Title

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Task Order 5500

June 2008

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Abstract

This report documents work conducted in order to support the development of a driver model. This work consisted of (i) a review of driver models for identifying the possibility to add some functionalities to the current model based on existing models and (ii) the data collection and analysis in order to describe the mechanism of distraction and potentially offer some quantification of its effect on drivers' behavior and performance.

Key-words: driver model, driver's distraction, driving simulator study

Executive Summary

This intermediary report on the project of developing a driver cognitive model addresses three main issues:

- the development of the model from a theoretical perspective, in terms of association of cognitive processes into a cognitive architecture
- the implementation choices of the model,
- the gathering of data supporting the development of the model.

In order to address the two first points, the report provides a review of current driver models with the goal of identifying how these models fit the needs for the development of a simulation environment which would allow driver behavior modeling, an Intelligent Transportation System, and observe a simulation of driver behavior using such a system. The challenges for this type of research are highlighted, especially the implicit work needed to develop a simulation environment integrating the necessary level of details for each component of the model, as well as the need to organize research from different fields, which bring different perspectives for describing the same phenomenon with different levels of abstraction.

The gathering of data provides quantitative results describing driver behavior that can be integrated to the model development. An experiment was conducted in order to investigate of the effect of repeated exposure to a non driving device (Ipod) on the driving performance in terms of vehicle control and hazard detection. This study was carried out on a driving simulator at the University of Calgary. The results provide insight regarding the effect of repeated exposure on driving performance, although it could not be established that the effect had reached its plateau. It also provides a new set of data to use for describing glances (duration and numbers) while using such a device, as well as the time required for completing several tasks involving a manipulation of the Ipod. This section also comprises a method for categorizing lane changes with data collected during a previous and related project and illustrates how the lane change decision can be related to the strategic level involved in driving.

List of Acronyms

ACME	A Common Mental Environment
ACT-R	Adaptive Control of Thought--Rational
ADAS	Advanced Driver Assistance System
ANOVA	Analysis Of Variance
AOI	areas of interest
ASL	Applied Science Laboratory
CD	Compact-Disc
FLOWSIM	Fuzzy LOgic based motorWay SIMulation
HF	Human Factors
HMO	Head Mounted Optics
ITS	Intelligent Transportation Systems
IVIS	In-Vehicle Information System
MIXIC	Microscopic model for Simulation of Intelligent Cruise Control
MOU	Memorandum of Understanding
MP3	MPEG Audio Layer III
MUTCD	Manual on Uniform Traffic Control Devices
PATH	Partners for Advanced Transit and Highways
PRT	Perception Reaction Time
RT	Response Time
SDLP	standard deviation of lane position
TCT	Task Completion Time
TNO	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek
TO	Task Order
TRB	Transportation Board Research
UCDS	University of Calgary Driving Simulator
VTTI	Virginia Tech Transportation Institute

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1 Introduction

From a general standpoint, generating driver models can be seen as equivalent to developing a comprehensive description of scientific knowledge about drivers. In making a hierarchy of scientific methods to approach a phenomenon such as the driving activity, a first step is to conduct specific studies to observe and understand the phenomena (e.g. drivers' glances, perception of speed, decision making process, drivers' attention control) and the second is to reconcile the results of the different studies into a comprehensive description, in other words, a model dynamically linking these results of these different studies to reproduce the driving activity. Hence, one of the interests of building driver models is to validate the results of studies looking into specific aspects of driving and identify the aspects that need to be addressed to further the understanding of driving.

From a practical standpoint, the development of the model consists of the following phases:

- identification of a relevant architecture or theoretical framework explaining human information processing,
- identification of relevant models of performance developed about driver behavior, identification of a relevant world simulation model, i.e., description of infrastructures (e.g. highway with entrances, merges, split, intersections, traffic lights), traffic and/or vehicles characteristics, and integration of these framework onto a simulation environment.

Until now, the work conducted at PATH (Partners for Advanced Transit and Highways) on the development of a cognitive driver model (Memorandum of Understanding (MOU) 369, Task Order (TO) 4222 and TO 4238) had identified a relevant architecture, some models of performance and perception, and relied on an in-house simulation tool, SmartAHS, as a simulation environment, this environment came with a vehicle model, sensors and communication models described at a relatively low level of details. As SmartAHS was developed in order to simulate automated highway, its representation of the world corresponds to what an automaton would see, and as such, is quite different from what a human would see. As the world's description is deeply rooted into SmartAHS, we faced the choice of either redeveloping a new world using SHIFT, the environment used for developing SmartAHS, or use other environment.

In order to make this decision, we set to explore several other driver models that are implemented or in the process of being implemented, in order to identify some potential redundancy with our effort. This will represent the first part of this report.

In a second part, we will present the continuation of our work on gathering data about driver behavior, with data collection distraction, research led at the University of Calgary by Professor Caird and his team, and a method of analysis for describing lane change behavior.

2 Review of driver models

This review is mostly a presentation of the models presented and debated at a workshop for the Transportation Board Research (TRB) conference in January 2005 on the theme of driver models, co-organized by D. Cody and T. Gordon[1]. The aim of the workshop was to bring together members from the various disciplines - Vehicle and Traffic Engineering, Psychology, Human Factors (HF), Artificial Intelligence to mention the most common – involving driver models. The definition of the term varies betweens disciplines, and even between different authors within any given discipline. Recent efforts in Applied Psychology and Human factors emphasize the interest of developing models that can be implemented and used in computer simulation, hence representing a possible link between these disciplines, and also a chance to consider the broader picture of driver model within a transportation/traffic system.

The need for developing such models resides in their application. We focus on two types of applications: i) application to safety and driver assistance system design and traffic assessment, and ii) prediction and evaluation of Intelligent Traffic Systems (ITS) on traffic flow. A major difference between these two types of application is mostly a matter of scale, most of the work conducted on the first one is developed at the "driver" level, i.e., the model focus on simulating one given driver, while for the second type of application, the model focus on modeling flows of drivers. This difference of scale leads to differences in requirements and levels of details for each type of models.

This section focuses on the models that were presented and debated during the workshop. Three models fall under the application to safety and driver assistance systems, namely, the "In-Vehicle Information System (IVIS) model", the ACT-R[2] driver model and the "workload in driver modelling". Two other Models, ACME[3] – Driver model, and the Fuzzy LOgic based motorWay SIMulation (FLOWSIM), address the traffic assessment category.

The purpose of IVIS is to provide a proof of concept design tool to assess and compare in-vehicle system concepts, prototypes and products for system designers and to provide insight into potential design improvements. The approach for the development of this model consists of compiling, analyzing and using data from actual empirical research for creating "micro-models" of performance prediction. The model predicts the visual and cognitive resources needed at a basic level. These predictions are made at the subtask level, because subtasks often require different resources, and subtasks can be combined into tasks which can themselves be combined into system assessment. Therefore, the model accounts for a variety of information input, information processing and response output combinations.

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[1] This workshop led to a presentation (Cody and Gordon 2005) at the workshop on "**Modelling Driver Behaviour in Automotive Environments"** organized by Network of Excellence HUMANIST, sponsored by the European Commission, General Directory INFSO, within the 6th Framework Program of R&D.
[2] Adaptive Control of Thought—Rational
[3] A Common Mental Environment

The theoretical endeavour of the ACT-R driver model is to provide a psychologically plausible model of an individual driver and combine cognitive, perceptual and motor dimensions. The approach consists of applying a cognitive architecture, ACT-R associated to a computational framework. The advantage of this approach is the possibility to re-use theories and mechanisms already integrated within the cognitive architecture. This approach currently focuses on highway driving involving moderate traffic. The two current practical applications are: i) the prediction of driver distraction, for which models of typical secondary tasks (e.g. phone dialling) are integrated to the model in order to predict real-world observables measures and ii) the recognition of driver intentions, where many models are run simultaneously, each trying to accomplish a different goal and the method consist of tracking which model best matches the observed data.

The driver modelling effort at TNO aims at evaluating driver behaviour, performance and workload and at providing inputs for traffic flow model, such as MIXIC driver model and Human-Kinetic traffic flow model. This approach focuses on individual driver and vehicle units and is based on experimental research. The framework applied for this modelling effort is the one of “optimal control”, i.e. the use of a linear system theory, where the assumption is that the driver is well trained and well motivated to behave optimally. The model also integrates inherent limitations and constraints. The resulting model is a realistic description of driver behaviour in terms of driver performance, workload and total system performance measures.

The purpose of the ACME driver model it to develop a combined view on car-following and lane-changing as well as evaluate the mental processes needed for driving and describe them. It is a man in the loop simulation of a “car-driver” unit composed of three sub-models: model of human sensors, model for information processing and a model for action execution. The simulation integrates models of the dynamics of the vehicle a driver uses and models of the simulated area.

FLOWSIM development started in 1997 and was initially focused on highway traffic. It now covers all type of roadway. This framework was first used for Advanced Driver Assistance System (ADAS) and infrastructure speed control applications. Recent urban applications include network travel time prediction. It is now the object of an intensive enhancement program with China and has been chosen as the traffic simulation tool for supporting the city of Tianjin transportation planning and management.

2.1 Driver models architecture and implementation

Model architecture can be seen as the blue print of the model. In that sense, a simple description of a model (see Fig. 1) consists of three elements: inputs, information processing or behaviour and outputs. This simple architecture allows generating parameters of factors that can be used to derive measures of effectiveness or evaluation. In this section, we will expose briefly the architectures that were presented for each of the model and refer the reader to the speakers' publications on their model for more thorough description. Also, each model will be described in terms of: simulation scale, along two dimensions: the unit simulated: one driver, groups of drivers or vehicle fleets and the number of unit that can be simulated at once; visualization, in terms of drivers' states, parameters that can be observed in simulation and traffic; and finally the ease of use of their model by other researchers will be addressed.

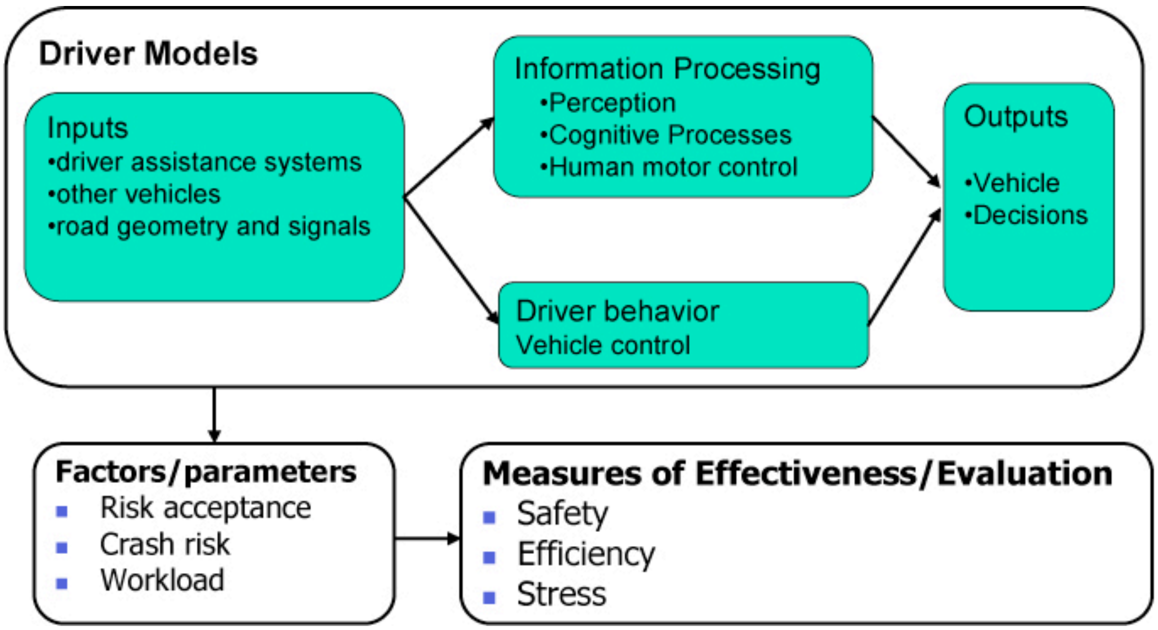

Figure 1: Modular high level representation of driver model structure

The overview of the IVIS demand model is presented in Fig. 2 below. During the workshop, the accent was put on the software development of the tool and how user would manipulate the tool. Hence, the component the most closely related to the information processing from Fig. 1 is in the top block with the list of Driver Resources Involved, i.e.: visual demand, auditory demand, manual demand and speech demand. The assumption of the model is that the driver is a finite capacity has a single channel processor of visual information. He/she can "share" cognitive resources to differing degrees and the resources needed to perform IVIS tasks compete with the resources needed to drive the vehicle. In order to avoid reducing the driving performance to unacceptable levels, only limited resources can be required by IVIS. It is considered that different resource components and/or magnitudes can be used to perform the same task and are required for different tasks. The combination of the demand of these specific components determines the required resources to perform a task. The required resource demand can be used to estimate the potential of a decrement in driving performance. The principle of IVIS is that nominal values for measures are derived that can be modified to match a task or design specification, for example, a subtask modifier is the message length and a task modifier is the roadway complexity.

