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Modeling Driver Mental Workload for Accident Causation and Prevention

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Abstract: Past road safety studies have mostly focused on the identification of scenarios involving high accident risk. However, risky scenarios can only describe accident outcomes rather than the real causality. Discussion of driver's cognitive interaction while driving is a necessity for deeper exploration about the nature of accident. To comprehend the entire structure of mental workload, this research proposes a research framework for studying mental models that incorporates task demand and motivated capability. Understanding the contributing factors of mental model and the individual difference in task demand and motivated capability can help evaluate the mental workload. In addition, integrating mental model with accident chain analysis enables exploring information net effect on mental workload. Thus, optimized information can hopefully be defined and provided to drivers in different scenarios without causing additional risk of accidents.

Key Words: *mental workload, information, task demand, motivated capability*

1. INTRODUCTION

Accident predictability has long been controversial. Bortkiewicz, usually considered the pioneer of modern accident research, said in an 1898 study that accidents are random and thus inexplicable (Elvik, 2006). However, the development of modern analysis techniques has inspired various attempts to explore the causality of accidents. Numerous contributing factors have been found critical to roadway safety. For example, rear-end accidents increased with the number of signal phases and width of traffic island (Chin and Quddus, 2003). Demographic characteristics such as age and gender also have been extensively studied (Chang and Yeh, 2007; Clarke *et al.*, 1998a; Clarke *et al.*, 1998b). That is, in addition to the contributing factors which are closest to accident, certain remote factors also have been seriously considered (Verschuur and Hurts, 2008; Wong and Chung, 2007a; 2007b). Recent research has further claimed that accidents should be analyzed from a chain perspective. For example, personality traits can be treated as prior-to-driving factors that affect risky driving behavior (Wong *et al.*, 2009; Wong *et al.*, 2010). Therefore, to understand not only the process through which crashes occur but also possible means of avoidance, an in-depth study of accident is vital.

Most previous studies of roadway accident were based on aggregated accident information. Accident chain analysis can extract accident scenarios with specific patterns. For example, Wong and Chung (2007a) found that young and inexperienced student drivers had an increased likelihood of being involved in off-road accidents on roads with speed limits between 51 and 79 kph under normal driving conditions. The scenario above explained the conditions in which drivers have increased risk of being involved in accidents, and possibly the mechanism through which such accidents occur. However, an unanswered question remains, namely the reasons accidents occur under specific conditions. The reality is that for each accident under certain conditions, there are numerous young and inexperienced student drivers who drive under identical conditions without experiencing accidents. The question thus arises of why different individuals react differently to identical conditions, resulting in different outcomes. Answers to these questions still are implicit. Obviously, aggregated data are inadequate for answering the above questions; instead it is necessary to closely examine individual driver actions.

The most important element in accident causation is well known to be the driver, who makes the decisions that control the vehicle. To explain the mechanisms of accident causation from a driver's perspective, Elvik (2006) proposed four universal laws of accident causation, including the laws of learning, rare events, complexity and cognitive capacity. Each law not only represents phenomena associated with accidents, but also reflects critical cognitive factors that are inherent in driving process and important to the causality of driving safety.

Thus, a driver's mental process must be analyzed to comprehend how accidents occur. In particular, elements in an accident prone scenario extracted from accident chain analysis and tasks under such driving environments are the most interesting. The scenario requires the driver to perform tasks that induce mental workload and mental resource consumption. Once the mental workload reaches an unacceptable level, driving safety may suffer. That is, scenarios involving high accident risk extracted from accident chain analysis indicate that driver's mental workload could be in a critical condition.

Regarding the driving tasks, advanced in-vehicle instruments further complicate the issue. Distraction by in-vehicle instruments may create additional task activities and thus decrease the spare capacity available for driving tasks (Horberry *et al.*, 2006a). Although some instruments, such as navigation systems, can help drivers allocate mental resources in advance by providing real-time information (Fuller, 2005; Verway, 2000), such devices also can increase workload and threaten safety during information acquisition. An in-depth discussion of the mental process involved in driving can help understand the impact of information on mental workload and clarify the net safety effect of ITS systems.

Workload, defined as the resources consumed in achieving a certain level of performance in tasks with specific activities and driver's capability (Hart and Staveland, 1988), is a critical indicator of driving safety. Drivers can be assumed to be more likely to encounter risky situations if the workload incurred from tasks exceeds a critical level. The workload mentioned includes physical and mental concepts. Since driving is not strength intensive, physical impairment does not seem to degrade driving performance (Elvik, 2006). DiDomenico and Nussbaum (2008) also suggested that no significant interaction exists between physical and mental workload. Consequently, this study focuses only on the mental workload issues.

Mental workload is a multifaceted issue that is critical to road safety. To understand the nature of accidents and mental workload, this study discusses issues of accident chain from the perspective of individual mental process. Section 2 analyzes the driving process from a mental perspective and identifies the critical issues to be addressed in this study. In section 3, following a critical review of related studies, a research framework is established for examining mental workload. Section 4 then discusses the issue of optimum mental workload and strategies for dealing with different levels of mental workload. Subsequently, section 5 discusses the impact of ITS safety techniques on mental workload. Finally, an issue discussion and concluding remarks are presented.

