Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 162 (2014) 310 – 319

Procedia
Social and Behavioral Sciences

XVIII Congreso Panamericano de Ingeniería de Tránsito, Transporte y Logística (PANAM 2014)

Mental Workload, Task Demand and Driving Performance: What Relation?

Fátima Pereira da Silva[a]*

[a]*Polytechnic Institute of Coimbra, Rua Dom João III, Solum, 3030-329 Coimbra, Portugal*

Abstract

This article aims to contextualize the conceptual definition of mental workload, conducting a review of its relation with driving task demands. In addition, it presents an overview of measurement tools used for evaluating driver mental workload.

Peer-review under responsibility of PANAM 2014.

Keywords: Mental workload, driving task, task demand, performance.

1. Workload and Mental Workload

Concerns related to the relationship between driving task demands, performance and human capacity appeared more than thirty years ago (Pereira da Silva, 2003). Focus was placed mainly in aviation industry, where the need to evaluate performance of pilots and air traffic controllers was increasingly important. Concomitantly, the concept of workload and mental workload was emerging as an important aspect to be considered not only in the evaluation of professional drivers, but also in the domain of scientific research.

Theoretical development of the concept was designed after an OTAN conference, with a following publication of the book *Mental Workload* (Moray, 1979). After the publication of conference conclusions, several theoretical studies emerged, approaching implications of mental workload evaluation in several organizational contexts (Parasuraman & Hancock, 2001). The need for a proper understanding of the interaction between human-machine systems, the advantages and limitations underlying this interaction and also the economic interest resulting from

* Corresponding author. Tel.: +351-965-006-455.
E-mail address: mpereira@esec.pt

Peer-review under responsibility of PANAM 2014.
doi:10.1016/j.sbspro.2014.12.212

greater profitability of this process were associated within theoretical research and practical implications of the mental workload concept (Pauzié & Manzano, 2007; Piechulla et al., 2003; Wu & Liu, 2009). In many organizational contexts, and air and land transport industry, mental workload began to be associated with studies on safety and effectiveness of operator performance. In this context, matters related to the limit and amount of mental effort, and tasks allowing to maintain an adequate level of performance began to guide research, with an emphasis on the relationship between task demand and operator capabilities (and features) (De Waard, 1996; Verwey, 2000).

In a simplistic way, workload concept can be defined and perceived as a demand placed to the man (De Waard, 1996). However, according to De Waard (1996), this is a very simplistic view, in that it puts more emphasis on external demands. Accordingly, workload is not reflected only on a particular task, but also, and inherently, reports to a specific person (Rouse et al., 1993). Hoedemaeker (2002) argues that workload is defined by the amount of resources required by a set of concurrent tasks, as well as by the use of resources needed to perform them. In an attempt to categorize workload, the author distinguishes three types: (a) visual workload (e.g., for many types of sources have the driver to look?); (b) motor workload (e.g., what should driver do with their hands and feets?); (c) mental workload (e.g., how many types of information has the driver to process?).

Specifically, mental workload involves various processes, where neurophysiologic, perceptual and cognitive processes are included (Baldwin & Coyne, 2003), and can be defined as the proportion of information processing capability used to perform a task (Brookhuis & De Waard, 1993, 2000; De Waard, 1996; Kahneman 1973). As stated by Brookhuis et al. (2009), mental workload reflects not only task specificities, but also performer features. In other words, individual capabilities and characteristics (e.g., age, driving experience), motivation to perform the task, strategies applied on task performance, as well as physical and emotional state affect the workload experienced (e.g., Verwey, 2000). In turn, evaluation of mental workload translates the ratio of mental capacity applied in task performance (O'Donnell & Eggemeier, 1986; De Waard & Brookhuis, 1997), attending to information processing cost, also mentioned as mental effort (Mulder, 1986). Mental effort is similar to what is commonly indicated as 'make the best' or 'try hard' to achieve a particular level or goal (Broohkuis & De Waard, 2010). Mulder (1986) distinguishes two types of mental effort, specifically the mental effort applied on information processing in a controlled mode (i.e., computational effort) and the mental effort needed to apply when operator's energy state is affected (i.e., compensatory effort). While controlled mode is used to maintain an adequate level of task performance, for example, considering variations in task complexity or introduction of secondary tasks; compensatory mode is applied when performance decreases until a certain level, for instance, of fatigue. This compensatory effort is only possible until a certain point, because when there are extreme levels of effort, task difficulty and mental workload increase. As an alternative approach to the application of high levels of effort, which are defined by the interaction between operator and task, operator may decide to apply adaptive strategies (e.g., Merat et al., 2005).

Considering suitability degree, mental workload can vary between low (i.e., underload) and very high levels (i.e., overload) (Brookhuis & De Waard, 2010; De Waard & Brookhuis, 1997). These two extremes of the optimal level (i.e., level at which operator feels comfortable, can manage task demands and maintains a good performance) are classified as inappropriate and can lead to imperfect or inaccurate perceptions, as well as to low levels of attention and capacity, and to insufficient time for a proper information processing (Brookhuis & De Waard, 2010; De Waard & Brookhuis, 1997; Lenné et al., 1997; Leung & Starmer, 2005; Ng Boyle et al., 2008; Nilsson et al., 1997; Rakauskas et al., 2008; Thiffault & Bergeron, 2003; Verwey & Zaidel, 1999). High levels of mental workload occur when task demands exceed performer capacity (Loft et al., 2007).

