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REVIEW OF RECENT RESEARCH IN APPLIED EXPERIMENTAL PSYCHOLOGY: IMPLICATIONS FOR COUNTERMEASURE DEVELOPMENT IN ROAD SAFETY

By

Michael Lenné
Michael Regan
Tom Triggs
Narelle Haworth

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Author(s)
Lenné, M., Regan, M., Triggs, T., & Haworth, N.

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Abstract

Much research that occurs within the field of traffic psychology leads to the development of effective road safety countermeasures. There may, however, be psychological research being undertaken in other domains, such as aviation or mining, that has the potential to both provide new directions for, and enhance the effectiveness of, current road safety countermeasures. The purpose of this report, therefore, was to review recent literature in the broad field of applied experimental psychology and distil from it, where appropriate, recommendations for countermeasure development. This work was completed in three stages.

The first task involved a review of research from selected journals in the period 1998-2002. The research was sorted into logical headings. The general headings that emerged were: information processing and cognition; decision making; mental workload; and human error. The review included research relating to specific fitness for duty issues, such as the effects on driving performance of fatigue, alcohol and drugs. The major advances in the understanding of these latter issues are occurring within the road safety domain, and hence are included here. Summaries of the recent developments in each of these areas are presented in the Executive Summary. The immediate outcome of this review was the identification of theories, frameworks, models, and countermeasures that are used in domains other than road safety that may provide some insight into the development of new ideas to be used for road safety countermeasure development, including behavioural, engineering, and enforcement-based approaches.

The second task involved consideration of the relevance of the research reviewed for refinement and development of road safety countermeasures. To achieve this, the literature review was distributed internally to a number of MUARC researchers, most of whom are highly experienced with a broad appreciation of road safety issues. They were invited to suggest possible countermeasures deriving from the material reviewed, and to document these under one or more of the following headings: education; training; promotion/advertising; traffic engineering; legislation; enforcement; licensing; vehicle design; and "other" countermeasures. Recommendations for further research were included within one or more of these categories. With the exception of the latter category, most countermeasures for injury prevention in the road safety domain fell under one or more of these headings.

The third and final task involved collating the outputs from the above into a final set of recommendations for countermeasure development. Two important outcomes of this review were noted: confirmation that there are developments in behavioural research, not widely known in the road safety domain, which have the potential to lead to the development of new countermeasures; and the realisation that some of the information gleaned can be used to refine existing countermeasures. Briefly, some of the key findings relate to: developments in training techniques and methodologies that have potential to enhance the effectiveness of the driver training regime in Victoria; opportunities for the use of advanced simulation to support improved design and evaluation of vehicle cockpit interfaces and of traffic management systems; tools and techniques that are being developed to support and optimise the design of the human-vehicle interaction, in ways that reduce driver reduce workload and distraction; and the absence of predictive models of human behaviour and error causation in the road safety domain. Recommendations for countermeasure refinement and development are outlined in detail in the final chapter of this report.

Key Words:
Applied psychology, countermeasures, road safety, fatigue, alcohol & drugs, training.

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Monash University Accident Research Centre,
Wellington Road, Clayton, Victoria, 3800, Australia.
Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363

Preface

Project Managers / Team Leaders: Dr Michael Regan, Prof Tom Triggs

Research Team:

- Dr Michael Lenné
- Dr Michael Regan
- Prof Tom Triggs
- Dr Narelle Haworth

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Author for correspondence:

Dr Michael Regan
Senior Research Fellow
Accident Research Centre
Building 70
Monash University VIC 3800