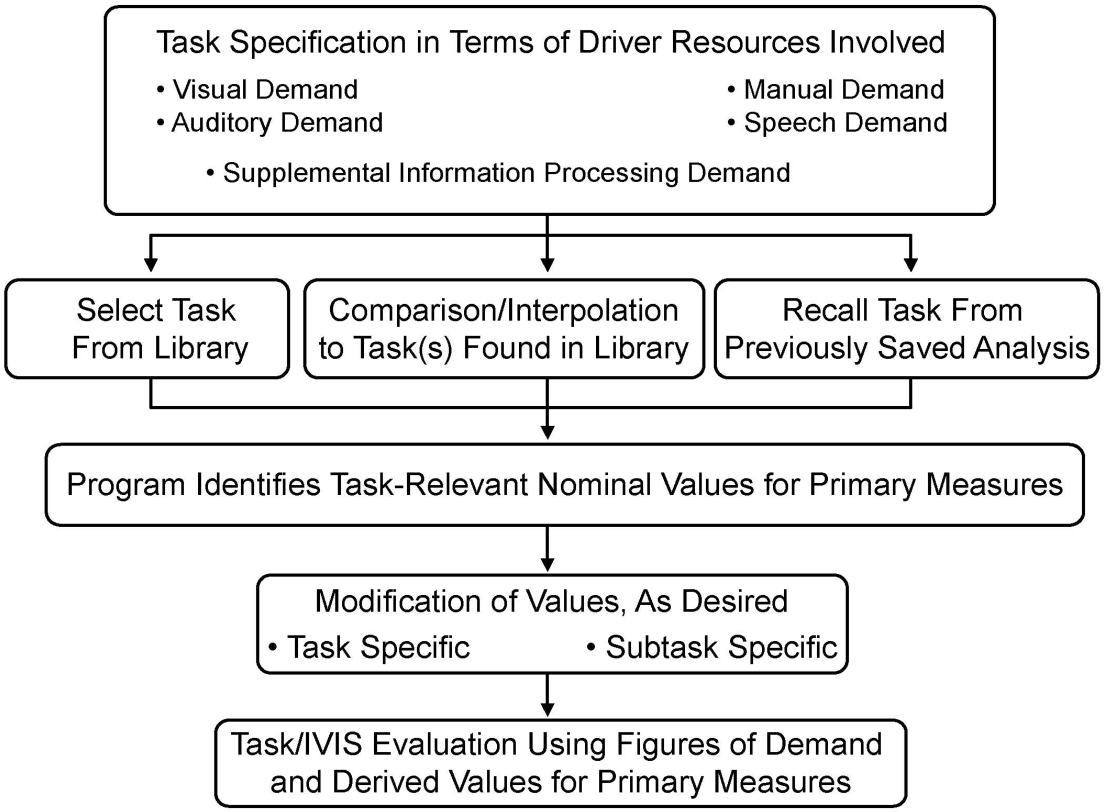

Figure 2: Overview of IVIS Demand Model

The scale of simulation is one driver within one of three age groups. The software allows visualizing the behaviour change outcome and the modifiers that can be selected to adjust. Finally, the source code and a user manual are available from FHWA. The software is still in a proof of concept stage.

Fig. 3 and 4 contain diagrams describing ACT-R and the ACT-R driver model. The diagram on Fig. 3 is an ACT-R architecture and details the overlap between brain structures and information processing steps. Fig. 4 describes the component involved in the ACT-R driver model. The approach used here is that ACT-R provides a framework and specific rules are developed for the driving model. The driver model also integrates cognitive models for other tasks, such as using a cell phone or a navigation system. The current scale of simulation for the ACT-R driver model is focused on one driver in an environment that provides interactions with other vehicles. This effort includes also the modelling of younger versus older drivers. The visualization allows observing driver's eye view and mirror and in a new system currently under development, graphs will provide measure of behaviour. On the ease of use topic, the current version of the ACT-R driver model cannot be used easily by other researchers, but here also, a new version is under development that should allow easier use of the model (Salvucci in press; Salvucci and Lee, 2003).

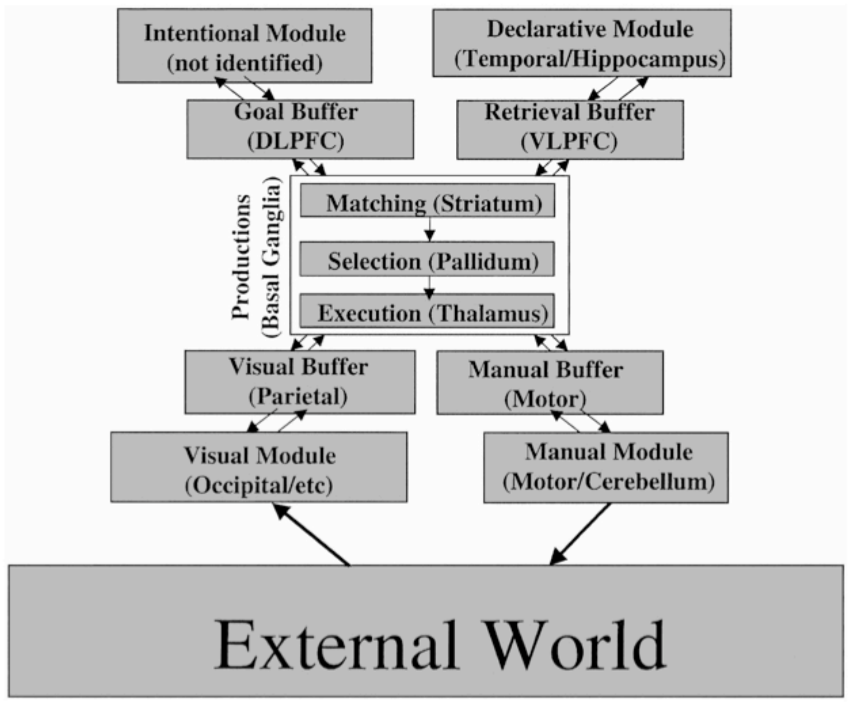

Figure 3: ACT-R architecture

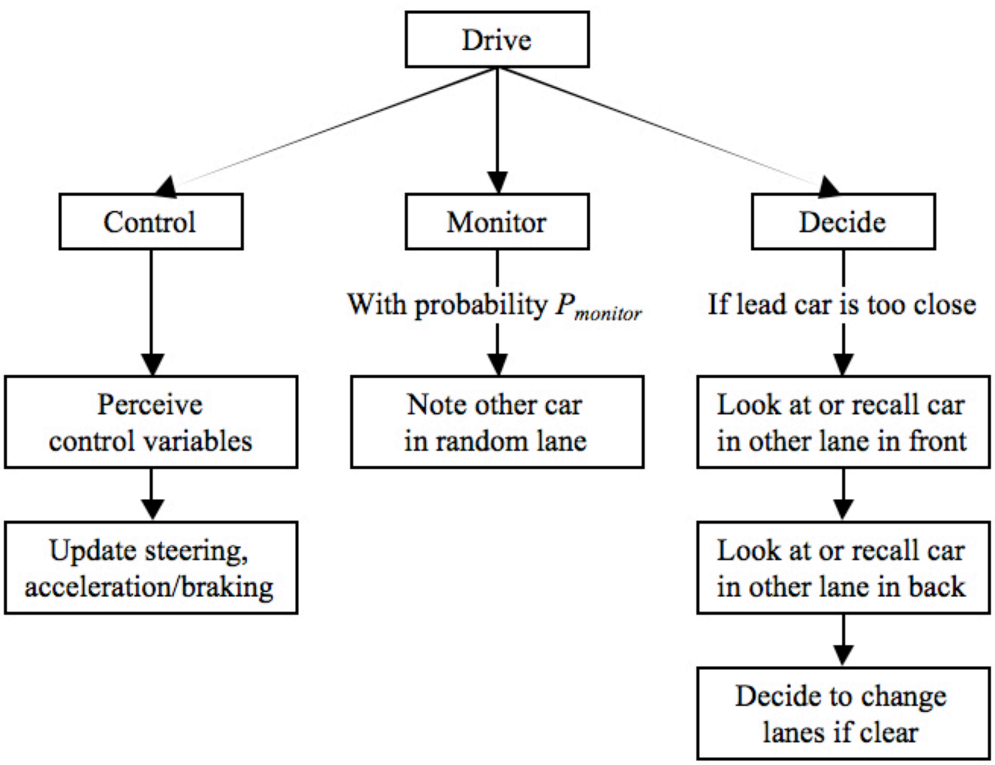

Figure 4: ACT-R driver model representation

In the work on incorporating workload in driver modelling for ITS (Intelligent Transportation Systems) applications, two figures are also used for describing the scope of the model. In Fig. 5, the concept of task covers elements such as lane keeping, car following or speed control, while the behaviour is described as measures of performance and workload. Fig. 6 illustrates a 3x3x3 description of driver behaviour (Theeuwes, 2001) relative to the task hierarchy, task performance and information processing. In dark is the part of the behaviour that is currently modelled, i.e. the control of the vehicle at a skilled based level. For this part of the behaviour, all of the information process is integrated, from perception to action. The presentation of the right hand side figure provoked a lot of interest from the audience, as it is commonly considered that strategic equals knowledge based, manoeuvring equals rule based level and control equals skill based level. The questions that was raised was about how to transition within this 3x3x3 representation, for one driver, for example how can a driver be at the skill based control and then go into the knowledge based level, is it only by learning and can it also be due to other factors? The example of degraded driving conditions was given to explain that even an experience driver could be in the knowledge based levels.

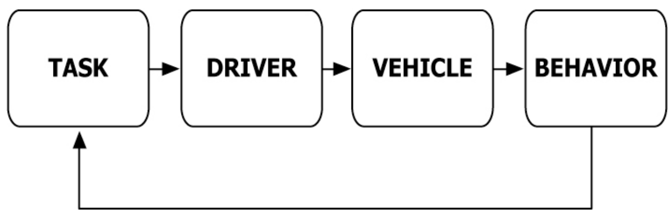

Figure 5: Block diagram driver vehicle system

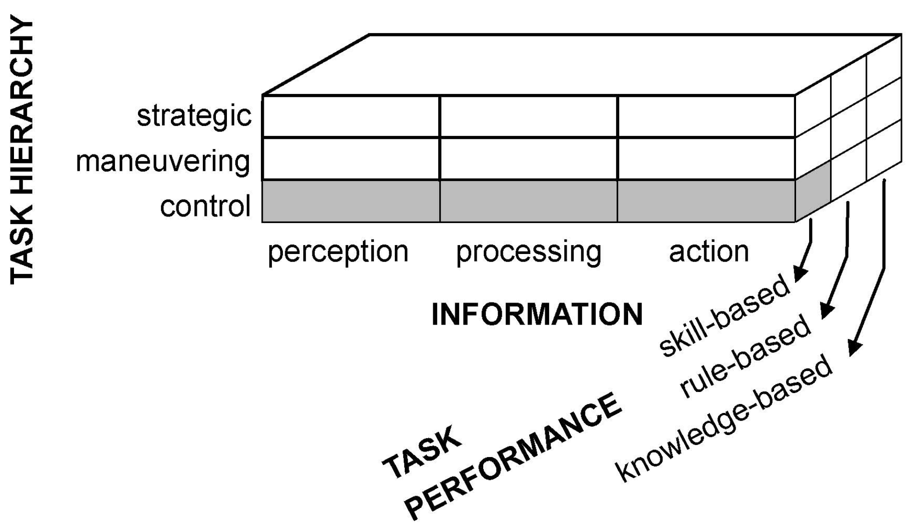

Figure 6: TNO's driver model

Fig.1.

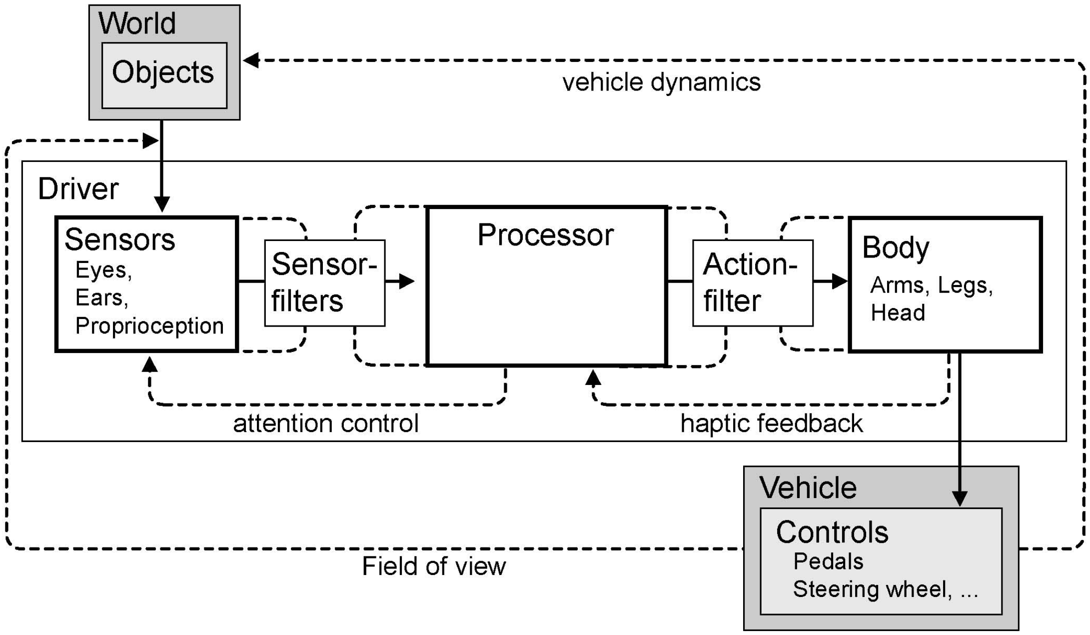

Figure 7: ACME driver model

The ACME driver model is a very modular architecture (Fig. 7) and one of the most driver vehicle infrastructure system oriented among the presentations given. The model can be decomposed in three major substructures: Senses, information processing and actions execution. The senses that are implemented are vision and hearing, the perception of acceleration is used to influence speed decision and the haptic input is not integrated. The information processor consists of an internal world representation storing, a planning instance and an execution instance. In order to carry out the execution of action, the extremities are simulated to move in-vehicles devices to certain position. These devices in turn determine the vehicles dynamic. Regarding the scale of simulation, approximately 20 vehicles can be simulated around an intersection. The simulation step ranges from 10 to 100 ms. The visualization represents the states within the driver's cognition and includes timelines of measures. In order to use the model, it would still require time from the user to become familiar with the model and its implementation.