2. DRIVING MENTAL PROCESS

Considering the interaction among mental workload related factors, a conceptual framework for driving mental process is illustrated in Figure 1. The mental process of driving broadly comprises three main stages, including task activity formation, interaction between task activities and motivated capability, and maneuvering against mental workload level.

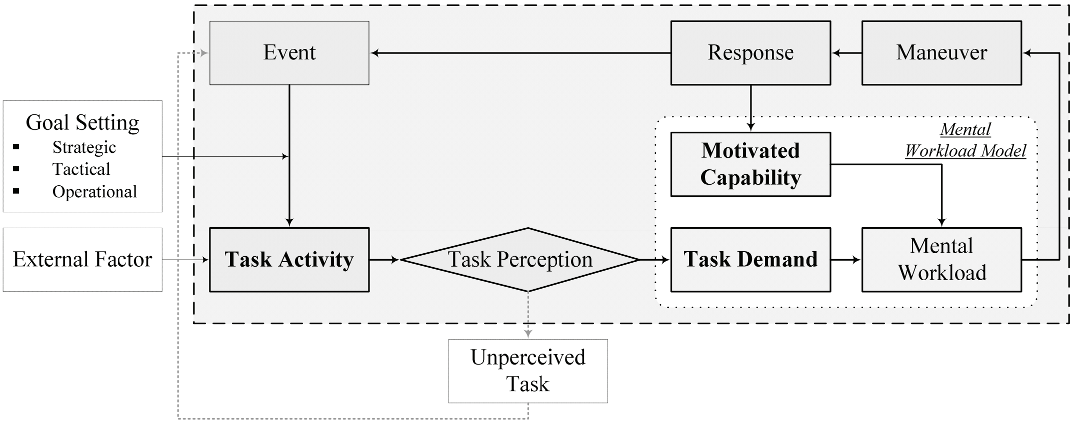


Figure 1 Conceptual framework of driving mental process

Forming driving task activities is event oriented. Here events, such as incoming phone call or traffic flows becoming congested, refer to everything that happens within the driving process that would influence the driver's behavior. To react against the events, task activities that rely on a hierarchy of goals set by the drivers are imposed and ideally must be properly undertaken. Goal setting comprises strategic, tactical and operational levels. Different levels of goal setting make different contributions to task activity triggered from the event and external factors. The strategic level of goal setting comprises knowledge based on cognitive processes which occur mostly in the pre-driving stage and are considered as remote factors affecting driving safety. The decisions, including route choice, departing and expected arrival time, or transportation mode, consist of the basic driving scenario and tasks. As for the tactical and operational levels of goal setting, both regard event recognition and related actions contribute substantially to driving behavior and task activity (de Waard, 1996; Gregersen, 2005).

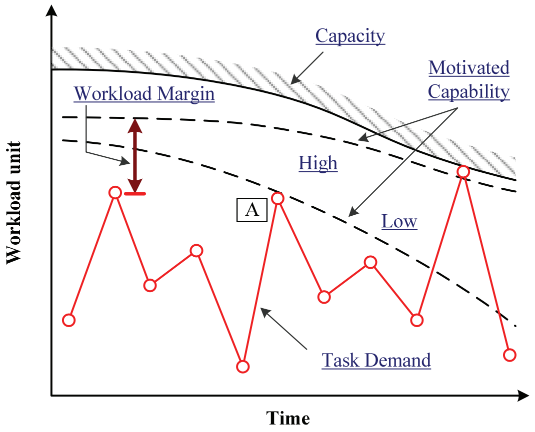
Task activity denotes the tasks that ideally would properly be performed by drivers to achieve their goals. However, not every task activity is undertaken owing to differences in vehicle control ability and situational awareness. Thus, only the task activity perceived and executed by drivers in a certain limited time interval, otherwise defined as task demand, consumes mental resources while driving. Notably, task demand or activity alone can not exhibit characteristics of mental workload. Drivers' motivated capability must also be taken into account. As shown in Figure 1, the main part of the driving mental process is the mental workload model. In which, mental workload is induced via the interaction between motivated capability and task demand.

Activities which are not perceived by drivers will not cause any task demand right at the moment. However, the gap between required task activities and the actual tasks undertaken afterwards increases the likelihood of unexpected events occurring. A larger gap indicates that drivers may be unaware that more additional work is required to achieve safe driving. Some unperceived events may immediately create other additional unexpected tasks, thus further increasing task activity and task demand. As a consequence, an accident could unfortunately occur.

3. FRAMEWORK OF MENTAL WORKLOAD MODEL

3.1 Mental Workload Model

The mental workload model comprises the linkage between perceived task demand and motivated capability of drivers. Höger *et al.* (2005) defined the mental workload model as schemas of dynamic systems or scenarios that include understanding of system components, as well as their interaction and time-dependent changes. Driver capabilities and perceived task activities vary according to conditions. Even in the same situation, different drivers may react differently, leading to different levels of mental workload. Figure 2 illustrates the mental workload model.



