone represents a situation where the driver is shifting from an absolute to a relative zone and vice versa.

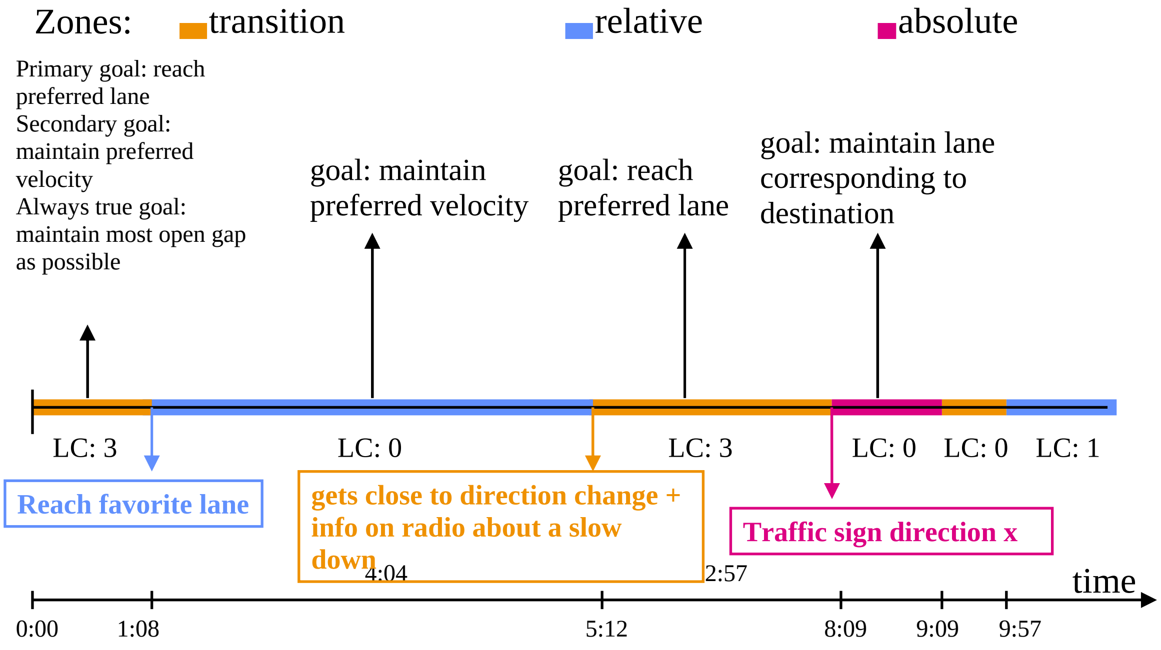

Figure 1: Lane change during one commute

In figure 1 above, we illustrate the notion of zone that we developed during one commute. This shows that the occurrence of lane changes is different based on the zone. In the first transition zone, we observe three lane changes, none in the following zone relative, three again in the next transition zone, none in a zone absolute, none in the next transition and finally one overtaking in the last zone relative. This concept is especially true in California where it is common practice to overtake by the right and where highways are organized in speed lane (right slowest to left fastest) and where a concept of preferred lane can be observed. Based on this example, we assume that drivers' choices are strongly influenced by:

- The direction they follow (absolute)
- Reaching a preferred lane (transition)
- Going onto a faster lane (relative)

We also expect different type of drivers. For example, a driver can have for preference to be in the lane with the less vehicle, and in case of distraction change lane even though he is in what correspond to an absolute zone for this itinerary.

Lane change for merging/exiting highway

Figure 2 below is an illustration of the challenge of identifying which target is the one in front of the subject. In figure 2, we added when the lane change where performed. The subject is on the third lane from the right and changes lane to the right starting at Lane change 1. Traffic is fluid and he has been comfortably regulating with the front vehicle at around 1.5, 1.7 of a time gap. There is a very distant lead once the subject reaches the next available lane. The third target is considered front vehicle slightly before the lane change, it is interesting to notice that he closes fairly fast to target 3. Target 3 took the same exit and went to the right lane while the subject stayed on the left lane of the exit. In this example, we can see that the shortest range was on the lane next to the exit and that the driver balances minimum gap with keeping speed. The next step is to verify if this is a pattern that can be seen throughout the transitions zone once the entire set of data is available.