Ph: (61 3) 9905 1838
Email: Michael.Regan@general.monash.edu.au

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GLOSSARY

ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ACD	Automatic Control Device
BAC	Blood Alcohol Concentration
CDM	Critical Decision Method
CDP	Concurrent-Duration-Production
CREAM	Cognitive Reliability and Error Analysis Method
CRM	Crew Resource Management
CTA	Cognitive Task Analysis
DALI	Driving Activity Load Index
DBQ	Driver Behaviour Questionnaire
DRE	Drug Recognition Expert
DSM	Driver Status Monitoring
EBD	Eye Blink Duration
EPIC	Executive-Process Interactive Control
ERA	Error Reduction Analysis
FMEA	Failure Mode and Effects Analysis
GEMS	Generic Error-Modelling System
HAZOP	Hazard and Operability
HEI	Human Error Identification
HM	Hierarchical Manager
HMI	Human-Machine Interface
HPT	Hazard Perception Test
HRA	Human Reliability Assessment
IMU	Integrated Monitoring Unit
ITS	Intelligent Transport Systems
KR	Knowledge of Results
LOA	Levels Of Automation
NDM	Naturalistic Decision Making
PERCLOS	Percentage of eyelid Closure
PHEA	Predictive Human Error Analysis
PPS	Parsimonious Production System
PSA	Probabilistic Safety Assessment
PSF	Performance Shaping Factors
RM	Recognition/Metacognition
RPD	Recognition-Primed Decision model
RT	Reaction Time
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situational Awareness Rating Technique
SA-SWORD	SA Adaptation Of Subjective Workload Dominance Technique
SAVE	System Of Effective Assessment Of The Driver State And Vehicle Control In Emergency Situations
SDLP	Standard Deviation of Lateral Position
SE	Situational Elements
SHEL	Software-Hardware-Environment-Liveware
SHERPA	Systematic Human Error Reduction and Prediction Approach
SILCS	Sleepiness-Induced Lapsing and Cognitive Slowing
SPM	Sleep/Performance Model
SWA	Sleep Watch Actograph
SWAT	Subject Workload Assessment Technique
SYBORG	System for the Behaviour of the Operating Group
TAFEI	Task Analysis For Error Identification
THERP	Technique for Human Error Rate Prediction
WDA	Work Domain Analysis

EXECUTIVE SUMMARY

While advances in the field of traffic psychology often lead to effective countermeasures, there may be developments occurring outside the domain of road safety that have the potential to provide new directions for, and enhance current, countermeasure development. The baseline sponsors typically do not have the time to keep abreast of such developments. The purpose of this report was therefore to review developments in the recent applied psychological literature, mainly in applied experimental psychology. Literature from selected journals in the period 1998-2002 was reviewed. This process served to identify theories, frameworks, models, and countermeasures that are used in domains other than road safety that may provide some insight into the development of new ideas to be used for road safety countermeasure development, including behavioural, engineering, and enforcement-based approaches.

The first task was to organise the literature into logical headings. The general headings that emerged from the recent literature that seemed to best incorporate the material reviewed were: information processing and cognition; decision making; mental workload, and; human error. There was also research reviewed relating to specific fitness for duty issues such as fatigue, alcohol and drugs. The major advances in the understanding of these latter issues are occurring within the road safety domain, and are included here. Summaries of the recent developments in each of these areas are presented below.

Information processing:

Visual scanning studies have continued to be prevalent in the literature since the well known studies of the early 1970's. One reason for this continued research is that there is an inherent assumption associated with the interpretation of findings from visual scanning studies; that is, that attention is directed to the point that is the focus of vision. The recent studies have continued to demonstrate differences in visual search strategy between novice and experienced operators, and have shown that experienced operators have a more efficient and flexible search strategy than novices. In an attempt to reduce specific crash types, countermeasures such as speed humps have been used successfully to alter drivers' visual search patterns in the field.

In terms of models of human performance, computational models continue to gain credence. It is likely that these models will be empirically tested and validated in the near future. Validation of these models may help to gain a better understanding of how the models operate and how they may potentially apply to performance in a road safety context.

In regard to skill acquisition and training, recent studies have confirmed the benefits associated with variable *priority* training over whole or part-task training, and benefits associated with training on systems with variable *reliability*. There are a number of promising training techniques that have significant implications for road safety. The DriveSmart driver training program is a CD-ROM based training product designed to accelerate the development of risk perception, attentional control, and time-sharing skills in novice car drivers. MUARC research shows that, at least within the virtual environment, the instructional strategies embedded within DriveSmart are effective in training safety critical skills in a manner which does not induce over-estimation of driving ability. Training techniques used in aviation, such as Crew Resource Management, may be applied to road safety in the future.

Decision-making:

In the previous decade there has been a paradigm shift in decision-making research, with a shift towards the study of decision-making in naturalistic settings. The focus has shifted to study decisions that are embedded within complex tasks and that are made by competent and experienced decision-makers. Models to account for decision-making in naturalistic settings have been prevalent in the recent literature. It would seem however that further empirical testing of these models is required. Within the framework of decision-making the concept of situation awareness has received much attention, being, for example, the subject of a special issue of the journal Human Factors in 1995.