2. Mental Workload, demand and performance in driving task

According to Kantowitz & Simsek (2001), much of the research is consistent to assume that accident risks are strongly associated with driver mental workload, attending to the impact that it has on driving task performance and road safety. As stated by Kantowitz (2000), the most common types of collisions involve, as a rule, lack or loss of attention.

Driving a vehicle in the twenty-first century is, increasingly, a complex task that involves extreme fluctuations in mental workload (Baldwin & Coyne, 2003; Verwey, 2000). Considering the increasing difficulty of driving task and the multitude of information that drivers have to process and manage inside and outside the vehicle, there are multiple potentially triggering factors of driver mental workload (Baldwin & Coyne, 2003; Silva 2003). The increase of traffic intensity and the introduction of new information technologies inside the vehicle pose new demands and increased levels of complexity to driving task (Engström et al., 2005; Jahn et al., 2005; Makishita & Matsunaga, 2008; Pauzié & Manzano, 2007; Piechulla et al., 2003). Stress, fatigue and motivation for risk-taking behaviours are some examples of human factors that limit an effective performance of drivers, which is associated to the excess of information inside and outside the vehicle and the consequent increase of distribution level in visual and auditory resources (Makishita & Matsunaga, 2008). In all these situations, driver mental workload is affected.

The permanent adaptive control approach is an important basis for understanding the relationship between mental workload, driving performance and task demand (as perceived by driver) (e.g., De Waard, 2002). In this context, there are moments on driving performance where simultaneous increase in number of tasks can increase their demand, resulting in an increase of mental effort invested, and also in a decrease of performance efficiency. There are other situations in which a decrease of driver ability implies an increase in mental workload. Decrease of driver ability can be triggered by various factors such as: monotonous traffic environment; driver experience type; or presence of circumstantial contexts (e.g., fatigue or sickness). In other situations, driving performance is stable, although there is an increase of mental effort invested. Thus, mental effort invested by driver may reflect how to maintain its performance in an appropriate or acceptable level.

In the words of Parasuraman & Hancock (2001), "human performance is thus the result of task demand effects and mediators factors related to its adaptive strategies" (p. 307). According to the authors, it is easily expected that there is an association or linear relation between task demand and mental workload, that is, when there is a high task demand, there is also a high level of mental workload. However, as stated above, it is not always so, because drivers develop a set of strategies that enable them to manage mental workload and regulate their performance. Thus, it is not possible to establish an association or a linear relation between task demand and mental workload, as this association is always dependent on strategies and internal factors of each operator. Also according to Parasuraman & Hancock (2001), there is a large number of situations where it is evident some insensitivity, and this means that even when there is an increase or decrease on task demand, it is possible to verify no changes in driver workload. There is another process, also described by Wickens & Yeh (1988) and Hancock (1996), defined by Parasuraman & Hancock (2001) as dissociation, which represents the moment when task demand increases and driver workload decreases. Considering the perspective of an integrated system in which task demand, adaptive strategies, workload and performance are closely related or interdependent, a change in each of these factors consequently affects all system.

3. Evaluation of Driver Mental Workload

A large part of research related with workload evaluation was and still is connected to the field of aviation industry (e.g., Hancock & Verwey, 1997; Loft et al., 2007). In those researches, pilots have to perform a complex task in extreme conditions, being the selection of pilots so strict that usually only young and without health limitations people are chosen (De Waard, 1996). The same does not happen when we are focused on evaluation of automobile driving task, where selection criteria concerning future drivers is much less restricted and, as a result, driving population is much more diverse in terms of skills, abilities and characteristics. We can even accept that the majority of drivers may not be prepared to drive modern cars and motorbikes at high-speed because of their potentialities.

Since each person uses different strategies, these can be applied more or less effectively and with more or less effort to achieve the same performance level (De Waard, 1996). If workload is defined taking into account driver and driving task, we can not only evaluate task demand, because individual differences and operator state also have an impact on mental workload (De Waard, 1996, 2002). Thus, assessment of mental workload is related to task difficulty such as it is experienced by the person, since many reactions are possible due to demands of the same task (Pauzié & Pachiaudi, 1996). According to Brookhuis & De Waard (2010), it can be pointed out three main reasons for the currently and in the near future importance of assessing mental workload, mainly due to changes in driving conditions over the last decades. Firstly, nature of driving task has undergone changes that have been extended from physical effort to cognitive effort, from calm interaction with other road users to traffic situations with high levels of complexity. Secondly, accidents have been numerous, with causes that are mainly attributed to victims themselves. Finally, human errors in road traffic related to mental workload (in the form of inaccurate perceptions, insufficient attention and inefficient information processing) are among the main causes of most road accidents (e.g., Smiley & Brookhius, 1987). The range of factors mentioned previously defines not only the specificity of workload analysis under road traffic, as well as their relevance.

3.1. Critical moment for evaluation

Considering the inherent relationship between mental workload, task demand and performance, Meister proposed, in 1976, an evaluation model that incorporates those valences. This model proposes the existence of three regions: region A, region B and region C. In region A, there is a weak task demand, a low workload and a high level of performance. If in this region happens an increase on task demand, performance efficiency is not compromised. In region B, operator's performance level decreases due to the increase of task demand, and may result on an increase in workload.