In Fuzzy Logic, this becomes

Fuzzy Input	**Fuzzy Firing**	**Defuzzification**
x (relative speed) = A′ y (headway divergence) = B′	If x = A and y = B then z = C	Because x = A′ and y = B′ z (acceleration rate) = C′

Figure 8: FLOWSIM driver model

For the FLOWSIM driver model (Brackstone 2000; Wu et al. 2000; Bracstone et al. 1997), the representation of the model (Fig. 8) presents the three basic steps of watching, thinking and responding and how these basic steps can be associated to fuzzy logic. The example used for the description of the model focused on speed and gap control. It showed how the relative speed and distance divergence influence the drivers' action in terms of acceleration rate. This model is the one that allows the most units to be simulated during one simulation, with the possibility of simulating up to a 1000 vehicles. Different behaviours are simulated using distributions. The speaker found little empirical evidence about the existence of groups such as young or old or aggressive drivers and therefore uses the distribution without labels tying the driver/vehicle unit to specific groups. The visualization displays mainly the individual vehicles and the road geometries. In order to use the system, it would be necessary to receive training.

2.2 Models calibration and validation

The model calibration and validation provoked interesting conversation and a notable question from the audience was on the difference between calibration and validation. This question was also treated differently based on the different approaches applied by the speakers. The issue of calibration is interesting in regard of the aspect of the model that is considered. For example, in a model such as ACT-R, the question is not as much calibration of the timing of information processing steps as inferences built on ACT-R on the global time it takes to process information. Therefore, the calibration aspect that was covered during the workshop was based on behaviour that can be identified, observed and measured.

We distinguished two main methods for calibrating models. The first one consists of first using data and results available in the scientific community. The second method consists of running specific data collection. This method can be subdivided in three more categories, depending if the data collected is driver centric (gaze, attention) or vehicle centric (steering, braking, speed control) or traffic centric (lane keeping, range, range rate). The use of the first method brings up the issue of standardization in method to gather and measure data and the definition of parameters that are derived.

On the topic of model validation, there is one main method of comparing the model output with data sets. The variation in the application of the method depends on the type of data used. For instance, the model output can be compared with collected data, with on-going behaviour, or with more general data. The point of comparison of model output with on-going behaviour brought up the very interesting question of the nature of the model output. Is a model providing a trend or should we expect to be able to predict real time behaviour? The question was not answered directly during the workshop, although some researchers present in the audience thought that a prediction of driver behaviour in real time would be a huge achievement for driver models, a lot of doubt about the possibility to reach such a level of accuracy was expressed.

Clearly, there is fundamental issue resulting from the inherently stochastic nature of driving. On the one hand, a 'real-time' model should be capable of making precise and detailed predictions of driver actions as a function of time. On the other hand, real drivers display a range of decisions, driving styles, levels of attention etc., and so should any realistic driving model; resolving these apparently conflicting viewpoints requires a somewhat deeper concept of what is required for model validation. At the very least, validation of real-time models must take account for a wide range of stochastic influences.

Out of the five models that were presented, four are proceeding with more or less extensive validation and one is still in the process of calibration. The IVIS model is at the level of a proof of concept. It is also important to note that the model is used and designed to be used in the industry which can make the feedback to the scientific community a slower process. For a review of the validation carried out at the Virginia Tech Transportation Institute (VTTI), the reader can consult Jackson and Bhise (2002). The approach applied for the ACT-R driver model is the comparison of model and human data sets recorded similarly in terms of real-world measures. The data sets that have been collected so far are highway driving, phone dialling and distraction, radio tuning and distraction and the age effects. Examples of measures are lane change steering profiles, gaze distribution on highway, lateral deviation during phone dialling. The outputs generated by the OCM are time simulation results, performance and workload measures and a workload index. The example of validation provided during the workshop was a comparison of data collected on a driving simulator and of model prediction on the lane keeping task. The agreement between the model and experimental results indicates a useful predictive capability. The ACME model is still on the process of development hence has not been validated yet. The validation of FLOWSIM (Wu et al. 2003) concentrated on the comparison of simulated and measured traffic flows and showed a very satisfying fit.

2.3 *Synthesis of presented models*

We consider that the basic architecture of a simulation involving a driver model is constituted of at least three main components: a driver model, a vehicle model and an infrastructure model. This hierarchy (Fig. 9) below can be further resolved into increasing levels of detail. For example, the driver model can be expanded in more modules or dimensions, such as driving tasks classification (strategic, tactical and operational), psycho-motor dimension, which is constituted of perception, cognition and motor control. For the purpose of the workshop, we defined a number of dimensions for each of these three main components and ask the speakers to rate their models on these dimensions.

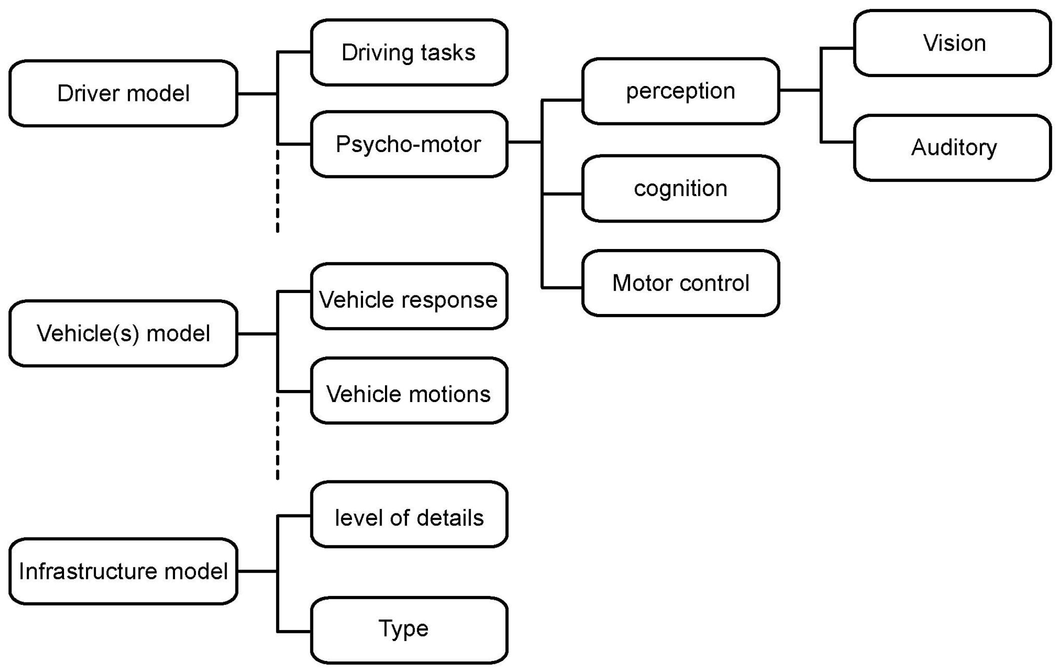

Figure 9: Hierarchy of model components

For the Driver model component, the proposed list of dimensions is the following:
psycho-motor
driving tasks
control level
model capacities
simulated phenomena
simulation control

For the vehicle model component, the dimensions were:
control variables
vehicle motions
vehicle subsystems
vehicle response

Finally, for the infrastructure, the two main categories that were proposed are:
level of details (lane, signalization),
environment type (highway, urban ….).

As the workshop was limited in time, we focused the scope of the description to the three main components and on the details of the psycho-motor dimensions. The rating was as follows:
0: not represented
1: indirectly represented (there is a related parameter)
2: basic inclusion (there is a specific parameter in the model that indicates relevant trends)
3: included (the parameter or state is directly represented via a simple sub-model)
4: modelled (a sub-model represents the process)
5: represented in detail (the process is a core aspect of the model, and be related in some detail to experiments or theories)

This rating was then integrated in a "radar web" graph. Each speaker presented for a graph for each of the three components and the psycho motor level. Then, all of the models ratings were integrated on a same graph as illustrated in Fig. 10 below.

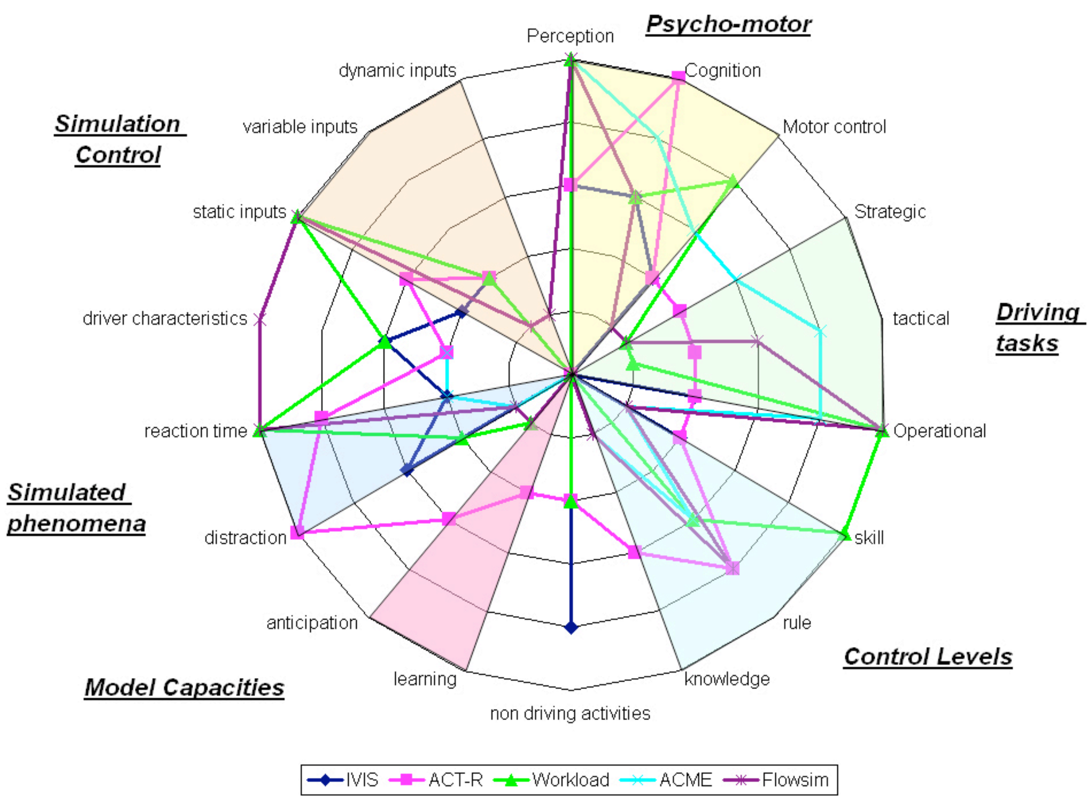

Figure 10: Representation of driver model dimensions

The value of representing the models presented at the workshop via a common graph is to identify synergies and limitations. In order to categorise synergistic dimensions, it was proposed that where a dimension was ranked three or above by at least three models, then a synergy between the three models is possible. In Fig. 10, the dimensions that fit this category are: perception, cognition, operational, rule, reaction and static input. A second category is one where dimensions could clearly be further developed, where at least one model ranks 3 or above. The dimensions in this category are: motor control, strategic, tactical, skill, non driving activities, knowledge, anticipation, distraction and driver characteristics. Another interesting category is when none of the model ranked three or above, with three dimensions: learning, variable and dynamic inputs.

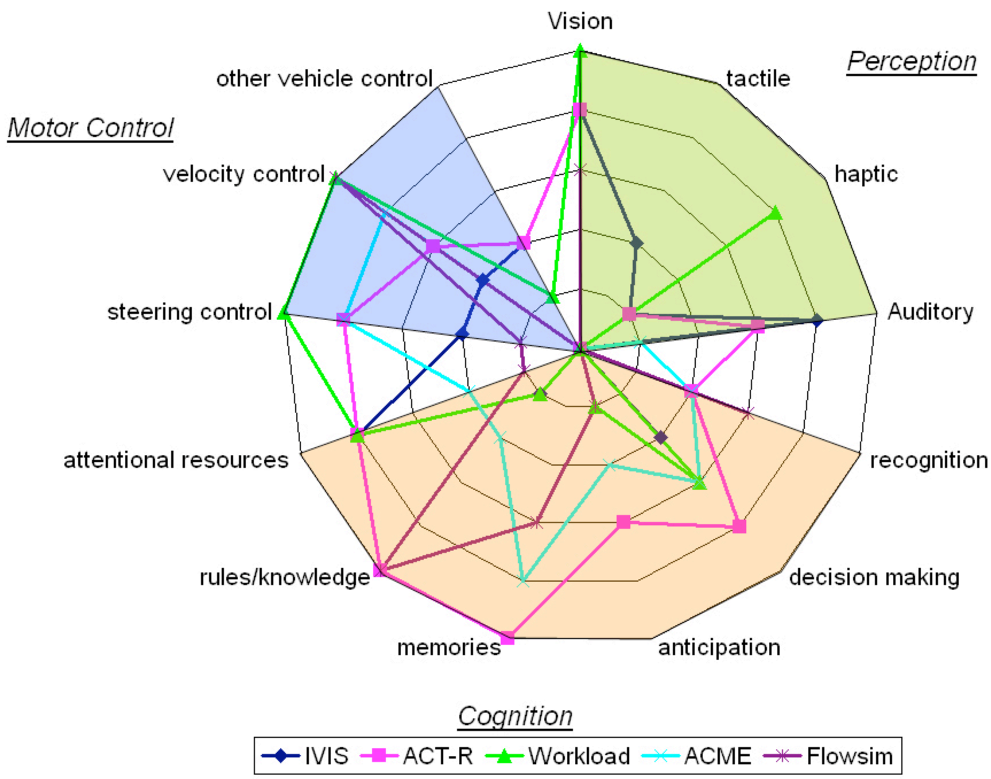

Figure 11: Representation of psycho-motor dimensions

The same method was applied to the description of the psycho-motor dimensions (Fig. 11). Here, the areas for which we can identify synergies are: vision, decision making, memories, steering control and velocity control. The areas to develop are: haptic, auditory, recognition, anticipation, rules/knowledge and attentional resources. Finally, the areas to cover are tactile and other vehicle control.

A question about the high and low ranking dimensions covered by the models is what dictates the choice of what to implement first? Is it because these dimensions are easier to implement than the low ranking or because they are more important to the concept of driver model and its current applications?

3 Data supporting the development of the model

The sets of data presented below illustrate the complementarities between inputs brought by controlled experiment results and behavior observation in naturalistic settings. This section is composed of two main parts. First, a study on drivers' distraction is presented, with a discussion of the metrics that can be extracted from this experiment. Secondly, a description of driver behavior is provided, as well as how these observations can support the development of the driver model.

