

3.12 Predicting the Impacts of Intravehicular Displays on Driving Performance with Human Performance Modeling

Predicting the Impacts of Intravehicular Displays on Driving Performance with Human Performance Modeling

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Abstract. A challenge facing the U.S. National Highway Traffic Safety Administration (NHTSA), as well as international safety experts, is the need to educate car drivers about the dangers associated with performing distraction tasks while driving. Researchers working for the U.S. Army Research Laboratory have developed a technique for predicting the increase in mental workload that results when distraction tasks are combined with driving. They implement this technique using human performance modeling. They have predicted workload associated with driving combined with cell phone use. In addition, they have predicted the workload associated with driving military vehicles combined with threat detection. Their technique can be used by safety personnel internationally to demonstrate the dangers of combining distracter tasks with driving and to mitigate the safety risks.

1.0 INTRODUCTION

Driving is a behavior humans perform on a daily basis. Unfortunately, so is distracted driving. According to the definition developed by the US National Highway Traffic Safety Administration (NHTSA) distracted driving occurs when drivers divert their attention from the driving task to focus on other activities (2010). Using a cell phone to text or talk or navigating with an intravehicular GPS system are examples of common distracter tasks drivers combine with driving. Regrettably these distracting activities can have extremely adverse effects on driving performance.

In 2009, within the US, distracted driving contributed to 448,000 motor vehicle injuries and 5,474 deaths (National Highway Traffic Safety Administration, 2010). However, the issue of distracted driving is not limited to the U.S. In May 2010, recognizing the risks associated with distracted driving, U.N. Secretary General Ban Ki-moon released a directive that banned the 40,000 United Nations staff from texting while they are driving U.N.-owned vehicles (U.S. Department of Transportation, 2010). In addition, driving and distraction consequences are not limited to the civilian population. Motor vehicle accidents are the primary cause of fatalities among U.S. military personnel (Krahl, Jankosky, Thomas, & Hooper, 2010). 84% of the accidents involved lack of awareness with approximately half

attributed to distraction (Ecola, Collins & Eiseman, 2010).

While safety experts compile statistics demonstrating the risks associated with distracted driving, many types of within-vehicle devices are becoming inexpensive and readily available to drivers. It is critical, therefore, for safety personnel to educate drivers about best practices for using intravehicular devices and for system engineers to develop within-vehicle devices with designs that minimize driver distraction. Human performance modeling is an inexpensive and effective method for achieving these goals.

Human performance models can simulate drivers driving with and without distracter tasks (Horrey, Wickens, & Consalus, 2006). System designers can compare the driving performance from these simulations and select the intravehicular device with the design that has the least effect on driving performance. In addition, they can use the models to determine if the devices can be used while driving and, if so, the optimum technique for device operation during driving. Risk management tools can be employed using the risk severity and frequency of task combinations to evaluate safety. They can then educate drivers by incorporating the best technique within drivers' education and safety programs.

Recognizing the capabilities and benefits of a human performance model of

distracted driving, analysts at the Human Research & Engineering Directorate (HRED) of the Army Research Laboratory (ARL) used the Improved Performance Research Integration Tool (IMPRINT) to model driving.

IMPRINT is a dynamic, stochastic, discrete event simulation tool designed to predict system and mission performance to support system design (U.S. Army Research Laboratory, 2010). IMPRINT analysts build task network models representing the human interacting with a system to perform a specific mission. The mission is represented by various functions and tasks that are required to complete the mission. The analyst enters parameters for each task such as the time it takes to perform the task and how much mental demand the task will require of the operator. The functions and tasks are then linked and coded to create a stochastic task network. During the model execution, IMPRINT calculates the mental workload associated with the combination of all the tasks the operator is performing simultaneously over the entire mission and provides output reports for the analyst to review. Using these output reports, the analyst can examine the mental workload profile of each operator over the entire mission to identify points where workload is high which is an indicator of potential performance decrements.

2.0 DRIVER WORKLOAD MODEL

Using IMPRINT, (Wojciechowski, 2004) developed the initial driving model for ARL. She developed this Driver Workload Model (DWM) to have a representation of driving in IMPRINT that could be used to investigate the mental workload of driving concurrent with communications. She developed the goals, functions, and tasks for the physical characteristics of driving in the DWM using hierarchical task analysis methods (Kirwan & Ainsworth, 1992). She augmented these with cognitive task analysis (Cooke, 1994) to include the non-physical aspects of

driving and controlling vehicles. In the DWM, the driver's primary goal includes the main functions of driving; visual function (see), psychomotor function (move), and the cognitive function (maintaining situation awareness (SA). Communications is an additional function the driver performs (Fig. 1).