In region C, there is a drastic decrease in performance as a result of an increase of task demand level and high levels of workload. Here, performance can be maintained at minimum levels of efficiency even when there is an increase of demand level. According to the author, region B represents the moment for determining the sensitivity of measures for evaluation of performance and mental workload. Specifically, measures of performance evaluation tend to remain stable in regions A and C, as they do not undergo changes that can be caused by task demand level. Moreover, evaluation measures of mental workload may show an overworkload in region C, while region B can also show some sensitivity. Region A is not presented as a sensitive region to assess workload experienced.

De Waard (1996) sought to complement the model of Meister (1976) and proposes the introduction of a region D (called desactivation) that is located before region A and reflects the effects and implications of monotonous tasks performance. As they possess a low demand level, monotonous tasks may precipitate an increase of task difficulty by reducing capacity, which happens in monotony and boredom. These states require investment of a greater ability to perform the same task, with a consequent increase in mental workload.

Although the described model can help us to understand the extremes of the process where region D features a low performance and a high workload, and in the opposite region (C) remains the same situation, there is not a clear specification of what is a high level of mental workload. This question brings us to questions of where is the boundary between a high *versus* moderate *versus* low workload, and what is the critical moment termed as red line (De Waard, 1996; Kantowitz, 2000). The notion of red line is associated with resources limits available by operator, reflecting the time when performance decreases sharply (De Waard 1996; Kantowitz 2000; Reid & Colle, 1988).

Given that, in recent years, the answer to the question "(...) how must workload is too much" (De Waard, 1996, p. 98) has received particular attention in the context of road traffic research, the concept of red line for mental workload has become useful, allowing to establish consequences of high levels of driver mental workload. For example, Reid & Colle (1988) report that the area par excellence where performance decreases (i.e., placement of red line) is located in the transition from region A to region B.

De Waard (1996), discriminating the exact moment that the decreased performance happens, proposes a partition of region A into several sub-regions. Thus, in the middle part of region A (called A2), operator can still easily handle with task demand and performance remains at a stable level even when there is an increase in task demand (i.e. there is not an increasing of effort); in sub-region A3, operator fails to maintain performance level without increasing effort, but evaluation measures do not show a decline of performance. In this sub-region can happen a temporary compensation for the use of occasional and not critical effort, which only reflects some operator adaptability and flexibility. However, if workload peaks in this sub-region start happening too often or if effort lasts to ensure performance, it emerges stress states, some disability, or scarcity situation, which need to be addressed. At this time, there may arise a critical moment, where operator can lose control of the situation (i.e., red line). If effort increases and difficulty between demand and performance occur, it seems plausible to assume that the critical moment for mental workload happens in the transition from sub-region A2 to A3. In turn, the transition from region D to region A1 is associated with monotony experienced by operator when he undertakes a major effort for not diminishing performance level. Thus, it is through a greater effort that operator does not change his performance.

In sum, we can classify various regions as follows: region D (desactivation), operator state is affected, showing a high workload and a low performance; region A2, performance level is considered as optimal and operator can easily handle with task demands; regions A1 and A3, performance does not change, but operator must use effort to maintain performance; in region B, there is a performance decline; and in region C, performance remains at a minimum level and operator has an experience of overworkload.

3.2. Measurement tools

In a literature review on methodologies for evaluating workload, Eggemeier & O'Donnell (1986) distinguish two selection criteria for measurement tools, including sensitivity (if technique or tool can discriminate between different levels of workload) and diagnosticity (if technique or tool can distinguish different types of workload). De Waard (1996) also adds as criterion the primary task interference, that is, the extent to which the introduction of a new task can damage performance of an essential or priority task.

There are three main types of measures for assessing driver mental workload, specifically: (1) subjective self-report measures; (2) performance measures; and (3) physiological measures (Baldwin and Coyne, 2003; Brookhuis & De Waard, 2002; Cantin et al., 2009; O'Donnell & Eggemeier, 1986).

3.2.1. Subjective self-report measures

Subjective self-report measures consist in the application submitted to the driver, attending to perceived level of task demand, and being widely used in research (Silva, 2003). As reported by De Waard (1996), "(...) no one else is more prepared to provide an accurate judgment on workload experienced than oneself" (p. 31). De Waard (2002) points out some advantages in its use: (a) in addition to the reduced application cost, they have a high validity; (b) they do not interfere with primary task performance when they are applied immediately after completing the task.

Regarding their disadvantages, Eggemeier & O'Donnell (1986) reported that sometimes it becomes difficult to discriminate adequately between physical workload and mental workload, and the person may be unable to distinguish between what are external task demands and mental effort experienced, and to quantify effective and properly the mental effort invested (De Waard, 2002). Brookhuis & De Waard (2000) also highlight the disadvantage of disability experienced by some people for detecting internal changes.