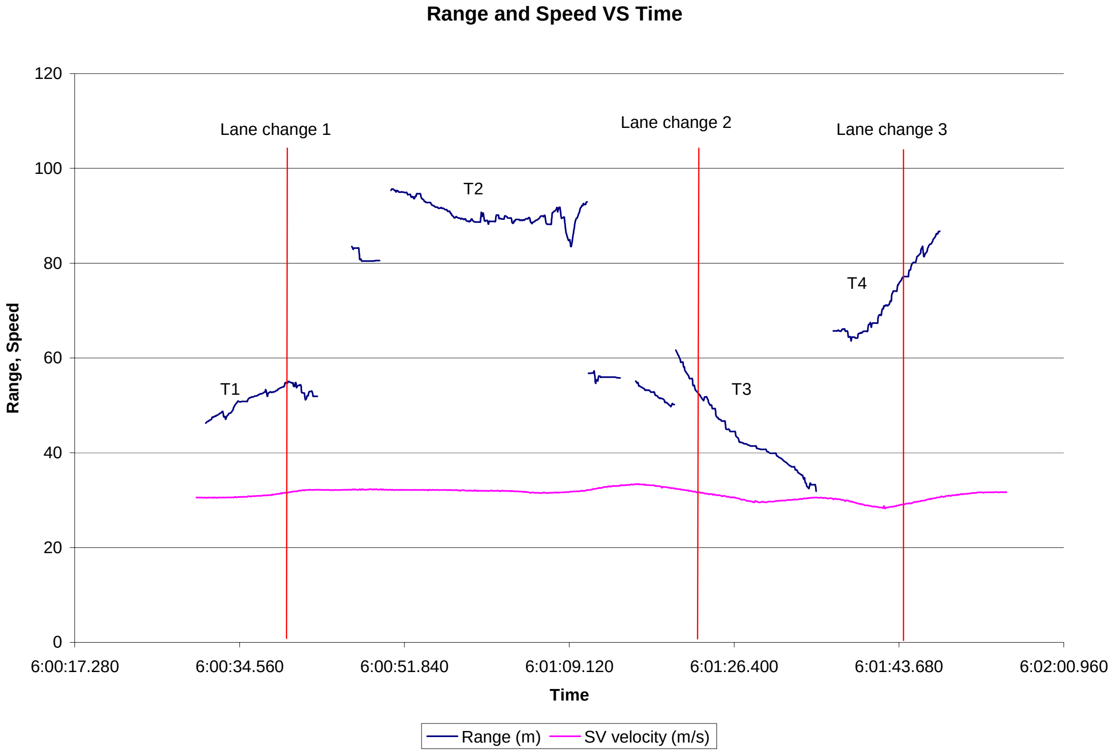

Figure 2: Range and Speed in transition zone

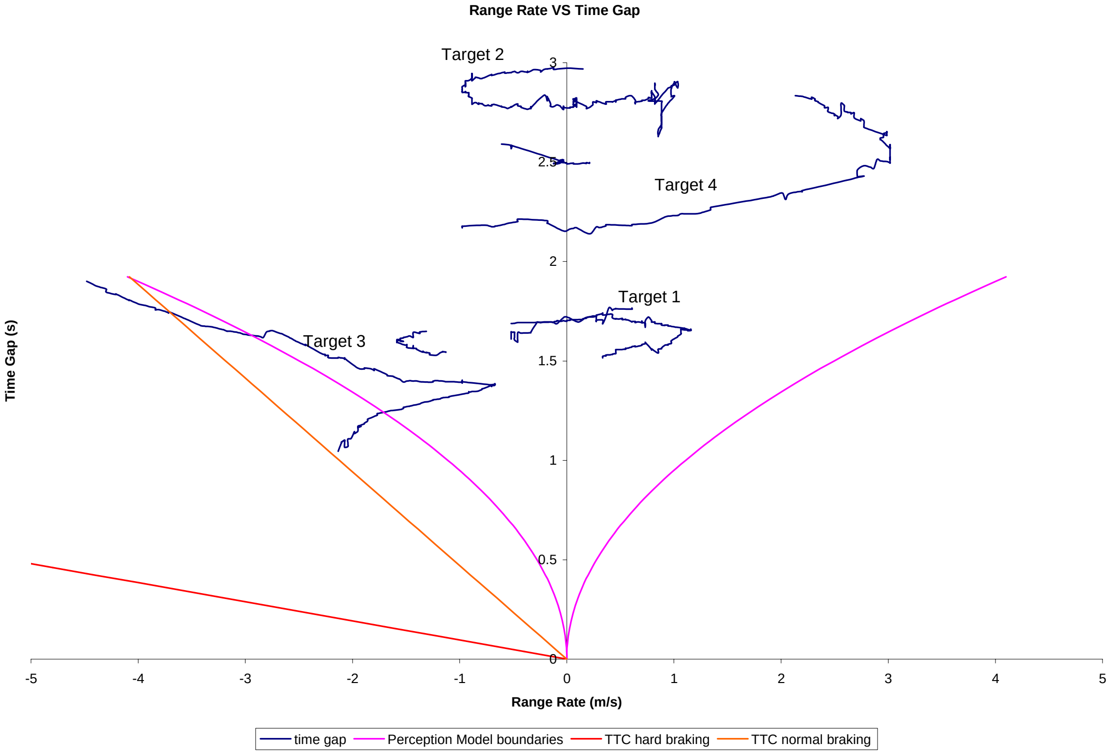

Figure 3: time gap regulation for lane change - zone transition

Overtaking while cruising

The three figures below illustrate two overtaking completed while the driver is in a relative zone. In TO4222, we established that this driver prefers the right lane. The first overtaking is realized when there is no vehicle behind the subject vehicle in the left lane (destination lane for lane change) and the vehicles already present in the left lane in front are at a long range. After the subject vehicle returns to the right lane, there is no lead and the vehicles on the left lane are going slightly slower. When the subject reaches a slower vehicle, he now has some close vehicle in front in the left lane and a vehicle in the rear that caught up with the left platoon. In figure 5 we can see that he has to considerably reduce speed in order to keep a minimum gap with the lead until he left lane clears. We intend to categorize the lane changes based on the presence of obstructing traffic on the destination lane, either front or rear and see the effect the time gap management. Once this is realized, we plan to compare lane changes with obstruction to the one performed in relative and absolute zone.