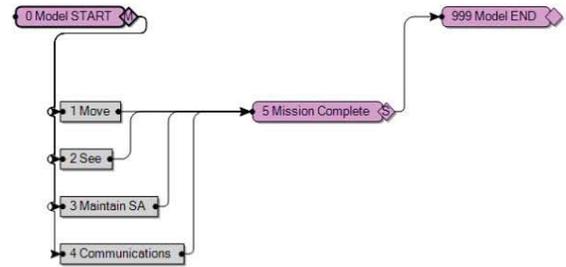


Figure 1 IMPRINT Driver Workload Model

The visual function of the DWM contained the tasks associated with visual processing of driving (Fig. 2). These tasks are; scanning the sector, detecting landmarks, recognizing the path, calculating the distance to the objective, and comparing to guidance or knowledge. Scanning the sector is the first task conducted. After scanning, the model uses a probabilistic decision to determine if a landmark is in the path. When a landmark is detected, two subsequent tasks are triggered simultaneously. They are recognizing the path, calculating the distance to the objective, and comparing to guidance or knowledge. The tasks in the visual function occur in a feedback loop similar to Wickens' human information processing model (Wickens and Hollands, 2000).

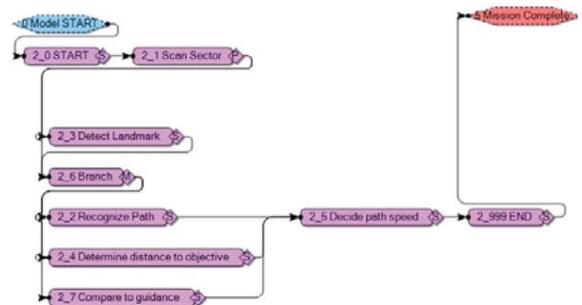


Figure 2 IMPRINT Driver Workload Model – Visual (See) Function

The psychomotor function contains tasks associated with the physical tasks of driving (Fig. 3). They are steering (and non-steering) and accelerating, decelerating, or coasting. As the model begins, there is an initial acceleration. Then a probabilistic decision is made to whether the driver accelerates, decelerates, or coasts. The model cycles through this loop to continually adjust the speed. Model coding can be used to influence this loop depending on the use of the DWM. Running simultaneously with the speed control loop is the directional control loop. This is a loop of two tasks; steer (adjust the steering mechanism) and do not steer (hold the steering mechanism steady).

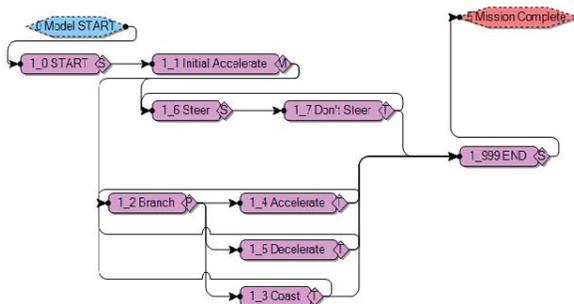


Figure 3 IMPRINT Driver Workload Model – Psychomotor (Move) Function

The cognitive function of driving was developed as a direct result of cognitive task analysis (Fig. 4). This function consists of tasks that represent assessing the orientation of the vehicle, assessing the motion of the vehicle, assessing the traction of the vehicle, and an awareness of the vehicle function. In typical driving scenarios, these tasks are quickly learned and automatic, based on cues from the environment. They do not require a lot of attentional demand or memory capacity as represented in Wickens’ model (Wickens and Hollands, 2000). When the tasks are completed the model probabilistically decides if there is an issue with the vehicle. Then, the model cycles back through the cognitive tasks.

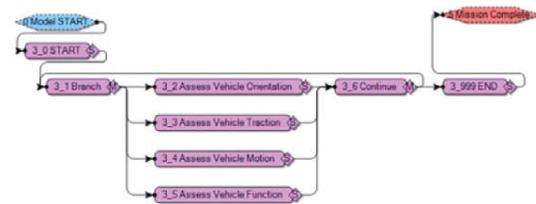


Figure 3 IMPRINT Driver Workload Model – Maintain Situation Awareness (SA) Function

The communication function in the DWM includes tasks representing communication with someone outside the vehicle (Fig. 5). They can be triggered randomly or designed to happen at specific intervals.

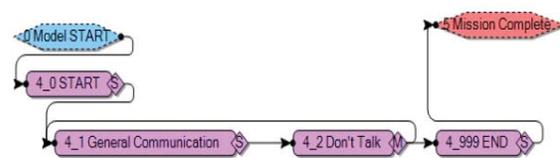


Figure 4 IMPRINT Driver Workload Model – Communication Function

In 2006, Wojciechowski conducted a study that verified the DWM accurately simulated driving performance and validated the workload predictions from the DWM. The study investigated the impact on performance and workload of driving while attending to an auditory task using both the DWM and a driving simulator. The results of the model and the simulator experiments were then compared to see if there was a correlation between the DWM workload predictions and the self-report workload ratings and performance of participants in the simulation experiment.