Considering the typology of subjective self-report measures, these can be unidimensional or multidimensional, being respectively related to the evaluation of one or more dimensions inherent to mental workload. Regarding unidimensional measures, we can highlight MCH-Modified Cooper Harper Scale (Cooper & Harper, 1969) that is made up of ten items, and RSME Rating Scale Mental Effort (Zijlstra, 1993; Zijlstra & Van Dorm, 1985) that evaluates only the proportion of mental effort invested in a task, which is marked by a cross in a continuous vertical line. Minimum and maximum of the scale are from 0-150 mm and all ranges of 10 mm are indicated. Along vertical line there are some landmarks identified with a verbal descriptor of effort (Hoedemaeker, 2002), ranging from "no effort" to "extreme effort". It should be noted that RSME is increasingly used to assess mental workload on traffic sector. Additionally, Vetman & Verwey (1996), by using nine measures for assessing mental workload in very short periods of time, found that RSME is one of the most sensitive measures of mental workload. According Hoedemaeker (2002), although presenting some sensitivity to changes in task difficulty, MCH is not as sensitive as NASA-TLX (multidimensional scale), or as RSME.

Regarding multidimensional measures, we can point out NASA-Task Load Index (NASA-TLX) (Hart and Stavelan, 1988) and Subjective Workload SWAT-Assessment Technique (Reid & Nygren, 1988). NASA-TLX is one of the most widely used multidimensional measures and evaluates six factors: mental demands, physical demands, temporal demands, performance, and effort and frustration levels. Its usefulness is mainly related to the workload evaluation after long periods of time, not showing, however, sensitive in detection of mental workload peaks or small increases (Hoedemaeker, 2002). As a limitation of NASA-TLX, Brookhuis & De Waard (2000) point out the lack of clarity in the attribution of mental and physical effort. SWAT considers the evaluation of three dimensions: time stress, mental effort, and psychological stress. According to Hoedemaeker (2002), although its evidence of validity and sensitivity, SWAT is not so sensitive and valid as NASA-TLX.

It is important to state that unidimensional scales have been more appropriate when assessing mental workload aims to determine a single overall measure (Silva, 2003). Additionally, according to De Waard (1996), if unidimensional scales are used separately in each dimension of the task, they also can provide multidimensional properties.

3.2.2. Performance measures

Performance measures are based on techniques of direct registration of driver ability to perform the driving task at a level considered acceptable and safe, and properly maintain the vehicle on the road without colliding with other participants of the road. Overall, we can consider two main groups of measures: (1) direct measurements, that is, they are only focused on performance of the main or primary driving task; (2) indirect measurements, which associate a secondary task to the primary driving task.

Performance measures focused on the main or primary driving task include the basic levels of driving task (i.e., levels of control and maneuver) (Michon, 1985; Theeuwes, 2002), where control of lateral and longitudinal position and running, and speed are considered (De Waard, 1996, 2002; Törnros & Östlund, 2002).

Attending to control of lateral position, this consistes into maintaining the vehicle on the road, within its limits, and it is a psychomotor task involving eye-hand coordination. This performance can be studied through variations occurred in lateral position and also through time that occurs before crossing a road. It can be assessed using perceptive measures, answered by driver or observers, as well as through objective measures. The latter are more feasible in national and rural roads, insofar as urban roads have several intersections and narrow streets that make it difficult to obtain an accurate measure of lateral position (Törnros & Östlund, 2002). According to De Waard (2002), lateral position deviation becomes one of the most important indicators of deficiencies in driving, and it can be translated by the possibility of the driver leave road centreline and get involved in an accident. The number of lateral position deviations increases if driver energy state is not appropriate after, for example, alcohol consumption, use of drugs or states of fatigue (De Waard, 2002). Also mobile phone use may precipitate a decrease in control of lateral position (De Waard, 1996). Lateral position desviations are presented as a measure of performance very sensitive (Brookhuis et al., 1985; Hicks & Wierwille, 1979; O'Hanlon, 1984; O'Hanlon et al., 1982).

Considering longitudinal control, this also allows keeping the vehicle safely, and its evaluation is usually performed taking into account distance or time of distance. Execution of this kind of manoeuvre requires perception and attention, and reaction time is one indicator considered for assessing driver performance.

Speed control aims to maintain security, prevents vehicle collisions with other vehicles that are in the same direction, keeps a steady flow of traffic and allows always the driver to keeps control even when faced with normal traffic events. This control can be studied by speed variation and speed adopted when compared to what is defined as speed limit, as also as by the time required to correct the speed before colliding with another vehicle (Törnros & Östlund, 2002). The speed increase under influence of distracters elements has been used as an indicator to determine driver inability to control speed. Since increased accidents correlates with increased speed, speed factor may be an indicator of decreased performance (Carvalhais, 2002). Speed is always a performance measure that is dependent on driver, although this may be constrained by high density of traffic and other road users. Always depending on these factors, speed increase or reduction can also translate an adaptive behaviour or a compensatory reaction due to distraction or increased mental workload. Thus, the study of reaction time has been considered a good indicator (Brookhuis et al., 1994).

It is also important to note measures related to time-to-line crossing, where performance lies at manoeuvre level (Michon, 1985). Time-to-line crossing is generally defined by the time required for overcoming any boundary line of traffic queue with any wheel, if speed of shuttlecock rotation angle remains constant. With mental workload increase, it is expected a decrease in the efficiency of such behaviour.

Finally, in the context of evaluation measures focused on the primary driving task, we also have those that are answered by experienced observers (Törnros & Östlund, 2002). These measures have the advantage of being used by observers who have greater sensitivity to numerous risk conditions experienced by drivers. However, these observers can become more flexible in their judgments, which can be pointed as a disadvantage.