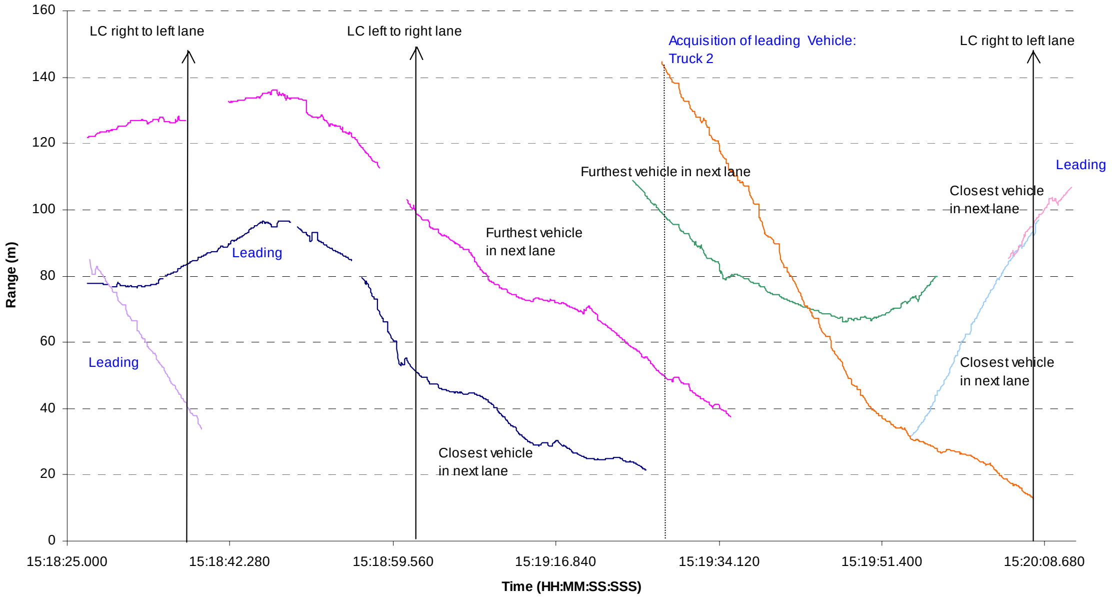

Figure 4: range with lead vehicles during two overtaking in relative zone

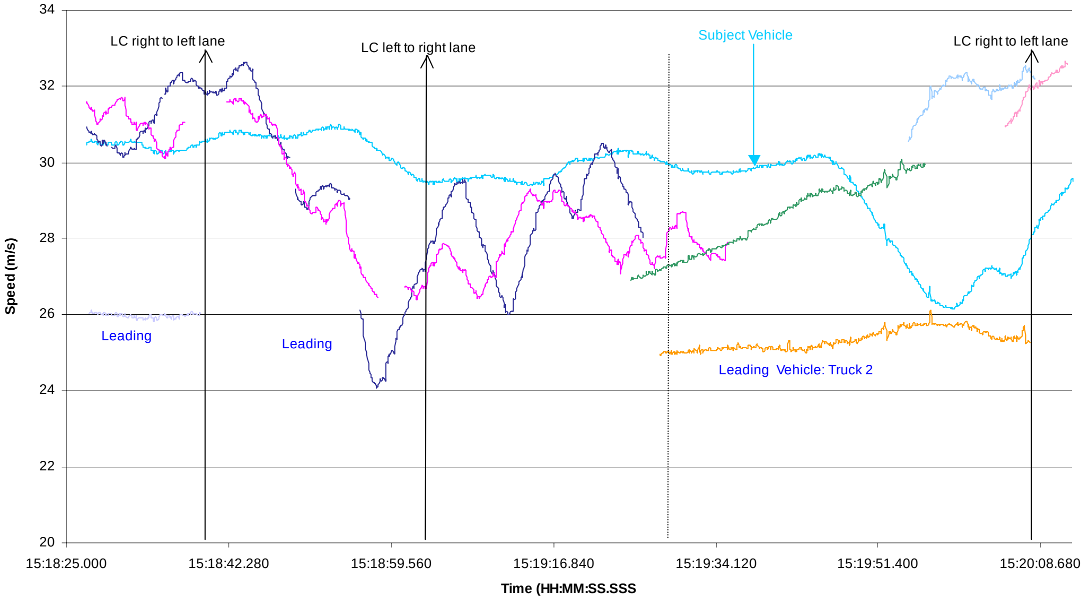