3.1 Investigation of drivers' distraction

3.1.1 Background

Driver distraction from a variety of in-vehicle sources, including car radios, has been cited since the 1930's as potential crash contributors (Caird & Dewar, in press; Goodman et al.,1997). In particular, the progression of in-vehicle audio entertainment systems has included radio, 8-track, cassette, CD, and now MP3 players, which is the focus of this study. The overwhelming majority of drivers use music systems while driving. Almost 92 percent of drivers were observed, in a naturalistic study by Stutts et al. (2005), using audio/music devices while driving their own vehicles. Interaction with these systems has resulted in crashes. Music system use (i.e., adjusting the radio/cassette/CD) was a contributor to about 11 percent of all distraction crashes compared to 1.7 percent of crashes when using a cell phone (i.e., talking/listening/ dialing) (Stutts et al., 2001). Interacting specifically with CD players was associated with a several fold increase in crash risk (Klauer et al. 2006). Cell phone use while driving, which has been the focus of the majority of research on driver distraction, has been associated with approximately a four-fold increase in crash risk (Laberge–Nadeau et al., 2003; McEvoy et al., 2006; Redelmeier & Tibshirani, 1997).

Relatively few studies have systematically examined the impact of more recent technologies on driver performance, including MP3 players. For example, the effects of email (Jamson et al., 2004; Lee et al., 2001), text messaging (Hosking et al., 2005) and MP3 players (Donmez et al., 2005) on driver performance are less common than studies of cell phones and driving (Caird et al., 2004; Horrey & Wickens, 2006). Performance decrements associated with distractive tasks have been found in significant increases in reaction time during cell phone tasks (Ålm and Nilsson, 1995; Ålm & Nilsson, 1994; Brookhuis et al., 1991; Strayer et al, 2004) and speech based e-mail interactions (Jamson et al, 2004). Lateral vehicle control, as indicated by measures such as lane positioning, and steering, has not consistently been affected by cell phone conversation (Brown et al., 1969;Parkes and Hööijmeijer, 2001) or speech based email (Jamson et. al., 2004). In contrast, text messaging while driving has been found to significantly increase the number of lane excursions observed (Hosking, et al., 2005). Additional research on more recent technologies that are brought into the vehicle by the driver is needed.

To determine the allocation of attention to specific sources within and outside the vehicle requires the use of eye movement measures. Previous research has shown that drivers reduce or constrain the breadth of eye movements in the presence of a distractor (Chisholm et al., 2006; Green, 1999a, Recarte & Nunes, 2000; 2003) such as a cell phone. However, while interacting with a visual secondary device, increased visual sampling into the vehicle is required and many eye movement behaviors. Hoskings et al., (2005) found a 400% increase in eyes off road time while sending or receiving text messages in a simulator. From a practical point of view, eyes off the roadway and the frequency of glances to a device have been used to suggest that eye movements that are too long or too frequent are unsafe (Green & Shah, 2004). When the eyes are focused into the vehicle the probability of missing critical external events while driving increases, thereby increasing the potential for collisions (Klauer et al., 2006).

Most studies that have addressed the impact of in-vehicle tasks have used a cross sectional design. With repeated exposures to a task, a variety of adaptations may occur that are not appreciated in cross sectional designs (Caird & Dewar, in press). For example, task sharing may become more efficient and less likely to produce common errors (e.g., missed detections). By allowing drivers to become accustomed to both the vehicle and the 5 secondary tasks, as well as having sufficient time to acquire multi-tasking skills, a more accurate picture of distraction effects will result. Only one other study has chosen this approach. Shinar et al., (2005) studied cellular telephone distraction over five simulator sessions, to see if multiple sessions improved vehicle control while drivers were engaged in a conversation task. The results of their study indicated that some improvement over sessions occurs, lessening the impact of cell phone conversation on driver performance.

To address this limitation and the lack of empirical studies on MP3 player interaction, the present study examined the effects of iPod interactions over multiple sessions to determine the effects on driver performance to both event-based responses and vehicle control measures. Participant practice over multiple sessions was used to determine whether the driver became more efficient, less error prone, and more aware of the risks associated with using a device. The addition of the distraction task was expected to cause decrements on several measures of driving performance relative to baseline. Specifically, degrading perception response times to critical hazards, increasing the number of collisions observed, more so for the difficult iPod interactions. Whereas the easy iPod interactions would be executed with little trouble and be less distracting than the difficult interactions while driving. The visual complexity of the difficult iPod task was expected to increase the frequency and duration of fixations made into the vehicle to complete the task. Over the sessions participants were expected to become more efficient in their interactions with the iPod, leading to a decrease in task completion time. Some increased efficiency in task sharing was expected over sessions, which will lead to decreases in perception response time and the number of collisions as performance improved. Although improvement equal to or beyond that of the baseline measures was not expected to occur.

3.1.2 Methods

3.1.2.1 Participants

Nineteen participants (10 Females, 9 Males) between 18 and 22 years of age were recruited from the University of Calgary and surrounding community to participate in the study. Participants were asked to volunteer for a preliminary screening session plus six simulator sessions conducted weekly over a two-month period. Remuneration for the sessions increased incrementally throughout the six sessions, each participant received a total of $200.00 ($CAN) for the successful completion all seven sessions. A prize draw was also conducted for those who completed all of the sessions.

All participants were required to hold a valid class 5 driver's license, not be in the graduated licensing program and drive a minimum of 10 000 kilometers per year. All participants were also required to be in good physical and mental health, free of any visual and hearing disorders, and not be under the influence of medications or drugs that would affect their driving or cognitive performance. Demographic information and driving experience information was collected via the Driver Experience Questionnaire. Due to the difficulties of calibrating the eye movement system, those who wore glasses while driving were not permitted to participate in the study. Those with contact lenses were allowed into the study.

Visual testing was performed using a number of tests to ensure participants met the minimum acuity requirements mandated by law for licensure, which is 20/40 acuity in Alberta (Casson & Recette, 2000). Corrected visual acuity was tested for both long and short distances. Specifically, long distance acuity was tested monocularly at 6.1 m (20ft) with the Snellen Visual Acuity eye chart. A short distance acuity test was performed binocularly at a distance of 70 cm with the Landolt C test to determine near distance visual problems that could affect viewing of the iPod device during testing. Contrast sensitivity was measured at 3 m with the Vistech Contrast Sensitivity Chart. The Ishihara Test for Color Blindness (plates no. 3 and 27) was used to test colour vision (Ishihara, 1993). Those who did not meet the minimum requirements for visual acuity (20/40), contrast sensitivity, or had colour vision deficits were not allowed to participate in the study (N = 2). All others were then screened for simulator sickness susceptibility with the Simulator Sickness Questionnaire (Kennedy et al., 1993) and provided information regarding their in-vehicle device use information was collected with the Device Use Questionnaire.

During the initial screening and testing session, participants also did a practice drive, which lasted about 10 minutes, and included stoplights, turns, curves, hills and speed changes. The purpose of the drive was to allow drivers to become familiar with the simulator and to screen out participants who were susceptible to simulator sickness (N = 3).

3.1.3 Apparatus and Materials

3.1.3.1 The University of Calgary Driving Simulator (UCDS)

The following brief description of the UCDS and eye movement system is abridged from Caird et al. (2007). The UCDS is composed of 5 networked Dell computers. A D-Link KVM (Keyboard Video Mouse) switch handles the network communication between the three 3.6 GHz visual channels with a NVIDIA GeForce6600GT graphics cards linked to the three projectors. Each Epson 703C projector displays (1064 x 768 resolution and maximum lumens 1000) onto a WrapAround Clarion Screen by Draper each of which measures 86.5" wide by 65" in height and are approximately 230 cm from the drivers head position. The display refresh rate of the system is 60 Hz. The total projected forward field-of-view from the drivers seated position is 150 degrees.

Traffic environments and experimental scenarios for the driving simulator are developed and run in HyperDrive ™ (v. 1.9.25). Tiles can be selected from an extensive pallet of intersections, freeway sections, streets, and so forth, all of which adhere to the Manual on Uniform Traffic Control Devices (MUTCD). The placement of dynamic objects, such as vehicles and pedestrians, require iterative testing and development using a variety of Tcl/Tk scripts. HyperDrive™ also manages the data collection of a number of driving variables such as perception response time (PRT), velocity variability, minimum headway, and lane positioning.

The purpose of the SimObserver and microphone audio systems is to record participant and experimenter activities and to facilitate communication among the same by integrating multiple visual and auditory inputs into a single display. A system of three black and white "lipstick" cameras (Model No. KPC 500) are mounted inside the Saturn and provide views of the driver's face, hands on the steering wheel, and feet on the brake and accelerator. A fourth colour camera (Panasonic Model No. WV-CP460 with a WVLA 9C3A 9mm Panasonic lens) shows the centre screen of the simulated traffic environment. Data was transferred to a 3.0Ghz Dell XPS 600 Intel Pentium D desktop computer, with two 232GB removable hard drives. Video analysis is then performed using Data Distillery, which is an offline data review and reduction analysis program.

3.1.3.2 ASL-501 Eye Tracking System.

Eye movements were captured during half of the experimental sessions (i.e., sessions 2, 4, and 6) using an Applied Science Laboratory (ASL) 501 eye tracking system. The ASL-501 uses a lightweight, head-mounted, infrared corneal reflection system that allows data collection while head and body movements occur. The illumination beam and image of the eye is reflected off of a headband-mounted monocle located just below the participants' left eye. The illuminator, eye camera, scene camera, and monocle are integrated by the Head Mounted Optics Module or HMO. Eye position is sampled at a rate of 60Hz (Applied Sciences Laboratory, 2001).

3.1.4 Procedure

3.1.4.1 Secondary Tasks

During each session, the participants had the opportunity to interact with the 20GB Apple iPod with a 2.5-inch colour LCD display screen while driving (see Figure 12). The iPod was placed in a holder and mounted on the center console of the Saturn. Music was played through a portable speaker system (i.e., JBL on tour), which was placed on the centre of the dashboard. All iPod task instructions were presented in green writing on the center screen. Both easy and difficult iPod tasks were performed during the sessions. Easy tasks were defined as having one or two steps, represent common tasks (i.e., achieved frequent goals), and took less than five seconds to accomplish when tested alone. These included turning off the iPod, pausing it, and skipping ahead a couple of songs. Difficult tasks required five to seven steps, are used to accomplish more complex or specific tasks, and took about 20 to 30 seconds to complete when tested alone. Difficult interactions required participants to turn on the iPod and find a specific song in the song titles menu. A total of 900 songs were programmed into the iPod for use in the study. The position of selected songs in the song list was varied. Time to complete the task as a function of song list location was recorded. In total three pairs of iPod interactions were performed in each session (3 easy and 3 difficult tasks).

Figure 12: The 20 GB iPod shuffle mounted on the center console in the simulator

3.1.4.2 Experimental Sessions

The first experimental session included training and benchmark testing on the iPod requiring participants to perform both easy and difficult tasks. The benchmark testing was performed at the beginning of both the first and sixth experimental sessions to determine whether changes in secondary task performance occurred as a function of practice over sessions. Time to complete each task was recorded in seconds using a stopwatch. During each of the six experimental sessions, participants drove a total of three drives. The first was a practice drive to familiarize participants each week with the handling characteristics of the simulator. The second and third drives were counterbalanced for presentation and included a drive interacting with the iPod and a baseline drive with no secondary task. Each drive lasted approximately 12 minutes. Participants were scheduled to return each week at the same time of day.

Over the course of the sessions participants were required to respond to four different events during iPod interactions as well as baseline drives (see Figure 13). The first event involved a pedestrian who emerges from between two parked cars and “walks” into the path of the driver on the road. The second event involved a parked vehicle that pulled out from the side of the roadway into the path of the participant. The third event was a lead vehicle traveling 1.5 s (approx. 40 m) in front of the participant. At a specified location, it decelerated at a rate of 8 ms2 for 75 meters before accelerating at a rate of 4 ms2 and resuming its original speed. The first three events required braking, steering, or a combination therein to avoid a collision and have been developed and used previously (Chisholm et al., 2006). The last event required participants to respond to a late yellow light that was initiated 2.69 seconds prior to the intersection stop line (Caird et al., in press). A total of three occurrences of each event type were encountered within each of the iPod easy, difficult iPod, and baseline secondary task conditions. All events were counterbalanced randomly across the six experimental sessions to reduce anticipation on the part of the driver.

Figure 13: Pedestrian event in residential roadways (top left) and pullout event in urban roadways (top right). Lead vehicle braking event (bottom left) and light changing intersection (bottom right)

3.1.4.3 Experimental Drive Descriptions

Eighteen experimental drives were created and used during the six experimental sessions. For the pedestrian and pullout events, 50 km/hr urban or residential roads that had two lanes of traffic were used. Parked cars and commercial buildings lined the urban route and parked cars and single-family homes with attached garages lined the residential routes. The late yellow light event occurred on 70 km/hr suburban roadways with two lanes in each direction, commercial buildings, and parked cars. Last, the lead vehicle braking events occurred on the 100 km/hr six-lane freeways, with three lanes in each direction, separated by a grassy median. The volume of ambient traffic encountered in the scenarios varied depending on road type, and consisted of a mix of cars, trucks, and SUV's.

3.1.5 Results and results discussion

3.1.5.1 Participants

All 19 young drivers successfully completed the seven sessions of the study (i.e., screening + six experimental sessions). A description of the demographic, driving experience and visual acuity test measures for the sample of participants is shown in Table 1. In our sample, males drove further per year than females. Females reported more crashes and more moving violations than the males. Eight males and seven females owned MP3 players. Eight participants (5 males, 3 females) reported owning a model of the Apple iPod player. Six of the 15 owners reported having used their MP3 players while driving (4 males, 2 females).