Source: Jex (1988)
Figure 2 Concept of mental workload model

As mentioned, each accident scenario represents a series of task activities. Even facing the same scenario, drivers with different characteristics (for example, risk-taking drivers versus average drivers) may make very different decisions, thus inducing different task demand. On the other hand, motivated capability represents the supply of mental resource in a specific condition. Due to the unique characteristics of each driver, they can have very different capabilities. External factors also may contribute to the heterogeneous nature of motivated driving capability. Briefly speaking, perceived task demand and motivated capability may differ with the driver's characteristics and other external factors.

Mental workload, shown in Figure 2, is assessed by the difference between task demand and motivated capability, which also is known as the workload margin (Jex, 1988). The level of mental workload will vary inversely proportionally with the margin (Fuller, 2005). The same task demand may have different margins under different motivated situation. Therefore, taking tasks as the only indicator of workload cannot fully describe the mental workload involved in driving. For example, point A in Figure 2 is critical in the low motivated capability condition but comparatively safe in the high motivated capability condition. An easy task can end up being difficult for drivers if their motivated capabilities are extremely low.

Macro accident data analyses can reveal the scenarios with high accident risk. However, the real causality remains unclear without deeper discussion of the differences in the reactions and behavior of individual drivers while driving. This section briefly discusses task demand, capability and mental workload model. Task demand and capability are claimed to be inconstant due to the differences in driver personal characteristics and external influences. Additionally, the transformation process from workload margin to mental workload may differ among drivers. Even given the same level of mental workload, dissimilarity in sensitivity to mental workload also cause drivers to react differently.

Up to this point, this research has highlighted the multidimensional characteristic of the mental workload model. The key, however, will lie on a series of work on task demand, motivated capability and mental workload. Thus, it appears that improving road safety is challenging, but opportunities exist to do so either through reducing task demand or increasing motivated capability via advanced technology and innovative strategies.

3.2 Task Demand

First, the two terms of task activity and task demand must be clearly clarified. Regardless of the individual differences in situational awareness or other driving skills, task activity is an event-oriented and task-centered measurement determined by the number of simultaneous tasks that must be undertaken to realize series of goals set by drivers when facing a specific event. Task activity is triggered by expected and unexpected events. Considering the influence of external factors and the goals set by drivers, each event creates certain task activities that would be performed. Task demand, on the other hand, is human-centered and is defined as the total amount of task units executed by drivers per unit of time. Clearly, the timing to execute a task is critical for task demand analyses. Unlike event-oriented task activity, task demand will be affected by the personality characteristics and situational awareness of individuals. Different drivers with different traits may make different decisions and suffer different task demands in relation to the same task activity. Restated, task activity denotes the tasks drivers should properly undertake while task demand comprises the tasks that drivers choose to and do undertake in a certain limiting time.

For example, when approaching a work zone, a driver is likely to change his/her lane. Activities against the event include decelerating, looking in the mirror, making a turn signal and turning the wheel. To novice and inexperience drivers, they might skip the activity of looking in the mirror and turning the wheel quickly. On the other hand, to those experienced drivers, they might undertake every necessary activity and change his/her lane under a permitted traffic condition.

Task activities that have not been perceived by drivers do not cause task demand but do increase the likelihood of unexpected events that might create more serious problems. As indicated by Elvik (2006), rare and unexpected events may increase the accident risk. If drivers can accurately predict potential events in advance, tasks could be well allocated and task activity per unit of time can be maintained at a reasonably low level. On the contrary, unexpected events mostly occur comparatively quickly. Although the total task activity remains the same, the sharp increase in task activity per unit of time sometimes makes drivers unable to maintain safety. As the example of approaching a work zone, drivers who do not look in the mirrors seem to have less task demand. But if it follows with a confliction with vehicles in the adjacent lane, the ignorance can result in a sharp increase of task demand. This also suggested that permitted time for executing tasks is crucial for task demand and can have substantially meaning in driver's mental resource allocation.

Figure 3 illustrates a framework for task demand analyses. Accident data provide valuable information for analyzing task activity and task demand. Although accident data analyses do not illuminate cognitive activities associated with driving, extraction of accident prone scenarios still provides crucial clues to identify conditions in which excessive task activities must be undertaken under a certain level of capability, thus impacting driver ability to drive safely.