Figure 5: Speed of lead and subject vehicles during two overtaking in relative zone

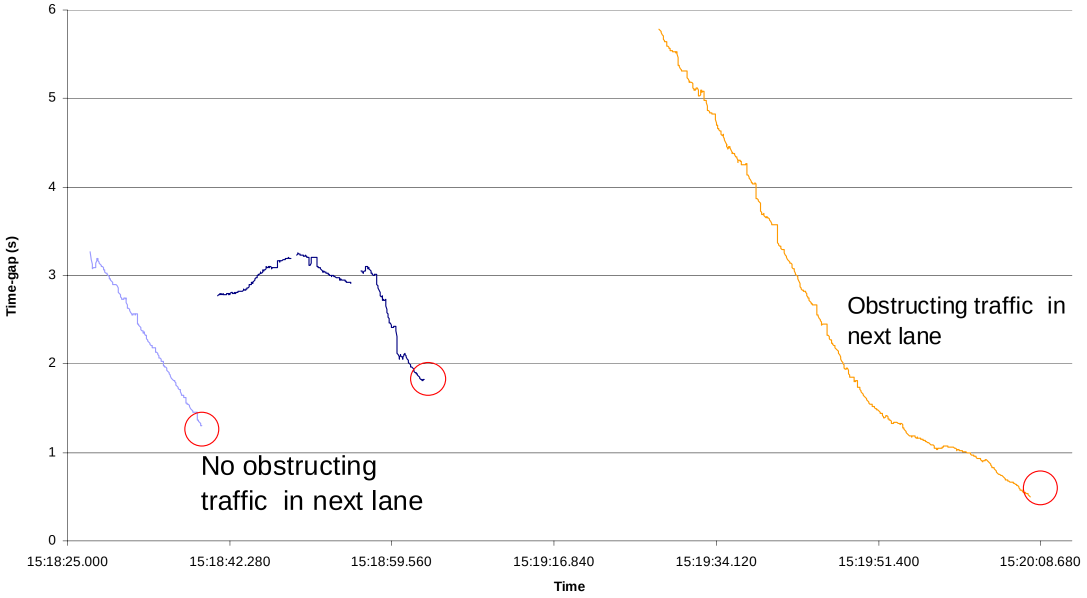

Figure 6: time gap with lead vehicles during two overtaking in relative zone