Table 1: Participants characteristics

	N	Mean Age (SD)	Avg. Km/yr	Crashes	Moving violation	Visual Acuity Left	Visual Acuity Right	Short Distance VA
Male	9	19.33 (0.87)	22,222 (10663)	0.11 (0.33)	0.44 (0.73)	1.0 (0.18)	0.99 (0.20)	0.81 (0.15)
Female	10	19.4 (1.35)	18,040 (12,246)	0.60 (0.70)	0.90 (1.29)	1.13 (0.38)	1.17 (0.50)	0.98 (0.10)
Total	19	19.37 (1.12)	20,021 (11,407)	0.37 (0.60)	0.68 (1.06)	1.07 (0.30)	1.08 (0.39)	0.90 (0.15)

3.1.5.2 Experimental Design

Data were analyzed using an adjusted split plot ANOVA with gender as the between subjects factor; secondary task (iPod easy, iPod difficult, Baseline), event type (pedestrian, lead vehicle braking, pullout vehicle, and light change), and occurrence of the event (3 per condition) were the within-subjects variables. Occurrence is defined as the order of each event type within each secondary task condition. Overall analyses examined the larger design with all sessions, events, and secondary tasks included to determine the pattern of results. Significant interactions were followed-up by examining each event type separately because event type was considered contextually different a priori. Multiple comparisons were made using the Sidak adjustment (Tabachnick & Fidell, 2006).

Analyses of a number of dependent variables are not included here due to manuscript length restrictions, but can be found in Chisholm (2006). These include perception time, response time (i.e., fractionated from PRT), minimum headway distance, velocity change during iPod interactions, standard deviation of lane position (SDLP), standard deviation of velocity, horizontal and vertical gaze variability, and percentage of time to complete a task (i.e., % of total glance duration to a task). The selection of dependent variables for inclusion here was based on the importance of the result, removal of redundant results and completeness of interpretation (i.e., one variable from hazard response, lateral vehicle control, eye movements and secondary task performance). Thus, the results are organized by hazard response (i.e., PRT and collisions), lateral control (SD of steering wheel angle), eye movements (glance frequency, glance duration), and secondary task performance (task completion time). Definitions of each of these dependent variables precede the results of each analysis and can be found in the appendix.

3.1.5.3 Discussion

This study examined the effects of repeated iPod interactions on driver performance to determine if performance decrements decreased with practice. A multi-measure approach was used to understand the range of driver performance dimensions including hazard detection and response, lateral vehicle control, eye movements, and secondary task performance. A comprehensive and convergent view of the effects of distraction on driver performance with practice is evident.

3.1.5.3.1 Hazard Detection

iPod interactions impaired drivers' ability to respond to hazards on the roadway and maintain safe vehicle control. Difficult iPod interactions resulted in decrements to PRT. Over the events and occurrence, PRT increased by 0.13 s or 13% over the baseline when performing the iPod difficult task, depending on event type. Similar to Donmez et al., (2006) who found a 0.33 s increase in perception time to a lead vehicle braking event, during iPod difficult interactions a 0.42 s increase in perception time was found for the first occurrence over that of the baseline for the braking events.

In Strayer and Drews (2004), younger and older drivers response times (RT) to a lead vehicle braking while naturalistically conversing on a cell phone, had an 18 percent increase in braking response time, which is analogous to PRT. Overall, a 16 percent increase was found for braking events in the present study. However, a 26% increase in PRT during iPod difficult interactions over the baseline was found for the first occurrence of the lead vehicle braking events, which would indicate that the difficult iPod task might be more difficult than cell phone conversations. Although similar distraction decrements between these studies are evident, cell phone conversations and iPod interactions differ in a number of important ways. First, a cell phone conversation is mainly cognitively absorbing but does not require deviation of gaze from the roadway. iPod interactions are both cognitively and visually absorbing, requiring attention to be directed away from the roadway and to the interface. Second, when an event occurs, attention must be disengaged from the conversation or returned from the iPod to the roadway. Many would argue that prolonged glances away from the road pose greater crash risk (Dingus et al., 1989; Green, in press). This argument is substantiated in this study by the higher frequency of collisions while interacting with the iPod difficult tasks (53) than during either the iPod easy (34) or the baseline drives (28).

During the easy iPod tasks, no consistent detrimental effects were found. The iPod easy task took very little time to complete (M = 4.3 s). The average time to complete iPod difficult tasks was approximately 30 seconds. This difference in task completion time had varying effects on driving performance. Specifically, the longer iPod difficult tasks exhibited consistent detrimental distraction effects, whereas the detrimental effects of the iPod easy task were brief and transient.

While iPod interactions had a consistent detrimental effect on hazard detection, however, vehicle control findings were less concise. Contrary to previous studies on cell phones (Shinar et al., 2005) and speech-based e-mail (Jamson et al., 2004) that found a significant decrease in steering wheel variation while drivers were engaged in conversations or email, respectively, participants had greater amounts of steering angle variability in the iPod difficult condition than in the baseline. Cell phone conversations and speech based e-mail tasks do not require a driver to physically manipulate something, and thus may not affect steering per se. Therefore, the driver is able to focus on the road and control the vehicle. Completion of the iPod difficult task, however, required attention to be directed into the vehicle and physical manipulations to be made. In particular, iPod interactions required attention to be focused, in a serial fashion, between the iPod and the roadway to accomplish both tasks. On average, it took approximately 15 glances into the vehicle to complete an iPod difficult task.

The largest eye movement effects occurred between the iPod difficult and baseline conditions. Glance durations toward the roadway during the iPod difficult task were 0.24 s shorter. Furthermore, average duration of glances into the vehicle during iPod difficult tasks was 1.35 s compared to 0.56 s in the baseline. This increase in glance duration is similar to previous findings (Green & Shah, 2004). Normal glances into the vehicle are shorter in duration than glances towards the center of the road, 0.41 s and 0.73 s, respectively (Olson et al., 1989). Attention to in-vehicle tasks caused other sources of driving information to be dropped from scan patterns (i.e. off road objects and rearview mirror). A serial sampling between in-vehicle task and immediate forward roadway resulted (Wierwille, 1993).

The demands of the driving environment also affected eye movements. In the higher velocity freeway environment (100 km/h), more time was spent looking at the road, less time off road, and slightly less time into the vehicle. In-vehicle task and roadway demands pull and push attention, and thus the eyes, while driving. If the eyes are inside the vehicle when a critical event occurs, the success of responding adequately is less likely. The added eye movement demands into the vehicle thus would degrade hazard detection to the degree that eyes are in the vehicle at event onset (also see Horrey et al., 2006).

3.1.5.3.2 Prolonged Experience

The purpose of a multiple-session approach was to determine if repeated practice of the secondary task while driving in demanding contexts would lessen the detrimental impact of the distraction on driver performance. Shinar et al. (2005) found repeated trials of conversation with a cell phone lessened the performance decrement on the vehicle control measures of speed maintenance, lane positioning, and steering wheel deviations. The present study used an event-based paradigm to examine the impact of a common MP3 player on distraction. However, Shinar et al. (2005) did not measure this variable sufficiently in their study. Thus, their conclusions that cell phones are less of a safety threat than previously thought may be premature.

Single session or cross-sectional studies may not provide an accurate picture of cumulative distraction effects. Results are likely to differ with driver practice. These results do not support the inference or conclusion that single session testing is invalid because with practice, the detrimental impact goes away. Although decreases in PRT were found with practice, performance with the iPod difficult task never achieved the same level of performance as in the baseline condition. Even after additional practice, drivers were still unable to improve their dual-task performance to a safe level. Multiple session studies do provide information with which to determine the practical effects of in-vehicle distractions over time compared to single session designs. While there are costs and benefits with each method, the added array of information provided over several months of testing sheds light on certain aspects of driver behavior such as adaptation.

3.1.5.3.3 Adaptation

With the addition of secondary tasks, drivers were hypothesized to adapt to the additional task demands by changing their behavior. Decreasing speed, task shedding, and stopping at the light change intersections, would indicate changes in behavior that compensate for these demands (Caird & Dewar, in press). One adaptive strategy would be to shed the secondary task in favor of the primary task of driving. There were no consistent differences in the time that it took to complete the secondary task that would seem to indicate adaptation. Instead, results indicate that participants actually sped up the movement time to the device itself from session 1 to session 6, and did not put off beginning the task as an adaptive behavior. A consistent adaptive behavior that was found involved stopping at the light changing intersections. Drivers often used the light change as an opportunity to complete iPod tasks safely and were more likely to stop at the light to do so.

Multiple session studies provide information with which to determine the practical effects of in-vehicle distractions over time compared to single session cross-sectional designs. This study found improvements in performance over the six sessions. However, it did not determine the extent of experience over which participants might continue to improve. Presumably a plateau or "ceiling" would be reached and no additional practice would affect performance. The learning curve associated with dual-task distraction performance is an area of potential future research.

3.1.5.3.4 Distraction Metrics

Two metrics have been suggested to quantify distraction potential of in-vehicle devices. These include number of glances to the device and task completion time (Blanco et al., 2005; Green, 1999b). Tasks that require more than nine glances or greater than 15 seconds to complete statically represent problematic tasks that should not be engaged while the vehicle is in motion. As can be seen in Figure 17, using the suggested metrics of task completion time and glance frequency, the iPod easy tasks (green) conform to the suggested criteria of less than nine glances and 15 second completion time. However, the iPod difficult results (red) took, on average, 15 glances and 35 seconds to complete the task. The iPod difficult interactions are clearly not appropriate to perform while the vehicle is in motion.

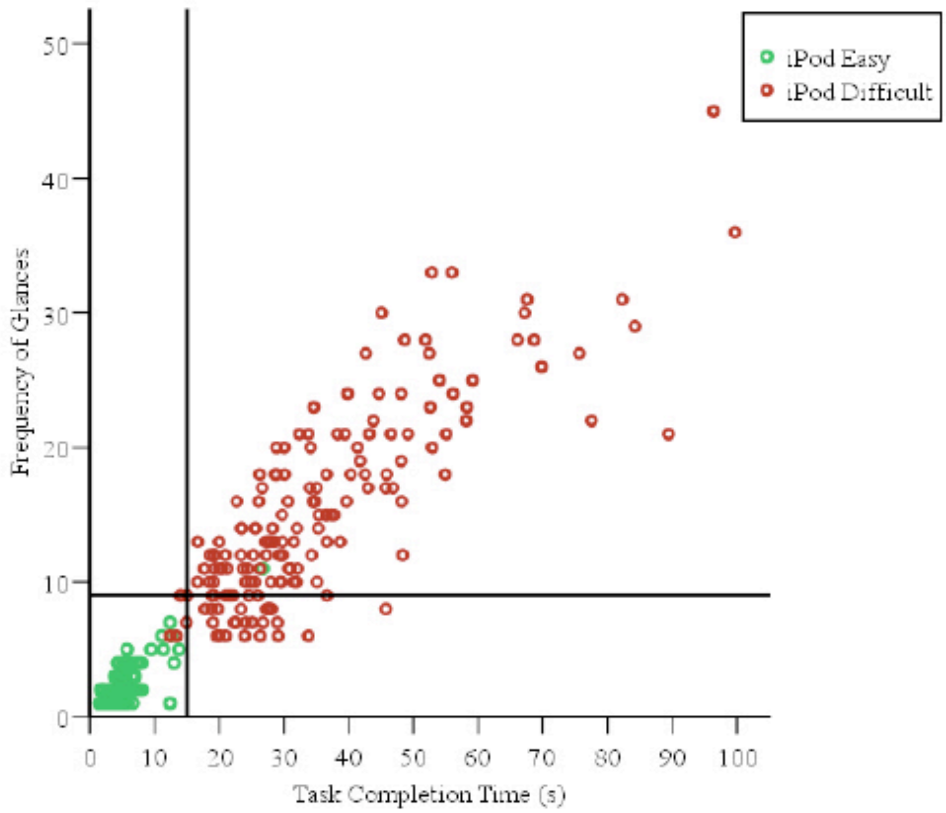

Figure 14: Frequency of glances and task completion time in seconds

3.2 *Naturalistic driving data mining*

Data collected during TO 4222 have been mined in order to quantify the triggers for lane changing due to reaching a slower vehicle. As a reminder, lane changes can be categorized based on the reason why they occur. For example, we distinguish between a lane change for entering the highway, a lane change for reaching a preferred lane, and a lane change for overtaking a slower vehicle. The work presented below is the description of the method. This method requires a fair amount of automatic processing that no PATH personal was available to conduct; therefore, all of the work presented below is the result of manual processing. This process is extremely time consuming and therefore could not be applied to the entire set of data available.

Data was collected for a two weeks period and the data analysis was carried out on commutes, where most of the variability in terms of driver behavior can be attributed to traffic. One of the assumptions of the model is that when commuting, drivers will first try to reach a preferred lane, then stay on this lane and start to move back toward the exit lane. These two moments, reaching the preferred lane and moving toward the exit, are called transition zone.

The figure below illustrates a method for assessing the length of the transition zone. The observed commute was composed of three distinct “cruising” zones, in other words, once the driver entered the highway, he would “cruise” for several miles, then exit on a highway split and reenter onto another highway. In this figure, all of the lane changes observed on the second section of cruising have been plotted. The x axis indicates the direction of the lane change, i.e. if it was toward the right or the left. The y axis indicates the position where the lane change was initiated on that section.