Mental workload:

There have not been any major developments in the understanding or measurement of mental workload in the recent literature. The recent techniques used to measure mental workload are similar to those used over the past 10-20 years, namely performance measures (primary and secondary), physiological measures, and subjective measures. A key area of research that continues to be undertaken is the development of globally sensitive secondary task measures of mental workload.

Human Error:

The work of James Reason still features prominently in the recent approaches in the study of human error. For example, the prominent methods for examining the role of human error in the aviation domain rely heavily on Reason's classification of unsafe acts. The two developing areas of human error are cognitive modelling and cognitive simulation. In particular, cognitive simulations have the potential to simulate operator performance and therefore predict the occurrence and type of errors for a given system. A recent model has even attempted to incorporate emotional aspects of performance. While having the most potential, cognitive simulations are yet to be fully developed and tested due to intensive time and workload involved. It is highly likely that much future research will be directed in this area, and it is probable that current human error techniques in road safety will be expanded to incorporate more complex analyses of driver error.

Automation:

Research is continuing to examine the psychological and behavioural impacts of automation on human performance. Psychological constructs such as locus of control and situation awareness continue to be the subject of further research. Behavioural adaptation to automation, and recovery from automation failure, are key elements that are beginning to be better understood. However, with increased levels of automation likely to continue to emerge both within vehicles and in the road infrastructure system as a whole, it is even more critical that the effects of automation on behaviour continue to be researched.

Fatigue:

In terms of education, further research that extends and improves upon the research by Dawson and colleagues, needs to be conducted. This information would be valuable for educative initiatives that raised awareness of dangers of driver fatigue while at the same time providing the general community with a reference point (alcohol impairment) to help provide a context with which to interpret fatigue-related impairments in driving ability.

In terms of enforcement, it is likely in the near future that a type of performance battery could be used on the roadside to measure the extent of any fatigue-related impairments. It should be noted that such a test battery is likely to also detect impairments from other sources, such as age, drugs, etc. Further research needs to be conducted if a fatigue test is to be developed.

Alcohol and other drugs:

Unlike the other sections of this report, and indeed the fatigue area, the vast majority of the recent applied psychology research relating to specific forms of impairment such as drugs and ageing has been conducted within the domain of road safety. For example, in the drugs area, it is no longer of significant interest to examine the effects of a particular drug on simple task performance in the laboratory. There has been a definite shift in the recent drugs research towards examining the effects of drugs on complex task performance. The task of driving has been the complex task of choice in recent literature. In particular, advances in simulator capabilities have allowed for more comprehensive examinations of how illicit drugs such as cannabis affect driving.

Despite recent attention to illicit drugs such as cannabis, alcohol remains as the primary drug of concern for road safety. Recent research has been directed towards enhancing our understanding of why people drink and drive, and in identifying target groups of drink drivers for countermeasure development.

Drug detection is an area of immense research activity in recent years. Some research has focussed on detection by observing behaviour change. Increased understanding of how drugs affect performance has informed the development of procedures such as the Standardised Field Sobriety Test. Research conducted in the previous year or so has been more directed towards detection in alternative samples such as saliva, sweat, and urine, as more objective indicators of drug use in the field.

Implications for countermeasure development:

The literature review was sent internally to a number of MUARC colleagues, most of whom are highly experienced researchers with a broad appreciation of road safety issues. These colleagues were invited to suggest possible countermeasures deriving from the material reviewed, and to document these under one or more of the following headings: education; training; promotion/advertising; traffic engineering; legislation; enforcement; licensing; vehicle design; and "other" countermeasures. Recommendations for further research were included within one or more of these categories. With the exception of the latter category, most countermeasures for injury prevention in the road safety domain fall under one or more of these headings.

The outputs from this process were then collated and distilled into a final set of recommendations for countermeasure development. These are outlined the final chapter of this report.

An important outcome of this review was confirmation that there exist developments in behavioural research, not widely known in the road safety domain, which have the potential to lead to the development of new countermeasures. In addition, some of the information gleaned can be used to refine existing countermeasures.

There has been no attempt in the final chapter to prioritise the various recommendations concerning possible research or countermeasures deriving from the material reviewed, as it is difficult to estimate in the behavioural domain the likely impact of associated countermeasures. However, the following are some of the more important conclusions that can be drawn from this study.