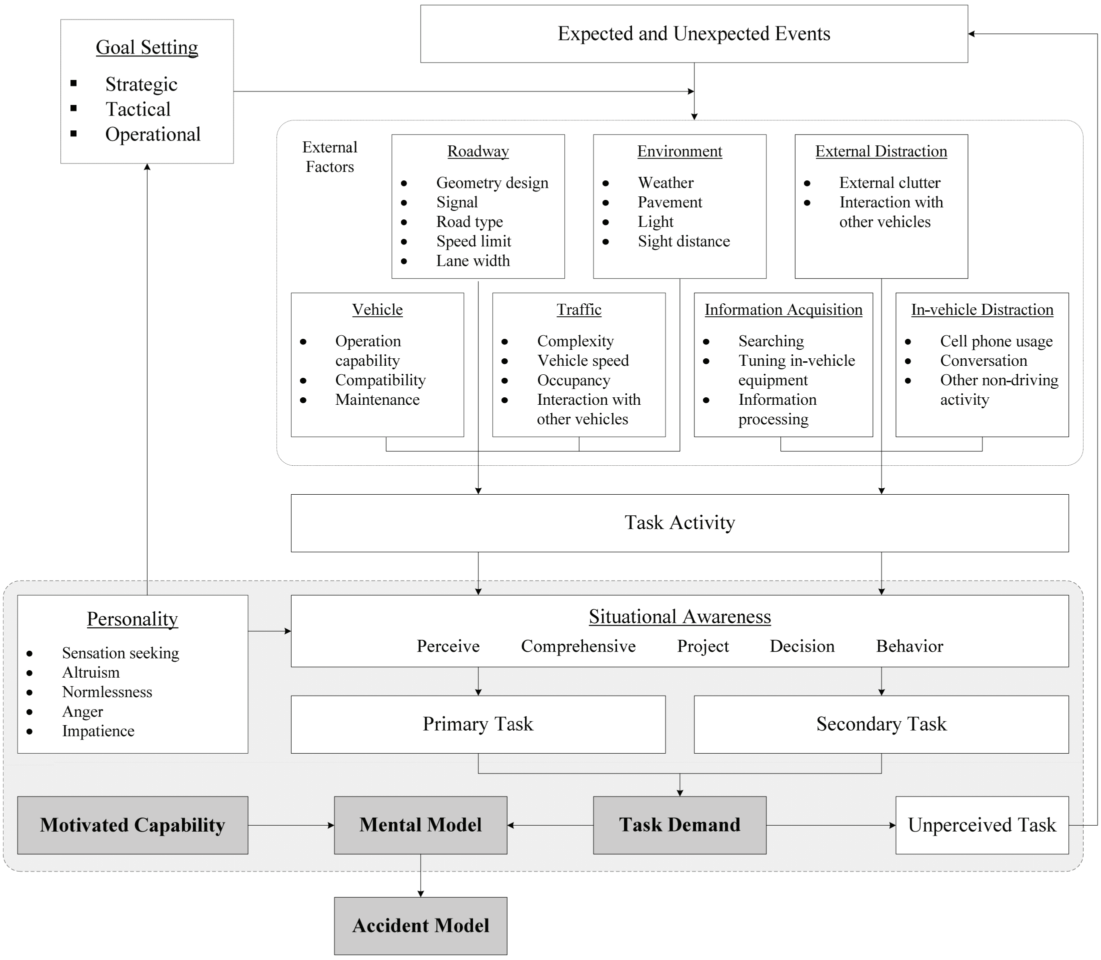


Figure 3 Research framework of driving task demand

Basically, task demand results from two task categories -- primary tasks and secondary tasks. Primary driving tasks, which are generally defined as tasks undertaken by drivers to maintain safety, can be divided into two types, controlling vehicles and preventing potential conflicts. Factors influencing driving tasks include vehicle design, traffic, road condition, distraction and external environmental factors which can influence driving task complexity and the difficulty of achieving goals. Many studies related to primary tasks have focused on analyzing accident prone scenario. For example, rear-end accidents generally occur in intersection areas since intersections require drivers to react and act in response to signal changes, particularly on the roads with more complex geometric design (Chin and Quddus, 2003; Mitra *et al.*, 2002; Wang and Abdel-Aty, 2006). In such a scenario, higher level of road design can enhance safety by making it easier for drivers to control vehicles (Horberry *et al.*, 2006b). However, better designs also encourage drivers to drive faster or take risks, thus increasing task activities (Chang and Yeh, 2007; Chin and Quddus, 2003). As a result, the driver's task demand can exceed his/her limit. Furthermore, traffic complexity is another important consideration. Recent works have found that drivers must allocate more mental resources to maintaining safety when driving under complex traffic conditions (de Waard *et al.*, 2008; Liu and Lee, 2005; Verway, 2000). Elvik (2006) also found that the more information drivers must process and the more decisions they must make, the greater the potential risk they endure while driving.

Secondary task refers to all non-driving activities, including in-vehicle distraction, external distraction and information acquisition. Undertaking secondary tasks causes distraction that shifts mental resource away from primary tasks. Among these issues, in-vehicle distraction, especially cell phone communications, has attracted heavy attention from researchers. Numerous studies have proposed that cell phone usage, or other in-vehicle instruments, increase task activities and decrease a driver's ability to react to emergencies (Caird *et al.*, 2008; Horberry *et al.*, 2006a; Liu and Lee, 2005; Nunes and Recarte, 2002; Patten *et al.*, 2004). External clutter such as advertising billboards, roadside buildings or surrounding traffic flow also were found critical to driver performance (Horberry *et al.*, 2006a). Furthermore, information provided to drivers also may cause distraction and increase task activities even when that information can help driver better pre-plan the allocation of mental resources and prevent danger arising from uncertainty.