The results of both the DWM and the experiment indicate an impact of an auditory task on driving. The mental workload predictions from the DWM correlated with the self-report workload ratings from the experimental simulation. Therefore the DWM is a good predictor of mental workload changes with auditory secondary tasks. While the workload numbers correlate with simulator numbers, this simulator did not have the fidelity to

demonstrate what the workload changes would mean in terms of performance measures. Additional testing is necessary to demonstrate performance changes due to workload increases predicted by the model.

3.0 DISCUSSION

The DWM has the benefit of providing analysts with a representation of driving that is generic enough that it can be simplified or expanded to simulate driving within a number of contexts. It was created to investigate off-road driving under differing levels of autonomy (Wojciechowski, Kogler, & Lockett, 2001). The off-road driving model has been expanded by an ARL analyst to represent autonomous control of an unmanned asset within a military mission (Mitchell, 2005). In addition, when building multi-task models of military missions, ARL analysts have simplified the DWM to represent driving within workload analyses of military missions (Mitchell & Samms, 2009). Consistent with the workload predictions from the initial DWM, the workload predictions from these multi-tasks models have been verified in laboratory and field studies (Chen & Joyner, 2009); (McDowell, Nunez, Hutchins, & Metcalfe, 2008).

The workload predictions from the ARL analyses of driving consistently predicted high workload associated with driving. Concurrently, safety organizations such as the NHTSA, were releasing statistics demonstrating the adverse effects of distracter tasks on driving performance. Consistent with the ARL analyses and safety statistics, researchers in industry and academia demonstrated that these detriments to driving performance occur because driving is associated with high mental workload (Reimer, 2010); (Ranney T. , 2008); (Battelle, 2006); (Horrey, Wickens, & Consalus, 2006); (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006); (McCallum, Campbell, Richard, & Brown, 2006); (Horberry, Anderson, Regan,

Triggs, & Brown, 2005); (Horrey, Alexander, & Wickens, 2003); (Kurahashi, Motonori, & Akamatsu, 2003); (Ranney, Mazzae, Garrott, & Goodman, 2000); (Tijerina, 1995); (Green, Lin, & Bagian, 1993); (Wierwille W. , 1993); (Wierwille, Tijerina, Kiger, Rockwell, Lauber, & Bittner Jr., 1992).

Although the ARL analysts' modifications to the DWM model have been for military applications, it can be modified for use by academic or industry researchers as well. The DWM, for example, could be modified to focus exclusively on the visual function of driving.

Driving research studies are in agreement that driving is a predominantly visual activity. Therefore, when time-sharing monitoring intravehicular displays with driving, drivers will focus their eyes on the forward terrain and use a short glance to look at an intravehicular display. If they cannot get all the information they need with one glance, they will alternate multiple glances with glances at the road ahead.

To represent this driver visual behavior, researchers could modify the visual function in the DWM to represent the driver alternating glances at the forward terrain with glances at intravehicular displays such as speedometers, warning and advisory alerts or navigation systems. They could then use this modified version of the DWM to compare the number of glances required for alternative intravehicular display designs. The display with the minimal number of glances would be recommended as the optimum design. ARL analysts have successfully implemented this approach in an analysis of the driver of a military mine detection vehicle (Mitchell & Sweeney, in review).

Researchers could also use the DWM to develop guidelines for use of intravehicular displays while driving. For this analysis, they could develop several DWM models with drivers glancing away for varying

lengths of time. By comparing the driving performance from the alternative models they could establish thresholds for glance duration times.

Additionally, the DWM could be used to address safety issues with distracted driving using safety assessment methods (Swallom, Lindberg, & Smith-Jackson, 2003). Risk analysis measures can be used because IMPRINT provides frequency of task combinations and workload levels. Severity of the risk can be estimated by the workload level. Critical task flows can be used in fault tree analysis to determine potential causes of hazardous combinations of tasks. Additionally, event tree analysis of multiple model runs can predict probability of hazardous combinations of tasks.

4.0 CONCLUSION

The DWM demonstrates the feasibility of using human performance modeling to represent driving. The inclusion of the DWM into many military analyses illustrates its adaptability for representing a variety of driving applications. The IMPRINT software that ARL analysts used to develop the DWM is available to universities, government organizations, and government contractors. Therefore, the DWM provides an inexpensive technique for predicting the impacts of intravehicular displays on driver performance. The statistics supporting the adverse consequences of distracted driver verify the need for this cost-effective modeling technique.

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