At a time when many in the road safety community are sceptical about training as a road safety countermeasure, this review identified some important research and developments in training techniques and methodologies that have potential to enhance the effectiveness of the driver training regime in Victoria. In particular, converging findings suggest that virtual reality, of various levels of fidelity, can be used to effectively train safety-critical skills, including driving skills.

The review suggested that there is great potential to enhance the effectiveness of the VicRoads-developed Hazard Perception Test as a device for screening for the presence of the full range of perceptual and cognitive skills required to drive safely. In addition, there is scope for making an enhanced Hazard Perception Test a more discriminating test than it current is.

There are significant opportunities for the use of advanced simulation to support improved design and evaluation of vehicle cockpit interfaces and of traffic management systems. Currently, advanced simulation is used very little for these purposes in Victoria or elsewhere in Australia.

The review identified various tools and techniques that are being developed to support and optimise the design of the vehicle Human Machine Interaction, in ways that reduce driver reduce workload and distraction. A particularly promising area is the use of the auditory modality to present safety-critical information and to facilitate the visual search process.

The road safety domain is lacking in predictive models of human behaviour and error causation. Understanding human error provides an important basis for the development of new and innovative countermeasures.

The detailed recommendations for countermeasure development are contained in the final chapter of this report.

INTRODUCTION

The behaviour of road users is clearly a critical factor in accident causation. Traffic Psychology, referred to by Rothengatter (1997) as the study of the behaviour of road users and the psychological processes underlying that behaviour, attempts to identify determinants of road user behaviour with the aim of developing effective accident countermeasures.

There are many approaches to the study of traffic psychology that have been explored in attempts to further understand driver behaviour and develop successful road safety countermeasures. As discussed by Groeger and Rothengatter (1998), some of these aspects include developmental approaches, the social psychology of driving, the state of the driver (arousal, stress, fatigue, etc), individual differences, education, driver training, public information campaigns, traffic law enforcement, driver improvement and rehabilitation, and road and vehicle design. There have been some attempts (e.g., Groeger, 2000) to incorporate some of these elements and other concepts into a comprehensive, unified theory of driving.

While advances in the field of traffic psychology often lead to effective countermeasures, there may be developments occurring outside the domain of road safety that have the potential to provide new directions for, and enhance current, countermeasure development. The baseline sponsors typically do not have the time to keep abreast of any such developments. The purpose of this report is therefore to review developments in the recent applied experimental psychology literature. This process may serve to identify theories, frameworks, models, or countermeasures that are used in domains other than road safety, but that may provide some insight into the development of new ideas to be used for road safety countermeasure development, including behavioural, engineering, and enforcement-based approaches.

Reviewing the behavioural literature is an enormous task and criteria were set to make the task more manageable. The review is focussed on recent advances in behavioural research, and as such, only literature published in the last five years is reviewed here. It should be noted that the authors also reviewed relevant behavioural road safety literature as there may be some instances where road safety researchers are in fact leading the way in a particular area of behavioural research. The review included, but was not limited to, articles from the following key journals:

- Accident Analysis and Prevention
- Human Factors
- Transportation Human Factors
- Applied Psychology: An International Review
- Journal of Applied Psychology
- Journal of Experimental Psychology: Human Perception and Performance
- Ergonomics
- Transport Policy
- Transportation Research Record
- Journal of Studies on Alcohol
- Transportation Research, Part F: Traffic Psychology and Behaviour

- Sleep
- Applied Ergonomics
- Psychopharmacology
- Journal of Traffic Medicine
- Transportation
- Aviation, Space, and Environmental Medicine
- Psychological Review
- International Journal of Aviation Psychology
- Drug and Alcohol Dependence
- Forensic Science International
- Perceptual and Motor Skills, and
- International Journal of Cognitive Ergonomics

Papers from a number of conference proceedings are also included in this review. The conferences examined included:

- Road Safety Research, Policing, and Education Conference
- The VTI Konferens series, which includes the Road Safety in Europe and Strategic Highway Research Program (1995, 1996), Road Safety In Europe (1996, 1998), and Traffic Safety on Two Continents (1998)
- The ITE International Conference, Road Safety and Traffic Enforcement (1997, 1999).
- Local Government Road Safety Conference, Coogee Beach, NSW, 1998.
- Confrontational methods in road safety campaigns, Bonn, Germany, 1999.
- Canadian Multidisciplinary Road Safety Conference, Nova Scotia, 1999.
- Behavioural Research In Road Safety, 1997, 2000.
- ARRB Conference Proceedings, 1996.
- ICADTS 1995, 1997, 2000
- Human Factors and Ergonomics Society Conference