A contributing factor analysis only deals with driver mental overload scenarios. Further exploration of these factors and associated scenarios are helpful for understanding how drivers encounter problems. Nevertheless, the most important elements in driving task activity analyses involve the behavior which drivers adopt to control their vehicles. Indeed, different behaviors might result in different task activities, thus, task demand and accident risk outcome. Young and male drivers are believed to exhibit more aggressive behaviors and violation when driving (Clarke *et al.*, 1998a; Chang and Yeh, 2007). Furthermore, male motorcyclists were found more likely to violate traffic regulations (Chang and Yeh, 2007). However, factors such as gender and age have no causal implications for driving behaviors. Instead, those observable factors reflect inherent psychological factors, such as personality traits, which can influence situational awareness or goal setting. Wong *et al.* (2010) suggested that personality traits of young motorcyclists, including sensation seeking, impatience and complaisance, can influence the occurrence of risky riding behavior. Riders who are impulsive or engage in seeking excitement have a higher acceptance of unsafe riding, and thus are exposed to more risky behaviors generating extra task activities. This phenomenon implies task activity, and thus task demand varies according to driver personality and characteristics.

3.3 Motivated Capability

Motivated capability indicates the maximum number of simultaneous task units that drivers can perform correctly during a unit of time. The law of cognitive capability proposed by Elvik (2006) suggested that capability impairment would increase accident likelihood. Figure 4 shows the framework for research on driver capabilities. As indicated, the main contributors to capability fall under physical and psychological conditions.

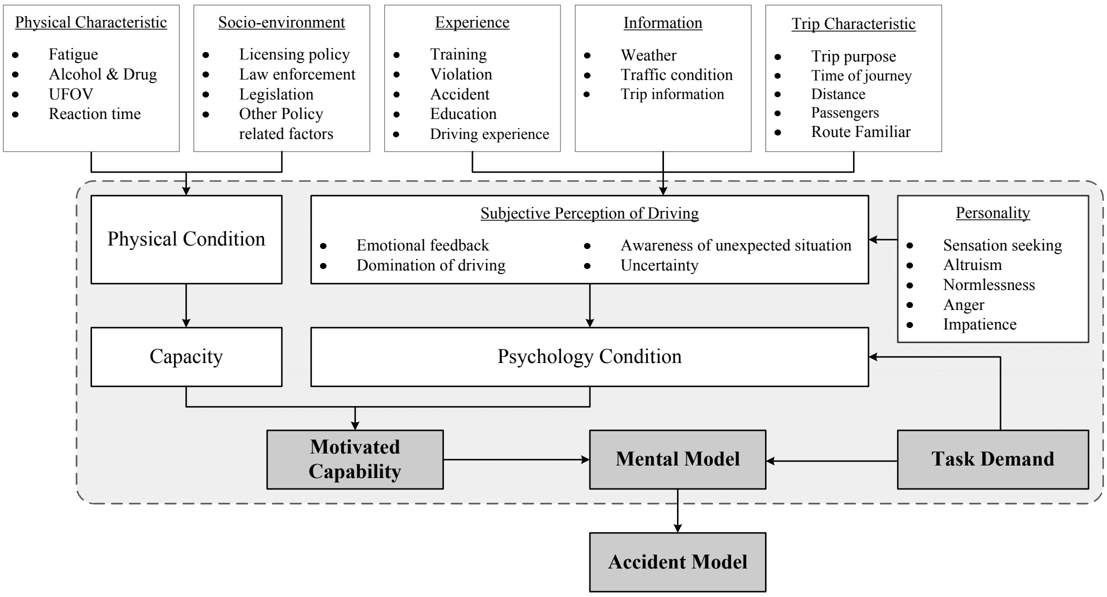


Figure 4 Framework for research on driver motivated capabilities

Drivers' physical condition forms the baseline capability, which is termed capacity. Drivers cannot increase capacity by adjusting their physical condition while driving. That is, capacity determines the mental resources limit that drivers can utilize. In discussing physical conditions, age is considered to strongly affect capacity when executing multiple and simultaneous activities (Liu and Lee, 2005; Hancock *et al.*, 2003). Owing to the degradation of physical conditions, such as consciousness, useful field of view (UFOV) or reaction time against urgent situation, senior drivers face significant changes in driving skill, reaction and, most importantly, cognitive capacity. Degradation of capacity may prevent senior drivers from identifying potential accident risk (Bayam *et al.*, 2005; Clarke *et al.*, 1999). Furthermore, use of alcohol and drugs and fatigue also can decrease a driver's capacity and thus increase the risk of getting into an accident. Lowering the driver blood alcohol limit and enforcing stricter drink-and-drive laws contribute to the reduction of accidents (Bernat *et al.*, 2004; Rios *et al.*, 2006; Ulmer *et al.*, 2000). Striker laws on blood alcohol limits and license renewal policies can help keep physically incapacitated drivers off the road.

Other important elements affecting a driver's capability are the driver's psychological condition and his/her response to task demand. A driver's psychological condition can be considered as an adjustment factor to determine how much mental resources can be utilized in driving under a given capacity. With regards to psychological conditions, a driver's subjective perceptions toward driving make critical contributions. The more self-confident and in control a driver feels, the easier it is for them to allocate mental resources and maintain their capabilities at a reasonable level. Driving under conditions where a gap exists between expectations and real traffic environment makes a driver depressed and stressed. Hill and Boyle (2007) indicated that drivers, especially female and senior drivers, who feel stressed while driving can be assumed to have reduced driving capabilities. Laws of learning and rare events proposed by Elvik (2006) also state that accident rate decreases with increasing exposure and driving experience, since positive experience accumulation and training can help drivers predict and control driving uncertainties. Furthermore, the acquisition of information about journeys including traffic conditions, weather and routing assistance can help drivers understand the situations they may encounter on their journey, and increase their confidence.