The evaluation method that resorts to observers, accompanying drivers, is a method of assessing driving performance initially developed by Risser (1985) to study inexperienced drivers. In this group, Observation Protocol of LUND is an example. This measure is a shortened version of "Wiener Fahrprobe", and it is focused on assessing tactical level of driving (Michon, 1985) and requires the existence of two observers already trained on its evaluation. One observer assesses variables related to driving performance considered as standard (driver condescending behaviour and choice of speed), while the other performs the registration of non-standard behaviours, such as the occurrence of risk situations or conflict with other road users. If there is only one observer, the protocol part considered as non-standard can be excluded. This evaluation method is difficult to apply on simulator or on laboratory, since it implies the existence of an observer inside the vehicle. If video recordings are made, sensitivity and reliability of the method can become smaller (Östlund & Törnros, 2002).

Considering measures that include the introduction of a secondary task, they seek to evaluate saturation point of the limited capacity of mental workload (Cantin et al., 2009), which reflects an operation of single channel for performing mental tasks and seeks to estimate the required proportion of this channel for a successful performance of primary task (Kahneman, 1973; O'Donnell and Cohen, 1993). To assess mental workload required by primary task, performance levels may be compared, that is, comparison between performance when secondary task (or load task) is performed alone and performance achieved when it is performed simultaneously with primary task (Cantin et al., 2009). The purpose of introducing a secondary task is not to disturb the main task (i.e., driving task), but rather to quantify mental workload imposed by various levels of complexity in driving, through changes in performance of secondary task (Cantin et al., 2009). Often, secondary tasks lead to the need to resort to memory, mental calculation, attention, etc. (Pereira da Silva, 2003). An example of this can be related to peripheral detection task, where it is required a manual (or verbal) response to a stimulus presented in the visual (or auditory) field (e.g., Jahn et al., 2005; Makishita & Matsunaga, 2008; Patten et al., 2004; Recarte & Nunes, 2003; Verwey, 2000).

It is important to state that the introduction of a secondary task becomes useful and relevant for researches that aim to study the relationship between intelligent systems introduced in vehicles and mental workload (Verwey & Veltman, 1996). Although those technological systems bring advantages, they may lead to greater distraction and driver mental overworkload, and may be considered as risk factors for accident occurrences (Ma & Kaber, 2005; Pauzié & Manzano, 2007; Verwey & Veltman, 1996).

3.2.3. Physiological measures

Physiological measures evaluate the answers given by peripheral and central nervous system during driving performance, and may involve, in particular: (a) heartbeat measuring; (b) electroencephalogram; (c) electro-myogram; (d) evaluation of eye movement and pupil dilation; (e) blood pressure evaluation; (f) assessment of breath levels; (g) assessment of electro-dermal activity; and (h) determination of hormone levels. Their main advantage lies in the fact that they do not involve a clear and objective response from the driver (De Waard, 2002). According Mehler et al. (2009), given the results obtained in their study, physiological measures are sensitive to changes in mental workload levels before registering clear decrements in driving performance. On the other hand, their application requires the use of a complex methodology, difficult to implement in real traffic situations, which is appointed as a disadvantage (Pauzié & Manzano, 2007).

In summary, it is noteworthy that in the study developed by Verwey & Veltman (1996), which evaluated the sensitivity and diagnosticity of a set of measures, the authors concluded that subjective measures (notably RSME-Rating Scale Mental Effort) are presented as the most sensitive to mental workload.

Considering the combined use of several types of measures, De Waard (2002) states that "the most important factor in determining the mental workload is change" (p. 171), and for coping with change in a dynamic environment with permanent changes it is justified the use of different types of measures in the evaluation of driver mental workload.

4. Conclusion

This article aimed to contribute for sustaining the relevance of mental workload concept under the road traffic literature, given theoretical and evaluation issues that have been addressed in this field. Thus, it is relevant to emphasize two main conclusions. Firstly, it persists the need to clarify mental workload concept, since it still exists an absence of a satisfactory and consensual definition for it (Parasuraman & Hancock, 2001). In this context, it is necessary a better understanding on the relationship between mental workload and other processes, including those that are cognitive in nature (e.g., attention, effort). Further clarification of mental workload role within a wider relational and interdependent puzzle can be considered a major factor for effectiveness and efficiency of its assessment and its implications on driver behaviour. If virtually all forms of man-machine interface imply interaction, mental workload assessment becomes a relational form and an important tool for understanding the demands placed on human performance (Pereira da Silva, 2003). Thus, it should be noted that mental workload could become an indicator of the relational effectiveness between new technologies demands and human capacity.

The second conclusion is related to measures for assessing mental workload. Literature review allowed to verify that measures that involve an introduction of a secondary task, as well as physiological measures are among the most used in recent research. Concomitantly, also because of difficulties associated to application of those measures, driving simulators can be identified as the most widely used methodological environment in researches. As referred by Brookhuis & De Waard (2010), the study of certain variables on an ecological context (i.e., real road situation), such as the case of mental workload, is difficult and often considered ethically unacceptable (or even impossible). Thus, according to the authors, simulators allow the creation of real conditions and situations without any objective risk, functioning as instrumentally important research laboratories.