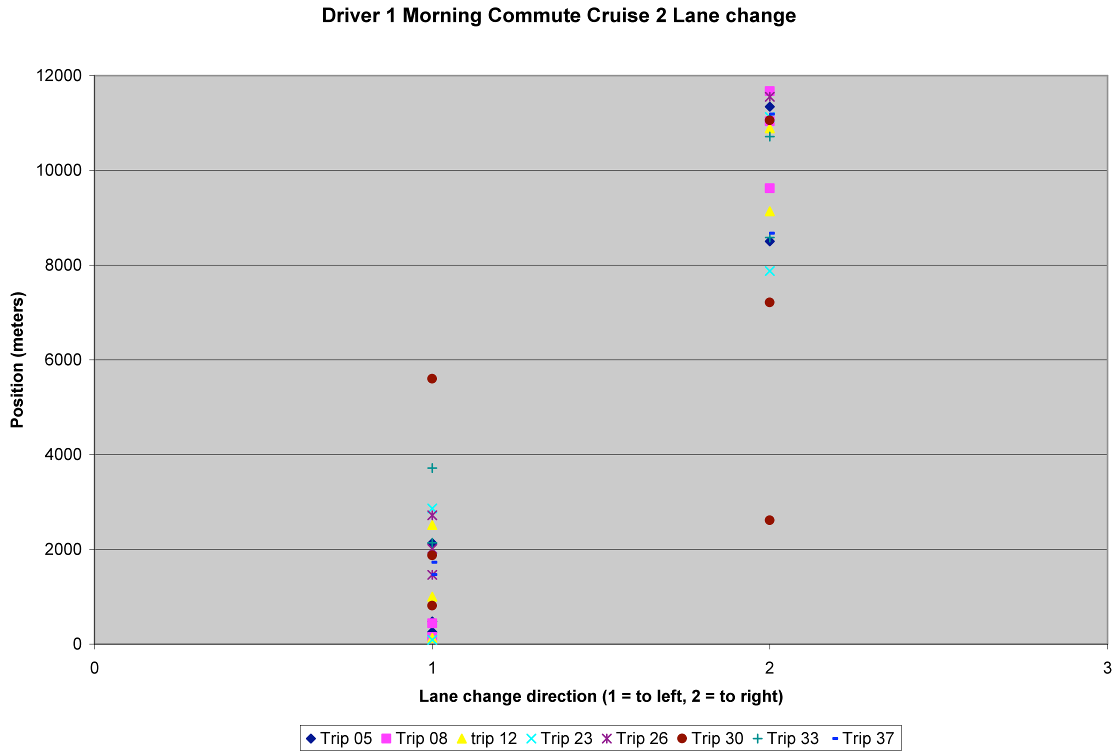

Figure 15: Lane changes categorization

From this graph, we can deduce that the driver's preferred lane was two lane to the left of the entrance and that he reached this lane within 2,5 km of the entrance, at the exception of Trip 30 where the driver returned to the right lane shortly after reaching his preferred lane and stayed there for a quarter of the commute. This difference is likely explained by the difference of traffic, with a denser traffic during that commute. It also shows that the driver prepares its exit in two phases, within 2 to 4 km from the exit, the driver start moving toward the exit lane. Within 1 km from the exit, he is taking the lane that will exit. This information can be used in order to determine when to trigger lane changes that correspond to the driver's plan on how to follow his itinerary and in order to give an order of criticality to the behavior.

The figure below illustrates the successive following events during one commute. For each of the following event, the end/beginning cause of the event is specified. For example, the first two following events are not considered following, as the driver reached slower vehicles and then changed lane, these two lane changes are also part of the transition when the driver intends to reach his preferred lane for this section. Another data contained in this graph is the brake activation, which occurred three times.

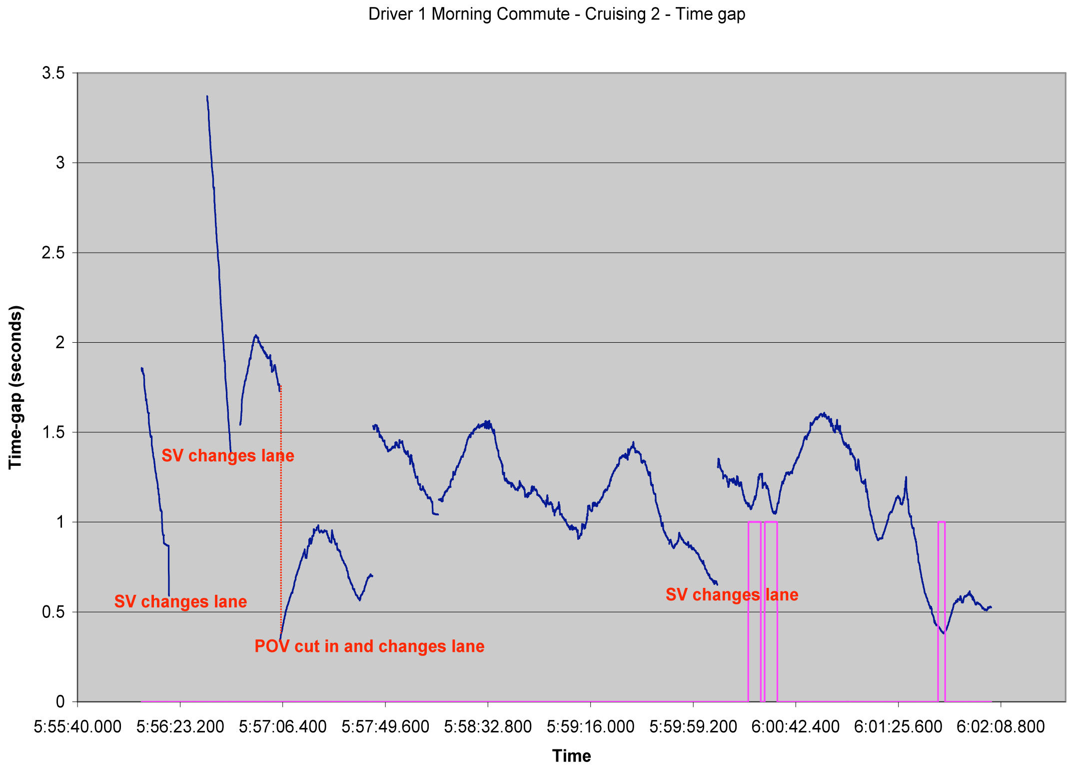

Figure 16: following events during one cruising section

Two interesting events are observable. The first one is when another vehicle (Principal Other Vehicle) cuts in front of the driver as a very short time-gap, initially measured at less than 0.4 seconds, which is a very short distance, however, the driver does not brake. On the other hand, when following the last target, the driver initiated a braking three times. This difference in behavior can be better understood when looking also at the vehicle speed, such as displayed in the figure below.

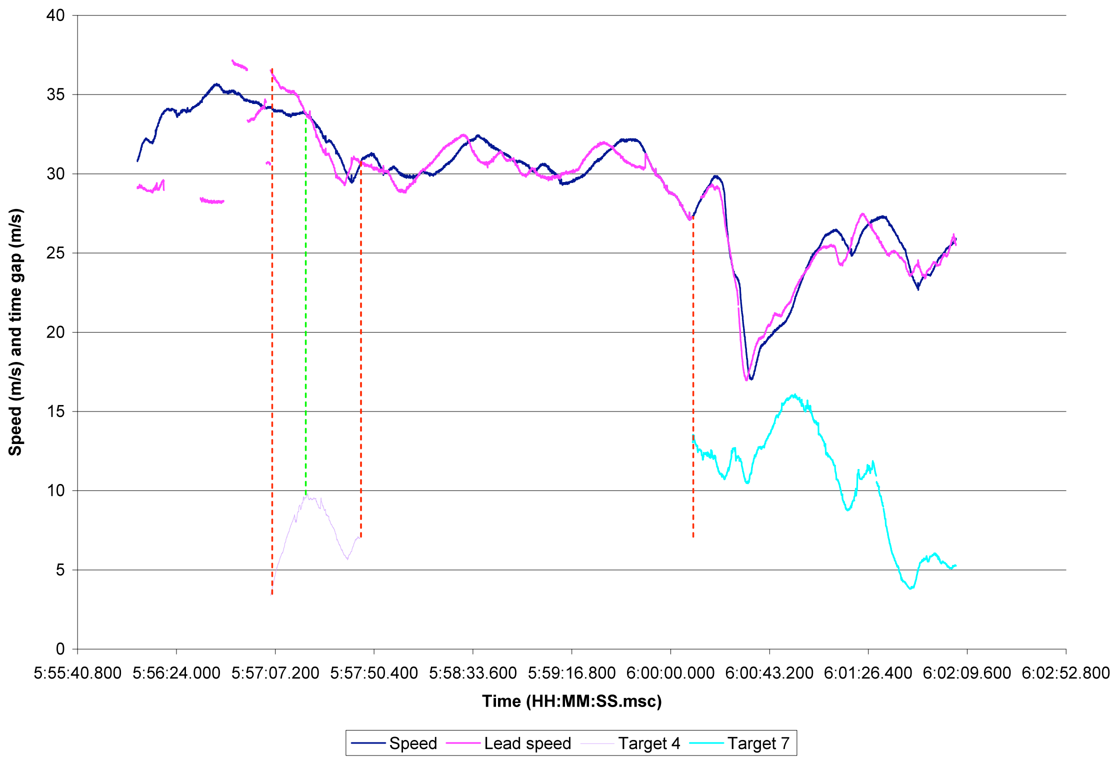

Figure 17: Vehicles speed and time gap

In this figure, the vehicles speed and time-gap between the host vehicle driven by our participants and the lead vehicle are plotted against time. The time gap is multiplied by 10 to accommodate the speed scale. For the cut-in event, the lead vehicle speed was superior to the one of the host vehicle, while for the second event, the speed of both vehicles was similar, and they both considerably reduced speed at one point, therefore the first two braking are a response to the lead vehicle braking.

Another way to look at this data is to plot the relative velocity on the x axis and the time gap on the y axis, as done on the figure below. The traces of each of the targets from the figure above have been plotted below.

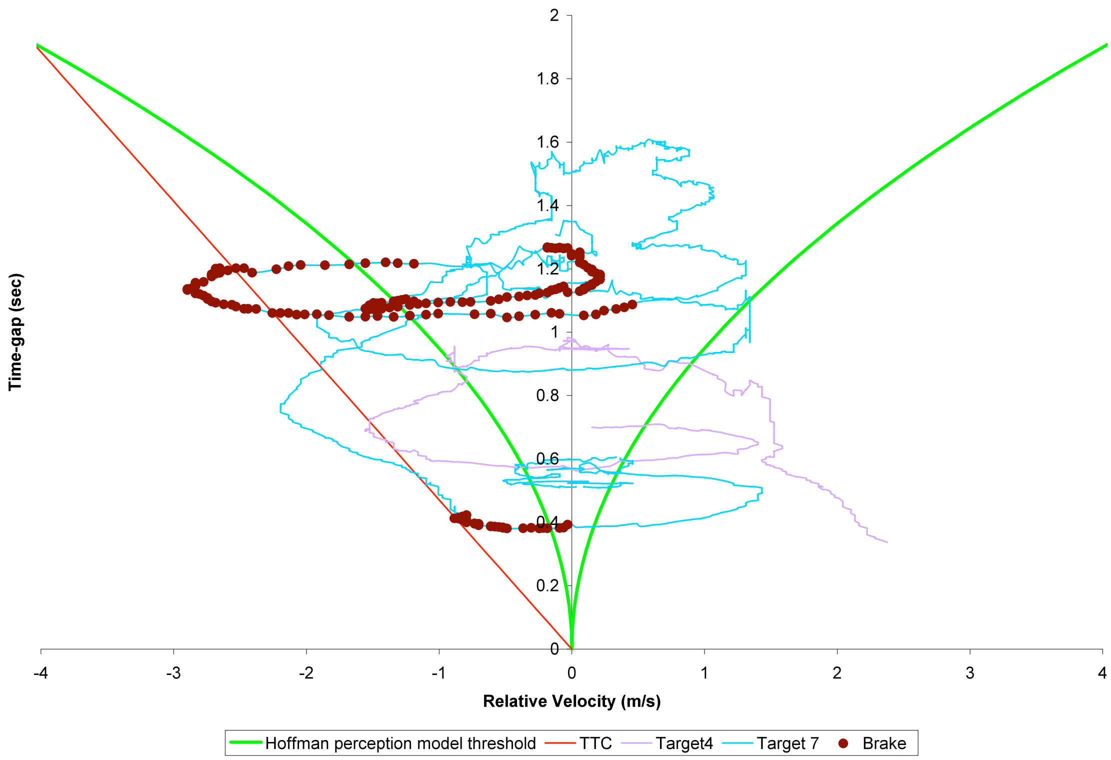

Figure 18: Gap regulation

We propose that in order to quantify the different triggers intervening during car following behavior, we should categorize the following events based on where they happen during the commute, how they are initiated (catch up with a slower lead or a vehicle from the adjacent lane pulls in front) and ended (lead vehicle changes lane, open the gaps, or host vehicle changes lane). For each of these categories, distribution can be made and then used in simulation. The biggest challenge with the dataset at hand is the difficulties with which to treat the radar traces, as the current sensor provide up to 7 different target, and that the interpretation of the target location depends of the road geometry, and distinguish between the lead vehicle and the other vehicles on the adjacent lanes. In other words, if the target ahead is on a curve, it becomes difficult to determine which vehicle is the lead vehicle. This type of processing is made for systems such as adaptive cruise control, but they require years of algorithm fine tuning and incur a cost that is beyond the scope of such a project. In future data collection, this problem could be overcome with the use of a different sensor on the host vehicle, and possibly the use of digital map providing information about the road geometry.

4 Conclusion

The goal of this report was to present two key steps on the development of a cognitive driver model that can be implemented and interfaced with micro traffic simulation tools:

- The support of the development of a cognitive architecture or the adoption of an existing architecture supporting the development of the driver model.
- The gathering of data supporting the development of the model in terms of calibration of parameters and a specific description of behavior.

Regarding the adoption of a cognitive architecture for a driver model, we first depicted several different meanings the term “driver model” can have among the various research fields involving driver models, and to the different approaches it produces for implementation. We then presented several models implemented in different simulation environments, and synthesized how these models cover the different components needed for such a simulation; for example, which type of behaviors they allow to generate. Our review concludes that most of the existing models are difficult to apply in our context. The main difficulty results from the state of development of these models. All of these driver models implementation are still in relatively early development stage, and cannot be exchanged with other platforms that already have some well developed components, such as roadway or vehicle models. Also, the in-house development of these models and simulation suffer from a lack of available documentation, making it also difficult for other developers to use. Although the level of detail provided regarding these models gives a mean to assess the models’ benefits and relevance, it does not allow for a direct application. Nevertheless, this review lead to a fruitful reflection about the challenges linked to the design and implementation of a model, where we identified the elements of the system/framework that the driver model is a part of, as well as how the level of details of these elements can vary in terms of their representation in the modeling effort.