From the accident chain perspective, the greatest contributors to capability occur during the prior-to-driving stage. However, Fuller (2005) claimed that task demand, which is mostly affected by factors in the driving stage, interacts with psychological conditions and further influences level of capability. For example, a driver may pay more attention when driving on rainy days. The interaction between task demand and capability, thus, must be clarified to clearly identify the nature of mental workload.

Compared to research on task demand, few efforts had been devoted to issues involving motivated capability. Most studies have only adopted simple measures of driver capability, such as driver age. This section proposes a concept of capacity that incorporates psychological adjustment. Capacity determines the upper limit of capability. Drivers can try to optimize the utilization of driving capability by adjusting psychological related factors to improve control while driving. Individual drivers may have different physical and psychological characteristics, resulting in different interaction between capacity and capability, where capacity level is fixed and cannot be adjusted (Friswell and Williamson, 2008). Additionally, similar to task demand, motivated capability also is a dynamic system that is affected by a driver's unique characteristics in terms of information acquisition, experience and motivation along the trip. Taking age effect as an example, young drivers, in average, are in better physical conditions which give them more capacity while driving. Meanwhile, young drivers may be inexperienced and thus unable to effectively utilize their capacity. Obviously, a single simple measurement such as age or gender cannot properly explain the phenomena, and deeper discussions are necessary.

4. OPTIMUM MENTAL WORKLOAD

The previous sections discussed induction of mental workload and its influence on driving. Based on the interaction between capability and task demand, drivers suffer a certain mental workload and must react properly to prevent hazardous situations. These vehicle maneuvering manifests the explicit mental process under the influence of perceived mental workload. The risk of mental overload has been widely discussed. However, existence of mental workload does not inevitably negatively impact driving performance and safety. Instead, the concept of optimum mental workload is worthy of consideration.

Drivers attempt to maintain optimum conditions while driving, including optimum speed, stress and mental workload (Hill and Boyle, 2007; Horberry *et al.*, 2006b; Recarte and Nunes, 2002; Oron-Gilad *et al.*, 2008). When drivers become unable to optimize their mental workload, corrective action would be taken. According to the mental workload model, strategies for maintaining optimum mental workload fall into two broad categories: task demand and motivated capability adjustment.

Compensation strategies can be adopted when mental workload exceeds the optimum level. For instance, from task demand analyses, several studies have indicated that drivers try to reduce secondary tasks like ending a cell phone conversation to devote greater attention to driving (DiDomenico and Nussbaum, 2008; Törnros and Bolling, 2006). Adjusting driving behavior is another means of compensating for insufficient mental resources. For example, drivers can increase headway (de Waard *et al.*, 2007; Horberry *et al.*, 2006a) to reallocate mental resources and decrease task demand. Moreover, speed adjustment offers another means of managing mental workload. Recarte and Nunes (2002) claimed that drivers adjust speed based on their selected optimum velocity. Generally, drivers can decrease task demands by decelerating whenever their speed exceeds the optimum condition (Caird *et al.*, 2008; de Waard *et al.*, 2007; Liu and Lee, 2005). Sometimes, drivers accelerate to reduce external clutter and workload (Recarte and Nunes, 2002). In the case of psychological adjustment, drivers may concentrate more on driving and allocate more resources to the activity once they find their driving performance deteriorated (Fuller, 2005).

On the other hand, when a driver's mental workload is lower than the optimum level, he/she may suffer passive fatigue and boredom (Fuller, 2005; Gershon *et al.*, 2009; Pattyn *et al.*, 2008; Oron-Gilad *et al.*, 2008). Conditions of boredom and passive fatigue increase reaction time and possibly further increase lapses and errors. When drivers drive continuously in such low mental workload conditions, their capabilities are reduced and, moreover, they become insensitive to this degradation. Under such situation, any sudden increase in task demand can be dangerous. To prevent risks associated with low mental workload, drivers should attempt to maintain a certain level of mental workload while driving by listening to music or keeping a conversation with others in the vehicle to maintain alertness (Fuller, 2005; Oron-Gilad *et al.*, 2008).

Decision-making and acting to optimize mental workload are the key factors of road safety. However, drivers sometimes fail to accurately estimate their mental workload and underestimate potential risks. Taking cell phone usage for example, talking on a cell phone increases one's reaction time, requiring drivers to maintain a longer headway or decrease their speed to stay on the safer side. However, studies have found that drivers using hands-free cell phones do not adopt compensation strategies despite suffering the same degradation in reaction time as drivers using conventional cell phones, thus increasing accident risk (Caird *et al.*, 2008; Liu and Lee, 2005; Nunes and Recarte, 2002; Patten *et al.*, 2004; Törnros and Bolling, 2006). Therefore, it is worth considering ways to help drivers manage their mental workload by providing adequate information or assistance via ITS safety systems, such as screening out phone calls when one's mental workload is high (Nunes and Recarte, 2002; Piechulla *et al.*, 2003).