Current demands of driving task are no longer only physical and became, par excellence, cognitive (Brookhuis & De Waard, 2010; Parasuraman & Hancock, 2001). Thus, it is necessary to understand the kind of specificity and demand that is currently placed on driver, on the limits of his performance capability and on the amount of mental workload that he can process without diminishing performance. Underlying current demands, we also can find the dominant and growing up introduction of automation and complex technological systems in vehicles. The main reason for electronics systems development corresponds to security support, insofar as human factor is appointed as the main cause of accidents (e.g., Brookhuis et al., 2009). These systems seek to reduce human error in information processing required by complex traffic conditions (Hancock & Verwey, 1997). However, they can contribute, on the one hand, for mental underworkload and, secondly, to its overworkload. Thus, some researchers put forward the hypothesis that deal with mental underworkload can become a problem as complex and difficult as dealing with mental overworkload (e.g., Young & Stanton, 2007). For example, Engström et al. (2005) and Brookhuis et al. (2009) state that those systems induce secondary tasks that are concurrent to primary task of driving. This point has rose, according to the authors, increased concerns about potential negative effects particularly related to excessive workload and distraction, especially in potentially dangerous situations. That is, they may inherently contribute to increased levels of mental workload, to the extent that they add information on those situations (Hancock & Verwey, 1997; Jahn et al., 2005; Pauzié & Manzano, 2007; Verwey, 2000).

It is therefore important to clarify and obtain a detailed understanding of the relationship between different technological systems introduced in vehicles, their demands, and their effect on levels of driver mental overworkload and driver performance (Engström et al., 2005; Jahn et al., 2005; Ma & Kaber, 2005). Hence, it is important to take into account all specific characteristics of different groups of operators. Definition and delimitation of a comprehensive path are, thus, presented as particularly interesting and relevant for designing and implementating new technological systems that have continuously been created and should be adjusted to expectations, needs, requirements and capacities of drivers (Pauzié & Manzano, 2007; Piechulla et al., 2003; Liu and Wu, 2009). That is, creation and application of man-centered systems. Thus, it emerges the need to design optimized vehicles where information systems aim to help driver, delegating their intervention to strategic decisions (Pauzié & Manzano, 2007). For effective technology, it is important to attend to the way driver concurrently manages driving task. For a continuous level of optimization achievement, mental workload should be continuously asserted as a relevant area of research interest, where theoretical and empirical knowledge needs further development.

References

Baldwin, C. L. & Coyne, J. T. (2003). Mental workload as a function of traffic density: comparison of physiological, behavioral, and subjective indices. *Proceedings of the Second International Driving Symposium on Human Factors*, 19-24.

Brookhuis, K. A. & De Waard, D. (2000). Assessment of driver´s workload: performance and subjective and physiological indexes. In P.A. Hancock & P. A. Desmond (Eds.), *Stress, Workload, and Fatigue* (pp. 321-333). London: Lawrence Erlbaum Associates, Inc.

Brookhuis, K. A. & De Waard, D. (1993). The use of psychophysiology to assess driver status. *Ergonomics 36*(9), 1099-1110.

Brookhuis, K. A., Louwerens, J.W. & O' Hanlon, J. F. (1985). The effect of several antidepressants on EEG and performance in a prolonged car driving task. In W.P. Koella, E. Ruther and H. Schulz (Eds.), *Sleep' 84* (pp. 129-131). Stuttgart : Gustav Fisher Verlag.

Brookhuis, K. A., De Waard, D. & Mulder, L. J. M. (1994). Measuring driving performance by car-following in traffic. *Ergonomics 37*(3), 427-434.

Brookhuis, K. A. & De Waard, D. (2002). On the assessment of (mental) workload and other subjective qualifications. *Ergonomics 45*(14), 1026-1030.

Brookhuis, K. A. & De Waard, D. (2010). Monitoring drivers' mental workload in driving simulators using physiological measures. *Accident Analysis & Prevention 42*(3), 898-903.

Brookhuis, K. A., Van Driel, C. J., Hof, T., Van Arem, B. & Hoedemaeker, M. (2009). Driving with a congestion assistant, mental workload and acceptance. *Applied Ergonomics 40*(6), 1019-1025.

Cantin, V., Lavallière, M., Simoneau, M. & Teasdale, N. (2009). Mental workload when driving in a simulator: effects of age and driving complexity. *Accident Analysis & Prevention 41*(4), 763-771.

Carvalhais, J. D. (2002). *WP2 - Pilot Dependent Measures-Internal Deliverable.* Human Machine Interface and the Safety of Traffic in Europe (HASTE) Project (Report no. GRD1/2000/25361). Institute for Transport Studies, University of Leeds, Leeds, UK.

Cooper, G. E. & HARPER, R. P. (1969). *The use of pilot rating in the evaluation of aircraft handling qualities*. Moffett Field, C. A. National Aeronautics and Space Administration, Ames Research Centre, NASA Report Tn-D-5153.

De Waard, D. (1996). *The Measurement of Driver's Mental Workload* (PhD thesis). Traffic Research Centre, University of Groningen, Haren, NL.

De Waard, D. (2002). Mental workload. In R. Fuller and J. A. Santos (Eds.) *Human Factors for Highway Engineers*. (pp. 161-175). Netherlands: Pergamon Press.

De Waard, D. & Brookhuis, K. A. (1997). On the measurement of driver mental workload. In J.A. Rothengatter and E. Carbonell Vaya (Eds.) *Traffic and Transport Psychology* (pp. 161-171). Amsterdam, N. L. : Pergamon.