Regarding the gathering of data, we presented to two different sets. In the first set, the goal of the data collection was to assess if practice with the system mitigates the decrease in driving performance in terms of vehicle control and hazard detection. The results indicate that under complex manipulation of the iPod (requiring 5 to 7 steps, for a task such as finding a specific song), the reaction time for the detection hazard increases, lane keeping control is also affected, most likely due to the manipulation of the iPod. In terms of effect over time, practice with the system improved the driving performance to some extent, but it depended of how complex the secondary task. This new set of data also provides quantitative descriptions of the time required to interact with this type of device is terms of glances duration and number of glances that can be directly integrated into the model.

The second set of data presented the results of the mining of a naturalistic data collection and addressed lane changes at the strategic, tactical and operational level. Most research focuses on the operational level involved during a lane change, and describes it in terms of time-gap with a lead vehicle prior to the action, gap with the side traffic. Here, we illustrated that lane changes can be categorized based on whether they are accomplished in order to respond to a navigation goal or overtaking of a slower vehicle. The application of this method will allow the creation of distributions describing the range of values to expect for the parameters involved in lateral control and decisions for lane changes.

The information presented in this report will be used in order to continue the development of the model, and further progress will be presented in a subsequent report.

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Appendix – Detailed Results from driving simulator experiment

Hazard Detection and Response

**Perception Response Time*

Perception response time (PRT) was calculated in seconds from the onset of an event to a braking response (Olson & Farber, 2003). Overall, male drivers had significantly shorter PRTs (M = 1.06, SE = .019) than females (M = 1.12, SE = .017), $F(1, 492) = 4.35$, $p = .037$. The longest PRT was found while drivers were performing the difficult iPod tasks (M = 1.17, SE = .02), than the baseline (M = 1.05, SE = .02), and iPod easy (M = 1.06, SE = .02) conditions, $F(2, 35) = 6.21$, $p = .005$, which is illustrated in Figure 14. Post hoc analyses showed significant differences between the iPod difficult and baseline conditions, $p < .05$, and between the iPod difficult and iPod easy conditions, $p < .05$.

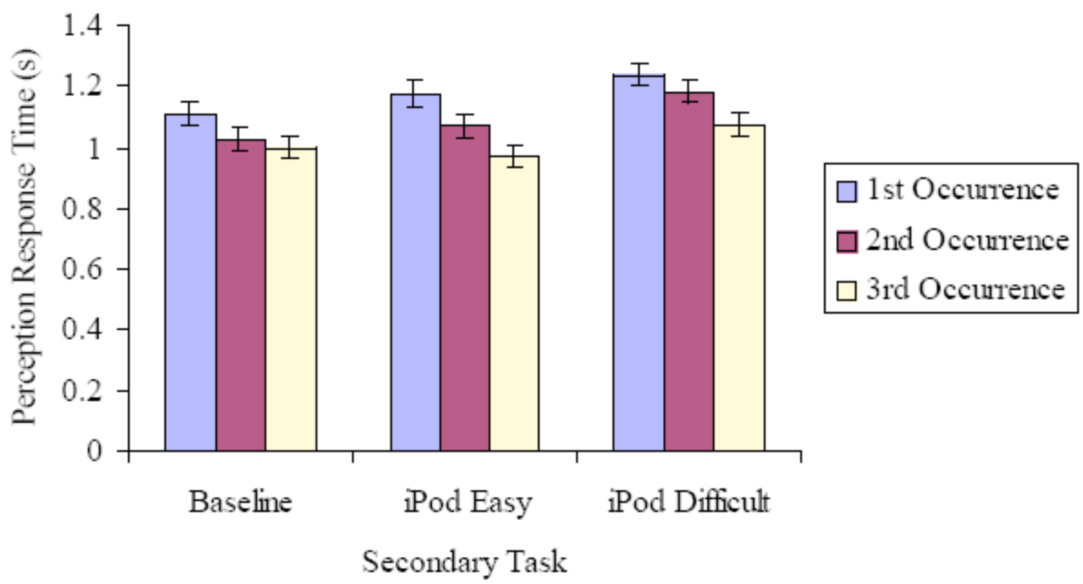

Figure 19: Perception Response Time (PRT) by secondary task and occurrence

Drivers' perception response time improved significantly over occurrences with the longest PRT in the 1st occurrence (M = 1.17, SE = .02) followed by the 2nd (M = 1.09, SE =.02) and the shortest PRT in the 3rd occurrence (M = 1.01, SE = .02), $F(2, 35) = 13.32$, $p <.001$. All of which differed significantly in post hoc comparisons, $p < .05$. Event type also significantly affected perception response times to hazards, $F(3, 475) = 92.38$, $p <.001$. Lead vehicle braking events had the longest mean PRT (M = 1.36, SE = .02) followed by the pullout vehicle (M = 1.19, SE = .02), the pedestrian (M = 1.04, SE = .03) and finally the light changing (M = 0.78, SE = .03) events. All event types differed significantly from each other, $p < .001$.

The two-way interactions between occurrence and event type, $F(6, 475) = 3.16$, $p = .005$, and between secondary task and event type, $F(6, 475) = 4.12$, $p < .001$, were also significant. Both interactions however, were embedded in a significant three-way interaction among occurrence, secondary task, and event type, $F(11, 475) = 5.53$, $p < .001$. Follow-up analyses examined each event type separately.

Pedestrian Event. Secondary task had a significant effect on PRT to the pedestrian event, $F(2, 34) = 5.97$, $p = .006$. The fastest PRT to the pedestrian event was observed with the easy iPod tasks (M = 0.90, SE = .05), which was significantly faster than the iPod difficult task (M = 1.15, SE = .04), $p < .05$. However, both iPod tasks did not differ significantly from the baseline (M = 1.03, SE = .04), $p > .05$.

The interaction between occurrence and secondary task type was significant, $F(3, 50) = 11.07$, $p < .001$. For the 1st occurrence of the pedestrian event, there were no differences in PRT between the baseline or iPod difficult tasks, $F(1, 35) = 2.31$, $p > .05$. In the 2nd occurrence of the pedestrian the fastest PRT was found in the iPod easy task (M = 0.78, SE = .07) followed by the baseline (M = 1.05, SE = .07), and the longest PRT times were found in the iPod difficult condition (M = 1.46, SE = .07), $F(2, 54) = 21.07$, $p < .001$. All of which significantly differed from each other, $p < .05$. By the 3rd occurrence of the pedestrian event, no significant differences were found between the secondary task conditions, $F(2, 54) = 0.58$, $p > .05$.

Lead Vehicle Braking Event. Perception response time (PRT) for the braking event indicated steady improvement in performance between the 1st occurrence (M = 1.54, SE = .06), and decreasing on the 2nd (M = 1.34, SE = .06), and 3rd occurrences (M = 1.20, SE = .06), $F(2, 39) = 8.61$, $p = .001$. The difference between the 1st and 3rd occurrence was significant, $p < .05$.

Secondary task also significantly affected drivers perception response time to the braking event, $F(2, 39) = 3.30$, $p = .048$. The fastest PRT to the lead vehicle braking was observed in the baseline condition (M = 1.24, SE = .06), followed by the iPod easy task (M = 1.40, SE = .06), and finally the iPod difficult condition (M = 1.44, SE = .06). Only the difference between the baseline and difficult iPod conditions was significant, $p < .05$.

Pullout Vehicle Event. During the pullout vehicle event perception response times were significantly longer in the iPod difficult task (M = 1.36, SE = .04), than the iPod easy (M = 1.15, SE = .04), and the baseline conditions (M = 1.08, SE = .04), $F(2, 36) = 12.95$, $p< .001$. Significant differences were found between the iPod difficult and baseline, $p < .001$, and between the iPod difficult and the iPod easy conditions, $p < .001$. The two-way interaction between occurrence and secondary task was significant, $F(4, 70) = 4.37$, $p = .003$.

As can be seen in Figure 20, for the pullout event over occurrences, baseline means remained relatively constant whereas in the difficult iPod condition, a decrease in PRT was found over occurrence. In the 1st occurrence of the pullout event results, as expected, the shortest PRT times occurred in the baseline (M = 1.10, SE = .05), followed by the iPod easy task (M = 1.14, SE = .05), and the longest PRT found in the iPod difficult condition (M = 1.41, SE = .05), $F(2, 54) = 10.08$, $p < .001$. No significant differences were found between the baseline and iPod easy conditions, but both differed significantly from the iPod difficult conditions, $p < .05$. During the 2nd occurrence of the pullout event, the shortest PRT was observed during the baseline (M = 0.998, SE = .07), followed by the iPod difficult (M = 1.33, SE = .07), and iPod easy (M = 1.34, SE = .07) conditions, $F(2, 53) = 7.73$, $p = .001$. Comparisons show that PRT for both iPod tasks were significantly longer than the baseline, $p < .05$. In the 3rd occurrence of the pullout event, PRT was significantly affected by secondary task, $F(2, 53) = 4.72$, $p = .013$. However, the iPod easy condition resulted in the shortest PRT (M = 0.96, SE = .07), followed by the baseline (M = 1.13, SE = .07), and the iPod difficult condition (M = 1.28, SE = .08). PRT in the iPod difficult condition was significantly longer than the iPod easy condition, $p < .05$.

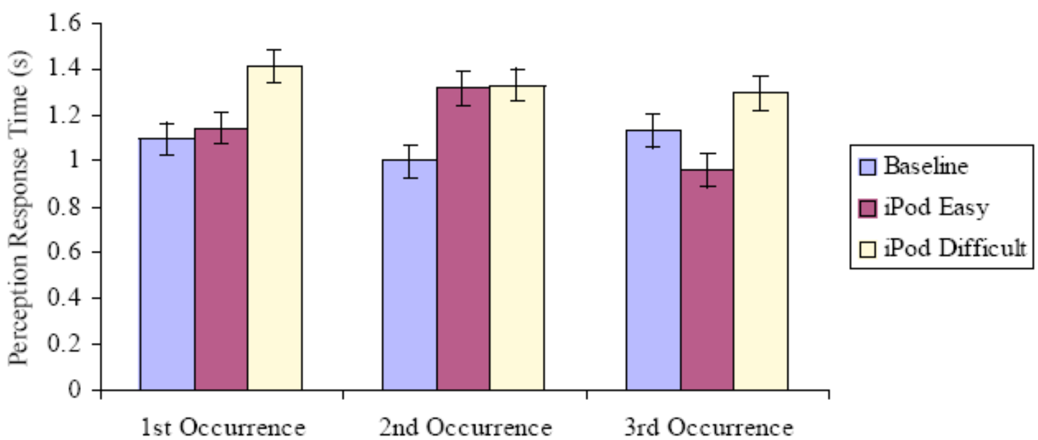

Figure 20: Perception Response Time to the pullout vehicle by the secondary task and occurrence

Light Changes. As hypothesized, the longest PRT was found for the 1st occurrence of the light change event (M = 0.86, SE = .03) and decreased for the 2nd (M = 0.76, SE = .03) and 3rd occurrences (M = 0.74, SE = .03), $F(2, 40) = 3.33$, $p = .046$. The latter two means significantly differed from the 1st occurrence, $p < .05$, but not from each other, $p > .05$. PRT to the light changes was not found to differ significantly depending on the secondary task being performed, $F(2, 47) = 2.21$, $p > .05$. Nor was the two-way interaction between occurrence and secondary task significant, $F(4, 50) = 0.73$, $p > .05$.

Collisions

The number of collisions that participants experienced during the various events was determined by examining the minimum headway distance data. A total of 513 event occurrences were included in this analysis, which represents all the experimental combinations of the independent variables, with the exception of the light changing events (i.e., pedestrian, lead vehicle braking, and pullout vehicle), for each of the secondary tasks (i.e., baseline, iPod easy, and iPod difficult). Of the 513 events encountered by participants over the course of the six sessions, a total of 115 collisions resulted. Secondary task had a significant effect on collision frequency, $\chi 2$ (2) = 11.67, $p = .003$.Twenty-eight collisions occurred during the baseline drives, 34 during the iPod easy condition, and 53 in the iPod difficult interactions. Significant differences in collision frequency were found between the iPod difficult and baseline conditions, $\chi 2$ (1) = 10.35, $p = .001$, and between the iPod difficult and iPod easy condition, $\chi 2$ (1) = 5.60, $p = .018$. Frequency of collisions also decreased significantly from the 1st occurrence (52) to the 2nd occurrence (39) and finally the 3rd occurrence (24), $\chi 2$ (2) = 8.98, $p = .011$.

Standard Deviation of Steering Wheel Angle

Steering angle variation was used to determine steering corrections made while interacting with the iPod and comparable baseline measures. Due to the short time needed to complete the iPod easy task, only the iPod difficult and baseline analyses are presented.

The iPod difficult tasks had larger variation in steering wheel adjustments (M = 2.17, SE = .04) than during the baseline (M = 1.21, SE = .04), $F(1, 19) = 58.35$, $p < .001$. Roadway geometry showed the greatest effect on deviation of steering wheel angle, $F(2, 39) = 103.82$, $p < .001$. The largest variation occurred on the straight freeway roads (M = 2.32, SE = .05) followed by the residential/urban (M = 1.39, SE = .04), and suburban (M = 1.44, SE = .06) roadways. No significant differences in means were found between the residential/urban and suburban roads, $p > .05$, but both of these means differed significantly from that of the freeway roads, $p < .05$.

The two-way interaction between secondary task and road type, $F(2, 477) = 6.85$, $p = .001$ was significant. Follow-up analyses examined each roadway type separately to determine differences between the baseline and iPod difficult conditions. On the residential/urban roads drivers had significantly higher variation in steering position during the iPod difficult tasks (M = 1.93, SE = .05), compared to the baseline condition (M = 0.86, SE = .05), $F(1, 19) = 85.03$, $p < .001$. Significantly larger amounts of steering wheel deviation were also found during iPod difficult secondary tasks on suburban roads (M = 2.11, SE = .08) than the baseline (M = 0.76, SE = .07), $F(1, 18) = 66.50$, $p < .001$. Finally, on freeways again greater steering deviation occurred during the iPod difficult interactions (M = 2.56, SE = .09) than in the baseline (M = 2.08, SE = .09), $F(1, 18) = 7.52$, $p = .013$.