5. IMPACT OF INFORMATION ON DRIVING SAFETY

The aim of providing information to drivers is to help drivers drive more safely and easily, and most important, to help drivers optimize their mental workload. Improvements in ITS safety technology make it easier for drivers to obtain real-time traffic information. However, different information affects drivers differently. It is important to understand the characteristics of information and its impact on driving safety. Furthermore, to understand the net effect of information provided on mental workload, the contribution of information on capability and task demand must be clarified and discussed.

One of the important goals of providing information to drivers is to improve the driver's understanding of traffic situations and their influences on driving. From a user perspective, drivers note that providing more information can support decision-making and thus reduce task demand (Brookhuis and de Waard, 1999; Creaser *et al.*, 2007). Gathering real-time information, including weather, traffic flow conditions, or accident prone site, reduces drivers' uncertainty and allows them to pre-allocate their mental resources to deal with future traffic conditions. Thus, a driver's active reactions increase and passive reactions, especially those uncomfortable ones, decrease. Several studies have indicated that such active reactions to traffic conditions can effectively decrease mental workload (Fuller, 2005; Verway, 2000).

Information also is intended to help drivers maintain optimal mental workload. As mentioned, once the mental workload exceeds the critical level, drivers will select compensation strategies to alter the interaction between task demand and capability. However, drivers sometimes misestimate potential risks in certain conditions and make wrong decisions . As indicated, drivers may underestimate the potential risk and end up not reducing their speed or increasing headway when using hands-free phones (Caird *et al.*, 2008; Liu and Lee, 2005; Nunes and Recarte, 2002; Patten *et al.*, 2004; Törnros and Bolling, 2006). A mechanism for in-vehicle cell phone management has been proposed to screen out incoming calls when one's mental workload exceeds a certain level (Nunes and Recarte, 2002; Piechulla *et al.*, 2003). On the other hand, if the mental workload is far below the optimum level and there is a risk of passive fatigue, external stimuli such as music or radio should be provided to increase task demands and hence driver alertness (Fuller, 2005; Pattyn *et al.*, 2008; Oron-Gilad *et al.*, 2008).

While information is generally beneficial, improper use of it can gain negative effects. Only providing the proper information to right driver at the proper time and place can exert positive effects and reduce accident risk (Wong and Chung, 2007a). Complex laws proposed by Elvik (2006) state that accident risks are increased with the information drivers must attend to during a given unit of time. Moreover, side effects of information should also be considered. Drivers influenced by multiple sources of information likely are to be distracted and miss critical information. Therefore, information overload will not help drivers and may even cause serious problems by distracting them. Figure 5 illustrates the impact of information provision on each element of the mental model. The dashed box represents the contribution of information during each stage. To prevent negative effects resulting from interference of ITS systems or other sources, analyses of information optimization and allocation is crucial for future ITS development and application (Verway, 2000).

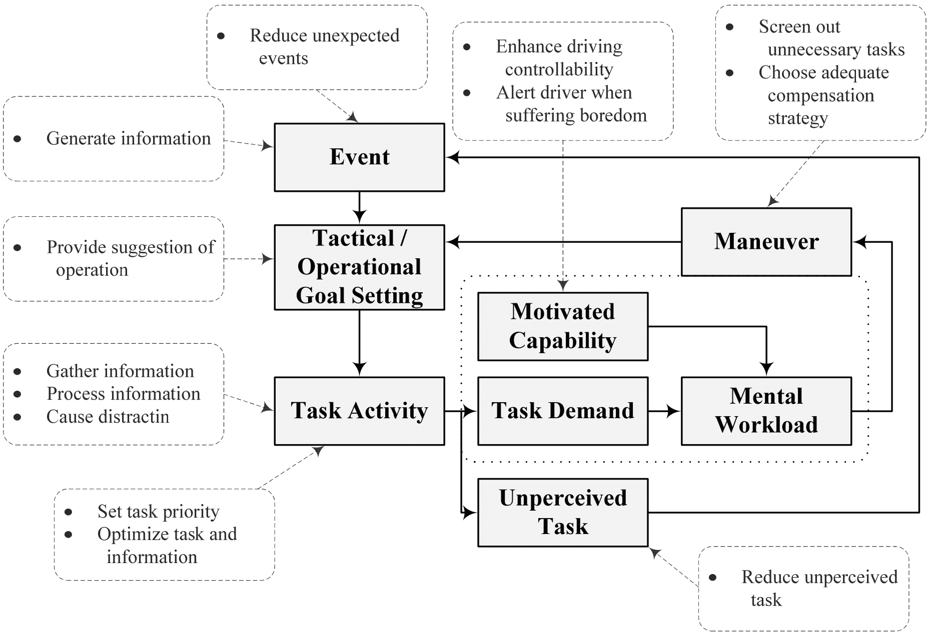


Figure 5 Impact of information provision

As shown in Figure 5, information can contribute to mental workload in each stage of driving and can simultaneously exert positive and negative effects. Furthermore, differences in the reactions of individual drivers to external stimulation, information customization and personalization must be considered. The success in doing so depends on a workable mental workload model. Individual capability and reaction to task demand changes in response to certain information under specific conditions should be evaluated. Consequently, via the proposed research framework, information prioritization hopefully can be conducted and effectively provided for each scenario, thus helping drivers select the most appropriate strategy.