Engström, J., Johansson, E. & Östlund, J. (2005). Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part F: Traffic Psychology and Behaviour 8*(2), 97-120.

Hancock, P. A. (1996). Effect of control order, augmented feedback, input device, and pratice on tracking performance and perceived workload. *Ergonomics 39*(9), 1146-1162.

Hancock, P. A. & Verwey, W. B. (1997). Fatigue, workload and adaptive driver systems. *Accident Analysis & Prevention 29*(4), 495-506.

Hart, S. G. & Staveland, L. E. (1988). Development of the NASA-TLX (Task Load Index): results of empirical and theoretical research. In P.A. Hancock & N. Meshkati (Eds.) *Human Mental Workload* (pp. 139-183). North Holland, Amsterdam: N. L..

Hicks, T. G. & Wierwille, W. W. (1979). Comparison of five mental workload assessment procedures in a moving-base driving simulator. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 21* (2), 129-143.

Hoedemaeker, M. (2002). *Summary Description of Workload Indicators: WP1 Workload Measures. Human Machine Interface and the Safety of Traffic in Europe Growth Project.* GRD1-2000-25361. HASTE. Institute for Transport Studies. Leeds, UK: University of Leeds.

Jahn, G., Oehme, A., Krems, J. F. & Gelau, C. (2005). Peripheral detection as a workload measure in driving: effects of traffic complexity and route guidance system use in a driving study. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(3), 255-275.

Kahneman, D. (1973). *Attention and Effort*. New Jersey: Prentice Hall.

Kantowitz, B. H. (2000). *Attention and mental workload*. *Proceedings of the Human Factors and Ergonomics Society* (pp.456-460). *Annual Meeting*. Human Factors and Ergonomics Society, Santa Monica, C.A.

Kantowitz, B. H. & Simsek, O. (2001). Secondary-task measures of driver workload. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, Workload, and Fatigue* (pp. 395-407). London: Lawrence Erlbaum Associates, Inc.

Lenné, M., Triggs, T. J. & Redman, J. R. (1997). Time of day variations in driving performance. *Accident Analysis & Prevention 29*(4), 431-437.

Leung, S. & Starmer, G. (2005). Gap acceptance and risk-taking by young and mature drivers, both sober and alcohol-intoxicated, in a simulated driving task. *Accident Analysis & Prevention 37*(6), 1056-1065.

Loft, S., Sanderson, P., Neal, A. & Mooi J, M. (2007). Modeling and predicting mental workload in en route air traffic control: critical review and broader implications. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 49* (3), 376-399.

Ma, R. & Kaber, D. B. (2005). Situation awareness and workload in driving while using adaptive cruise control and a cell phone. *International Journal of Industrial Ergonomics, 35* (10), 939-953.

Makishita, H. & Matsunaga, K. (2008). Differences of drivers' reaction times according to age and mental workload. *Accident Analysis & Prevention, 40* (2), 567-575.

Mehler, B., Reimer, B., Coughlin, J. F. & Dusek, J. A. (2009). Impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers. *Transportation Research Record: Journal of the Transportation Research Board 2138*(1), pp. 6-12.

Meister, D. (1976). *Behavioral Foundations of Systems Development*. New York, NY: Wiley.

Merat, N., Antilla, V. & Luoma, J. (2005). Comparing the driving performance of average and older drivers: the effect of surrogate in-vehicle information system. *Transportation Research Part F: Traffic Psychology and Behaviour, 8* (2), 147-166.

Michon, J. A. (1985). A critical view of driver behaviour models: what do we know, what should we do? In L. Evans & R. C. Schwing (Eds.), *Human Behavior & Traffic Safety* (pp. 485-524). New York, N. Y.: Plenum Publishing Company.

Moray, N. (1979). *Mental Workload*. New York, N.Y.: Plenum.

Mulder, G. (1986). The concept and measurement of mental effort. In G. R. J. Hockey, A. W. K. Gaillard & M. G. H. Coles (Eds.), *Energetics and Human Information Processing* (pp. 175-198). Dordrecht, N. L.: Martinus Nijhoff Publishers.

Ng Boyle, L., Tippin, J., Paul, A. & Rizzo, M. (2008). Driver performance in the moments surrounding a microsleep. *Transportation Research Part F: Traffic Psychology and Behaviour 11* (2), 126-136.

Nilsson, T., Nelson, T.M. & Carlson, D. (1997). Development of fatigue symptoms during simulated driving. *Accident Analysis & Prevention 29* (4), 479-488.

O'Donnell, B. F. & Cohen, R. A. (1993). Attention: a component of information processing. In R. A. Cohen (Eds.), *The Neuropsychology of Attention* (pp. 11-48). New York, N. Y.: Plenum Press.

O'Donnell, R. D. & Eggemeier, F. T. (1986). Workload assessment methodology. In K. R. Boff, L. Kaufman & J. P. Thomas (Eds.), *Handbook of Perception and Human Performance - Cognitive Processes and Performance* (pp. 1-49). New York, N. Y.: Wiley.

O' Hanlon, J. F. (1984). Driving performance under the influence of drugs: rationale for, and applications of, a new test. *British Journal of Clinical Pharmacology 18* (S1), 121S-129S.