Eye Movement Variables

Eye movements were collected on the even numbered sessions (sessions 2, 4, and 6) in both the iPod and baseline conditions. Video data analysis of eye movements was analyzed using SimObserver and Data Distillery hardware and software. A glance was defined as consecutive fixations to an area of interest (i.e., in the vehicle, on road) not including saccade transition time and blinking behavior (International Standards Organization, 2002). In-vehicle, on road, off road (which included any signs, buildings, parked cars that are not in the central roadway), rearview mirror, and on-screen text instructions were the areas of interest (AOI) that were extracted.

Mean Glance Frequency

Glance frequency is defined as the number of glances to a target during the task where each glance is separated by at least one glance to a different target (ISO, 2002). The numbers of glances made during iPod interactions into the vehicle were examined to determine the average number of glances needed to complete the required tasks. Obviously the iPod difficult task required significantly more glances into the vehicle ($M = 15.30$, $SE = .37$) than the iPod easy interactions ($M = 1.93$, $SE = .37$), $F(1, 17) = 223.44$, $p < .001$. The number of glances to the rearview mirror could not be compared using parametric statistics because too few participants in the iPod tasks glanced at the rearview mirror. Chi-square analyses revealed that there was a significantly higher frequency of glances to the rearview mirror in the baseline condition (76/95) compared to the iPod easy condition (11/171), $\chi2\ (1) = 150.18$, $p < .001$; and iPod difficult condition (27/171), $\chi2\ (1) = 106.12$, $p < .001$.

Mean Glance Duration

Glance duration was calculated as the time (in seconds) from first looking at an AOI until gaze was moved off that area. The mean duration of each glance in seconds was extracted and categorized into various AOIs (i.e., in-vehicle, on-road, off-road, etc.) for each secondary task (i.e., baseline, iPod easy, hard). The duration of glances significantly differed depending on the AOI, $F(6, 156) = 128.34$, $p < .001$. Specifically, longer glances were made into the vehicle ($M = 0.87$, $SE = .02$) than on the road ($M = 0.69$, $SE = .03$), off the road ($M = 0.45$, $SE = .03$), and to the rearview mirror ($M = 0.30$, $SE = .03$), all of which significantly differed from one another, $p < .05$.

Mean glance durations differed by secondary task, $F(2, 80) = 12.92$, $p < .001$. Shorter glance durations were found in the iPod easy condition ($M = 0.62$, $SE = .03$) compared to both the iPod difficult ($M = 0.81$, $SE = .02$) and baseline ($M = 0.81$, $SE = .02$) conditions, $p < .05$. The two-way interactions between AOI and secondary task, ($F(11, 1524) = 27.69$, $p < .001$) and AOI and road type, ($F(23, 1524) = 5.57$, $p < .001$) were significant. The three-way interaction among AOI, secondary task, and road type was also significant, $F(28, 1524) = 4.10$, $p < .001$. Follow-up analyses examined each AOI (i.e., on road, in-vehicle, off road, and rearview mirror) separately to determine the effects ofsecondary task on glance duration.

On-Road. Glance duration to the roadway differed depending on secondary task, $F(2, 42) = 4.67$, $p = .015$. Longer glances to the roadway were found in the baseline condition ($M = 0.83$, $SE = .05$) followed by the iPod easy ($M = 0.62$, $SE = .05$) and iPod difficult ($M = 0.59$, $SE = .05$) conditions. No difference in means were found between the iPod easy and iPod difficult tasks, $p > .05$, but both of these conditions had significantly shorter glances to the roadway compared to the baseline, $p < .05$.

Mean glance duration to the roadway significantly differed depending on the two-way interaction between secondary task and road type, $F(7, 278) = 2.92$, $p = .006$. On the residential roadways, significantly longer glances were made during the baseline condition ($M = 0.81$, $SE = .11$) than the iPod easy ($M = 0.52$, $SE = .08$), and iPod difficult ($M = 0.54$, $SE = .06$) conditions, $F(2, 37) = 6.61$, $p = .004$. No difference was found between the iPod conditions, $p > .05$, but both means differed significantly from the baseline, $p < .05$. No other significant interactions were found between road type and secondary task conditions for the urban ($F(2, 27) = 3.24$, $p > .05$), suburban ($F(2, 35) = 1.38$, $p > .05$), or freeway ($F(2, 5) = 2.08$, $p > .05$) roads.

In-Vehicle. The in-vehicle AOI was defined as any glances that were made into the vehicle, whether at the iPod device, center console, or speedometer. Mean glance durations made into the vehicle, ostensibly at the iPod or speedometer differed depending on secondary task, $F(2, 37) = 100.02$, $p < .001$. Longer glances were made in the iPod difficult condition ($M = 1.35$, $SE = .02$) compared to the baseline ($M = 0.56$, $SE = .03$) and iPod easy ($M = 0.64$, $SE = .03$) conditions. No differences were found for glance duration between the iPod easy and baseline conditions, $p > .05$, but both were significantly shorter than those in the iPod difficult condition, $p < .05$.

Mean glance duration differed depending on the road type, $F(4, 330) = 19.90$, $p < .001$. Significantly longer glances were made on the suburban roadways ($M = 1.13$, $SE = .04$) compared to all other road types: residential ($M = 0.83$, $SE = .03$), urban ($M = 0.75$, $SE = .04$), freeway ($M = 0.77$, $SE = .03$) and curved freeway ($M = 0.84$, $SE = .05$), $p < .05$. This increase in glance duration on suburban roads could be due to the fact that 88% of drivers stopped at the lights and had more time without control or visual demands to complete the iPod tasks. The two-way interaction between secondary task and road type was also significant, $F(7, 330) = 20.85$, $p < .001$, see Figure 21.

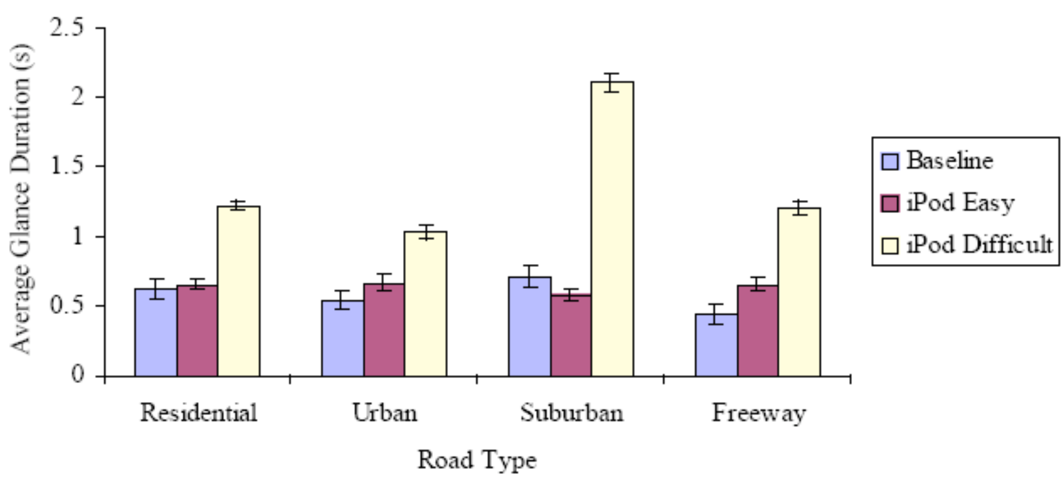

Figure 21: Average duration of glances (s) made into the vehicle by secondary task and road type

Glance durations made into the vehicle were significantly longer in the iPod difficult condition regardless of road type, but due to changing intersection lights on the suburban roadways, increasingly longer mean glance durations were found compared to the other roadways. For example, on the suburban roads significantly longer glances were made in the iPod difficult task ($M = 2.11$, $SE = .07$) compared to the iPod easy ($M = 0.58$, $SE = .04$) and baseline ($M = 0.71$, $SE = .08$) conditions, $F(2, 85) = 109.45$, $p < .001$. However, on freeway roads, shorter glances into the vehicle were made in the baseline ($M = 0.44$, $SE = .07$) followed by the iPod easy ($M = 0.65$, $SE = .05$), and the iPod difficult ($M = 1.20$, $SE = .07$) conditions, $F(2, 83) = 45.58$, $p < .001$. All of which significantly differed from one another, $p < .05$. Residential roads showed similar results, with significantly longer glances into the vehicle being made in the iPod difficult condition ($M = 1.22$, $SE = .04$) compared to both the iPod easy ($M = 0.66$, $SE = .04$) and baseline ($M = 0.62$, $SE = .07$), $F(2, 120) = 25.36$, $p < .001$. Finally, on the urban roads again glance duration in the iPod difficult condition were significantly longer ($M = 1.03$, $SE = .05$) than either the iPod easy ($M = 0.67$, $SE = .07$), or baseline ($M = 0.55$, $SE = .07$) conditions, $p < 0.5$. Off Road. The off-road AOI was defined as any area surrounding the roadway; including signs, buildings, parked cars, and grass medians. Task difficulty did not have a significant effect mean glance durations made off road, $F(2, 52) = 2.05$, $p > .05$. Off road glance durations were significantly affected by road type, $F(4, 238) = 4.62$, $p = .001$. On the freeway roads, glance durations off road were significantly shorter ($M = 0.26$, $SE = .05$) than all other road types of residential ($M = 0.43$, $SE = .03$), urban ($M = 0.51$, $SE = .04$), and suburban ($M = 0.51$, $SE = .04$), $p < .05$. No other significant differences were found among the other road types, $p > .05$. On freeway sections, fewer objects such as parked cars and signs are available for fixation, as well more ambient traffic is present, so less glances are made off road.

The interaction between secondary task and road type was significant, $F(7, 238) = 2.47$, $p = .018$. No differences were found among the various road types for duration of glances off the road during the iPod difficult conditions, $F(4, 136) = 0.67$, $p > .05$. Similarly, no difference among the road types were found in the iPod easy interactions, $F(3, 79) = 0.70$, $p > .05$. However, mean duration of glances in the baseline condition differed significantly by road type, $F(4, 88) = 6.38$, $p < .001$. Glance durations off road were significantly higher in the suburban road ($M = 0.62$, $SE = .07$) than in the residential ($M = 0.47$, $SE = .06$) and freeway roads ($M = 0.39$, $SE = .06$), $p < .05$.

Secondary Task Performance

<u>Task Completion Time (TCT)</u>

Time needed to complete each task was analyzed using SimObserver and Data Distillery. Data were categorized into segments of actions that include: starting the task, movement towards the iPod, touching the iPod, and selecting the correct song, these segments were then aggregated to gather total task completion time in seconds. Because various songs were required for each iPod difficult interaction, they differed in their position in the menu system. Therefore, song position in the menu system was used as a covariate to account for differences in task time due to distance in the menu system. All analyses were performed on each of the secondary tasks separately. Adjustments for violations of sphericity using the Greenhouse-Geisser correction are indicated with a GG next to certain results (Tabachnick & Fidell, 2006).

Difficult iPod Interactions. Males were significantly faster at completing the iPod difficult tasks ($M = 31.75$, $SE = 1.16$) than were females ($M = 39.16$, $SE = 1.11$), $F(1, 320) = 21.28$, $p < .001$. Task completion time for the iPod difficult task also differed by session, $F(5, 320) = 13.09$, $p < .001$. The longest time taken to complete the task was in Session 2 ($M = 45.21$, $SE = 2.11$), and Session 3 ($M = 44.31$, $SE = 1.99$), which did not differ between each other, $p > .05$, but were significantly higher than TCT in Session 1($M = 34.43$, $SE = 1.98$), 4 ($M = 30.38$, $SE = 2.05$), 5 ($M = 27.90$, $SE = 2.02$), and 6 ($M = 30.48$, $SE = 1.94$), $p < .05$. No other significant differences were found between the sessions, $p > .05$. The two-way interaction between gender and session was significant, $F(5, 320) = 2.19$, $p = .05$. In Session 1, TCT was significantly longer for the females ($M = 38.57$, $SE = 2.70$) than the males ($M = 30.29$, $SE = 2.84$), $F(1, 55) = 5.65$, $p = .021$. Similar results for the females ($M = 52.08$, $SE = 2.90$) and males ($M = 38.33$, $SE = 2.90$) were found in Session 2, $F(1, 52) = 6.30$, $p = .015$, and Session 3 with the females ($M = 51.50$, $SE = 2.82$) taking longer than the males, ($M = 37.13$, $SE = 2.82$), $F(1, 52) = 6.30$, $p = .015$. Meanwhile, in sessions 4, $F(1, 55) = 2.63$, $p > .05$, 5 $F(1, 52) = 0.11$, $p > .05$, and 6 $F(1, 55) = 0.19$, $p > .05$, no significant gender differences were found.

Movement time to the device also decreased slightly but progressively by session, $F(5, 70) = 5.84$, $p = .003$ (GG). Longest movement times occurred in Sessions 1 ($M = 0.92$, $SE = .04$), and 2 ($M = 0.95$, $SE = .06$), but decreased for Sessions 3 ($M = 0.83$, $SE = .03$), 4 ($M = 0.72$, $SE = .03$), 5 ($M = 0.79$, $SE = .03$), and 6 ($M = 0.76$, $SE = .03$). Significant differences in means were found between Session 1 and both Session 4 and 6, $p < .05$, and between Sessions 2 and 4, $p < .05$.

Easy iPod Interactions. No gender differences in task completion time were found in the iPod easy tasks, $F(1, 14) = 0.511$, $p > .05$. Time to complete task did differ depending on the session, $F(5, 70) = 3.48$, $p = .03$ (GG). A significant decrease in completion time was found between Session 2 ($M = 5.55$, $SE = .47$) and Session 5 ($M = 3.81$, $SE = .11$), $p < .05$. No other significant differences were found amongst Session 1 ($M = 4.10$, $SE = .39$), Session 3 ($M = 4.25$, $SE = .49$), Session 4 ($M = 4.55$, $SE = .21$), and Session 6 ($M = 4.21$, $SE = .24$), $p > .05$. Movement time during the iPod easy task did not differ by gender, $F(1, 13) = 0.067$, $p > .05$, or by session, $F(5, 65) = 0.565$, $p > .05$. Nor was the two-way interaction between gender and session significant, $F(5, 65) = 0.417$, $p > .05$.