The first task was to organise the literature into logical headings. The logical headings that emerged from the recent literature capable of properly organising the material reviewed were information processing and cognition, decision making, mental workload, and human error. While not necessarily as theoretically driven, there was a significant amount of recent applied psychological research concerning fitness for duty issues. Unlike other areas of research reviewed in this report, much of the advances in understanding fitness for duty issues occurred within the road safety domain. Hence research relating to specific forms of impairment such as fatigue, alcohol, and drugs, was included in the report.

The final chapter of this report discusses how the research reviewed might enhance countermeasure development. The literature review was sent internally to a number of MUARC colleagues, most of whom are highly experienced researchers with a broad appreciation of road safety issues. These colleagues were invited to provide input into the development of countermeasures deriving from the material reviewed, and to document these under one or more of the following headings: education; training; promotion/advertising; traffic engineering; legislation; enforcement; licensing; vehicle design; and ”other” countermeasures. With the exception of the latter category, most countermeasures for injury prevention in the road safety domain fall under one or more of these headings.

The outputs from this process were then collated and distilled into a final set of recommendations for countermeasure development. These are outlined the final chapter of this report.

THEORETICAL ISSUES ARISING FROM RECENT BEHAVIOURAL RESEARCH

1.1 INFORMATION PROCESSING AND COGNITION

The literature reviewed under this broad heading fell into a number of distinct subject headings. Some research had utilised visual scanning paradigms in order to gain a better understanding of visual search strategies and allocation of attention. Secondly, there were a some models to account for human performance in multi-task situations that were evident in the literature. Thirdly, the topic of training and the acquisition of automated skills was the topic of some research in the recent literature.

1.1.1 Visual scanning

Recent literature that has continued to utilise visual scanning paradigms. One reason for this continued research is that there is an inherent assumption associated with the interpretation of findings from visual scanning studies; that is, that attention is directed to the point that is the focus of vision, and this moves from location to location with the saccadic movements of the eye, although it is possible to spatially shift attention with no associated eye movement (Gale, 1997).

Visual scanning behaviours have also been used as indicators of performance strategy (Bellenkes, Wickens, & Kramer, 1997). This study examined the performance of novice and experienced pilots using a flight simulator program. A head-mounted eye-tracker measured scanning behaviour, and the analyses determined the number and duration of scans on each of the cockpit instruments. Not only were there differences in flight performance between the two groups, but there were also differences in scanning behaviour.

While experts tended to scan instruments more frequently, novice pilots tended to spend longer periods of time scanning each instrument (Bellenkes et al., 1997). This finding replicates patterns of visual scanning previously identified in experienced and novice drivers (Cohen & Studach, 1977; Shinar, McDowell, & Rockwell, 1977). Furthermore, more recently it has been suggested that there is a much greater flexibility in the visual search strategies of experienced drivers, and inexperienced drivers had more rigid and dashboard oriented search strategies (Underwood, Crundall, & Chapman, 1997). Increasing visual scanning demand (in terms of increasing uncertainty of target location) is associated with increased response time and workload (Liu, 1996). The more flexible search strategies of experienced operators would therefore be advantageous over the more inflexible strategies of novices in situations with high target uncertainty and therefore high scanning demand.

More importantly, the different scanning patterns (in terms of the specific instruments that were scanned) observed in the two pilot groups provide information about the strategic differences between the groups (Bellenkes et al., 1997). For example, experts and novices did not differ in lateral error and control, although there were differences in scanning behaviour. The two most important lateral controls were scanned more frequently by the experts, particularly during segments where heading was not manipulated, and as such experts were better able to monitor a wider range of performance indices than novices. So while this strategy did not result in superior lateral accuracy for the experts, it was suggested that this strategy was an adaptive one which presumably would enable more resources to be devoted to information on the vertical and longitudinal axes, and contributed to the experts' superior performance on these axes. It was concluded that experts had a more refined mental model which facilitated more flexible allocation of visual attention and hence better performance (Bellenkes et al., 1997).