O'Hanlon, J. F. O., Haak, T. W., Blaauw, G. J. & Riemersma, J. B. J. (1982). Diazepam impairs lateral position control in highway driving. *Science*, *217*(4554), 79-80.

Östlund, J. & Tornros, J. (2002). *WP1 - Driving Performance Measures.* Human Machine Interface and the Safety of Traffic in Europe (HASTE) Project (Report no. GRD1/2000/25361). Institute for Transport Studies, University of Leeds, Leeds, UK.

Parasuraman, R. & Hancock, P. A. (2001). Adaptive control of mental workload. In: B.H. KANTOWITZ (Eds.), *Stress, Workload, and Fatigue* (pp. 305-320). London, U. K.: Lawrence Erlbaum Associates, Inc.

Patten, C. J., Kircher, A., Östlund, J. & Nilsson, L. (2004). Using mobile telephones: cognitive workload and attention resource allocation. *Accident Analysis & Prevention 36*(3), 341-350.

Pauzié, A. & Manzano, J. (2007). Evaluation of driver mental workload facing new in-vehicle information and communication technology. *Proceedings of the 20th enhanced safety of vehicles conference (ESV20),* Lyon, FR.

Pauzié, A. & Pachiaudi, G. (1996). Subjective evaluation of the mental workload in driving context. In *Traffic and Transport Psychology: Theory and Application* (pp. 173-181). Berksire, U. K.: University of Derby.

Pereira da Silva, M. F. (2003). *Aprendizagem e Comportamentos na Condução Automóvel* (*Learning and Behaviours in Automobile Driving*) (Non-published master thesis). Faculty of Psychology and Sciences of Education, University of Coimbra, Coimbra, PT.

Piechulla, W., Mayser, C., Gehrke, H. & König, W. (2003). Reducing drivers' mental workload by means of an adaptive man–machine interface. *Transportation Research Part F: Traffic Psychology and Behaviour 6*(4), 233-248.

Rakauskas, M. E., Ward, N.J., Boer, E. R., Bernat, E. M., Cadwallader, M. & Patrick, C. J. (2008). Combined effects of alcohol and distraction on driving performance. *Accident Analysis & Prevention 40* (5), 1742-1749.

Recarte, M. A. & Nunes, L. M. (2003). Mental workload while driving: effects on visual search, discrimination, and decision making. *Journal of Experimental Psychology: Applied 9*(2), 119-137.

Reid, G. B. & Colle, H. A. (1988). Critical SWAT values for predicting operator overload. In *Proceedings of the Human Factors Society 32nd Annual Meeting*. Human Factors Society. Santa Monica, C. A.

Reid, G. B. & Nygren, T. E. (1988). The subjective workload assessment technique: a scaling procedure for measuring mental workload. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (pp.185-218*)*. Amsterdam, N. L.: North Holland.

Risser, R. (1985). Behaviour in traffic conflict situations. *Accident Analysis & Prevention 17* (2), 179-197.

Rouse, W. B., Edwards, S. L. & Hammer, J. M. (1993). Modelling the dynamics of mental workload and human performance in complex systems. *IEEE Transactions on systems, cybernetics*, *23*, 1662-1671.

Smiley, A. & Brookhuis, K. A. (1987). Alcohol, drugs and traffic safety. In J. A. Rothengatter & R. A. De Bruin (Eds.), *Road Users and Traffic Safety* (pp. 83-105). Assen, N. L.: Van Gorcum.

Theeuwes, J. (2002). Sampling information from the road environment. In R. Fuller & J. A. Santos (Eds.), *Human Factors for Highway Engineers* (pp. 131-145). Amsterdam, N.L.: Pergamon Press.

Thiffault, P. & Bergeron, J. (2003). Monotony of road environment and driver fatigue: a simulator study. *Accident Analysis & Prevention 35* (3), 381-391.

Verwey, W. B. (2000). On-line driver workload estimation. Effects of road situation and age on secondary task measures. *Ergonomics 43*(2), 187-209.

Verwey, W. B. & Veltman, H. A. (1996). Detecting short periods of elevated workload: a comparison of nine workload assessment techniques. *Journal of Experimental Psychology: Applied 2* (3), 270-285.

Verwey, W. B. & ZaideL, D. M. (1999). Preventing drowsiness accidents by an alertness maintenance device. *Accident Analysis & Prevention 31* (3), 199-211.

Wu, C. & Liu, Y. (2009). Development and evaluation of an ergonomic software package for predicting multiple-task human performance and mental workload in human-machine interface design and evaluation. *Computers & Industrial Engineering 56* (1), 323-333.

Young, M. S. & Stanton N. A. (2007). What's skill got to do with it? Vehicle automation and driver mental workload. *Ergonomics 50* (8), 1324-1339.

Yeh, Y. Y. & Wickens, C. D. (1988). Dissociation of performance and subjective measures of workload. *Human Factors: The Journal of the Human Factors and Ergonomics Society 30*(1), 111-120.

Zijlstra, H. & Van Doorm, L. (1985). *The Construction of a Scale to Measure Perceived Effort.* Department of Philosophy and Social Sciences, Delft University of Technology, Delft, NL.

Zijlstra, H. (1993). *Efficiency in Work Behavior. A Design Approach for Modern Tools* (Published doctoral thesis). Delft University of Technology, Deft University Press, Delft, NL.