6. ISSUE DISCUSSION

Analyzing accidents from the perspective of the individual mental model can help clarify the nature of accident causation and the interactions involved in the cognition associated with driving. This study presents a research framework for a mental model that incorporates task demand and capability to measure mental workload. However, several issues are worthy of consideration.

The first issue is overall mental model formulation. Most studies have focused on the interaction between task demand and mental workload. By giving a series of primary tasks and secondary tasks to drivers, researchers are able to observe changes in overall mental workload towards task activities (Caird *et al.*, 2008; de Waard *et al.*, 2008; Horberry *et al.*, 2006a; 2006b; Liu and Lee, 2005; Verway, 2000). However, the level of mental workload is based on the difference between task demand and driver capability (Fuller, 2005). Neglecting the contribution of capability might bias the interpretation of mental workload. Several studies have discussed the effect of gender and age on the basis that they possibly reflect a driver's capability (Caird *et al.*, 2008; Fuller, 2005; Hancock *et al.*, 2003; Liu and Lee, 2005; Makishita and Matsunaga, 2008), but few have discussed the capability motivated in different situations and personality characteristics.

The second one is measurement. To clarify the interaction between capability and task demand, measuring and quantifying each element is important. However, no index of task demand equivalent can be adopted to evaluate task demand intensity. The same difficulty occurs when measuring driver capabilities or determining the threshold of optimum workload. Moreover, capability is dynamic and varies with changes in driving task activities. Though "capability" is used here, in reality drivers may have multiple capabilities, each of which can be influenced by different task demands. Identifying and clarifying task demand and capability is a major challenge and also a critical step in constructing the mental workload model.

The subsequent difficulty in developing a mental model lies in measuring mental workload. Since the workload is difficult to directly observe and quantify, latent variables were used as measurements. The most commonly adopted approaches can be broadly divided into three categories: subjective self-report questionnaire (Hart and Staveland, 1988; Horberry *et al.*, 2006a), physiology measurement (de Waard *et al.*, 2008; Hill and Boyle, 2007) and driving performance (Törnros *et al.*, 2006; Vashitz *et al.*, 2008). However, sensitivity of each measurement may vary with the situations. Horberry *et al.* (2006a) found that performance difference is not significant in low mental workload conditions despite subjective questionnaires showing that drivers had been influenced by tasks. Considering differences in measurement characteristics, an integrated indicator incorporating each methodology should be considered (Jung and Jung, 2001; Miyake, 2001).

The fourth is model structure. The inverse proportion relation between workload margin and mental workload indicates that a two-stage model structure deserves considerations. When the workload margin is comparatively high, driving task turns out more like an automated behavior and drivers do not have to allocate too many resources on driving and have a larger buffer to perform other secondary tasks. Previous studies also revealed that differences in secondary tasks or task complexity do not make any difference in mental workload under simple scenarios (Horberry *et al.*, 2006a; Liu and Lee, 2005; Matthews *et al.*, 2003). Once the task demand exceeds the threshold, mental workload begins to increase with increasing task demand.

Finally, according to Figure 3 and Figure 4, the mental workload model is designed to identify the causative links between disaggregate information and accident occurrence. However, mental workload overload is not necessarily linked to accidents. Instead, the issue of mental workload should be considered a critical element in the accident chain. Accident occurrence relies on interaction among drivers, the environment and other road users. The relationship between mental workload model and accident model requires further exploration.

7. CONCLUDING REMARKS

Mental model is a critical element for clarifying the nature of traffic accidents. Previous studies mostly focused on the interaction between contributing factors and the occurrence of accidents. However, accident prone scenario can only explain what accidents occur and the mechanisms through which they occur, but not why they occur. Since drivers perceive external stimuli and control vehicles, understanding the characteristics of driver mental process is crucial for clarifying the question of “why drivers fail to maintain safety under certain circumstances.” To fill the gap, developing a research framework is an important step towards the development of a workable mental model to gain insight of accident causality.

Review of the related literature reveals several difficulties in assessing mental workload. First, task demand and motivated capability, which can be seen as the demand and supply of mental resource, represent the two major components of the mental workload model. Focusing on either task or capability only cannot reveal the nature of driving mental process. Second, considering the complexity of real driving environments, drivers perceive multiple events simultaneously while driving. Single factors such as driving speed, headway or distraction level do not reflect the true situation. Meanwhile, task demand and motivated capability are considered a dynamic system which varies according to driving conditions. Without a further understanding of state transit that may affect mental workload, the nature of driving mental process can not be clarified.

Issues of mental workload models still require further discussion and study. Identifying the cognitive interaction of drivers while driving is a necessity for understanding accident causality. Therefore, this study proposed a research framework that incorporates task demand and capability to identify mental workload. Furthermore, drivers have increasing access to information. The provision of large quantities of poor quality information, however, can create serious problems of information overload and distraction. Applying the mental workload model in accident chain analyses enables the discussion of the net effect of information on mental workload. Optimized information hopefully can be defined and provided to drivers in different scenarios without causing additional risk of accidents.

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