Drivers' visual search patterns have been used to examine possible countermeasures for road accidents. For example, Summala, Pasanen, Rasanen, and Sievanen (1996) examined drivers' visual search patterns at non-signalised T-intersections in order gain an understanding of why so many car-bicycle crashes occurred. The research confirmed that drivers used a scanning strategy that focussed on the detection of more frequent and major dangers, and not on infrequent dangers. Summala et al. (1996) then conducted research to examine the effects of different countermeasures on visual search behaviour, with the aim of changing search behaviour at such intersections and potentially reducing car-bicycle crashes. The reduction of driver speed through the use of a speed hump immediately prior to the intersection was found to alter visual search behaviour in favour of a reduction of the crash type under investigation, presumably in part because the slower vehicle speeds allowed for a more time to scan the entire intersection.

Other researchers have examined driver eye movements in an attempt to partly explain the differences in visual performance between older and younger drivers. Older drivers do need longer search times than younger drivers to extract the same information. Their scanning patterns are characterised by large variability (not present in younger drivers), and occasional lapses that result in searching difficulty. When viewing traffic scenes from the driver's perspective, older drivers spent more time scanning a smaller subset of areas whereas younger drivers scan images more evenly. Older drivers also rescanned the same areas. These results show how ageing might affect visual information processing. Potential applications of this research include training older drivers for a more effective visual search strategy (Maltz & Shinar, 1999).

There is perhaps a role for auditory cues to alter an operators' visual search. Auditory spatial cues have been used in the laboratory to facilitate visual target localisation and identification (Rudmann & Strybel, 1999). Whilst inaccurate auditory stimuli may hinder visual search performance, auditory spatial stimuli may have beneficial applications in the cockpit, and perhaps even in automobiles. Auditory stimuli/cues become more important as the visual search field increases. The integration of visual displays with spatial audio cueing also enhances performance efficiency during a simulated flight task (Tannen et al., 2000).

Visual search patterns have also been used to examine the influences of increased levels of automation associated with the introduction of Intelligent Transport Systems on performance. Lansdown examined the influences of collision and route guidance systems on the distribution of drivers visual searching (Lansdown, 1997). The two devices were congestion warning devices, which displayed constant information that could be used at the driver's discretion (driver control). The second was a route guidance system (symbols) that displayed symbols prior to each intersection (system control). The duration of glances was higher for the congestion warning device, whilst the mean number of glances was higher for the route guidance system (then warning device, then control). Drivers in the control condition spent more time glancing at the driver mirror and forward of the vehicle than for the devices. Subjective workload was also higher with the two devices. The congestion warning device would pose more of a safety risk because glance durations were longer (suggesting that drivers have more difficulty obtaining larger chunks of information from such devices). It was seen as important that in-vehicle devices be designed such that the driver can self-select the information as required.

A potential approach to speeding up the detection of hazards by novice drivers is to train them in visual scanning strategies. Chapman, King and Underwood (2001) express concern that this may be ignoring a deeper problem, that poor scanning strategies may be the inevitable outcome of slow processing of information at any particular location. They state that there is no point in training drivers to scan more rapidly if this prevents them fully processing information from the locations that they have already fixated. Nevertheless it is important to remember that training should be given to novices in order to direct their scanning to those objects and events in the environment that are most safety critical, and that they be taught to avoid functional fixedness, that is, focusing of certain parts of the visual field to the detriment of others.

Harrison (2002) questions the potential benefits of training to improve visual scanning strategies. He states that teaching scanning skills assumes that where drivers look is determined by their knowledge about the locations of potential hazards. While he cites research that argues that overt visual attention may be more controlled by stimulus characteristics rather than top-down attentional processes, there is ample evidence to support the notion that executive processes play a large role in guiding visual search.

1.1.2 Models of information processing

Traditionally there have been many theories and models that have aimed to account for human performance in single and multiple task settings. Two of the major theoretical approaches have centred around single-channel or bottleneck models, and multiple resource theory (e.g., see Gopher & Donchin, 1986, for a review).

A new theoretical framework has emerged in the literature with which precise computational models can be developed for various types of multiple-task performance. While this theory has featured in premier psychological journals, it is not apparent at this point in time what influence this model may have on road safety. However, given the project brief, this model is presented in some detail.

This theory is a computational theory of executive cognitive processes and multiple-task performance (Meyer & Kieras, 1997a). The theoretical framework is formally referred to as an executive-process interactive control (EPIC) framework. Using this framework in combination with a production-system formalism, computational models have been developed to simulate performance in a range of situations. The situations that have been modelled include simple laboratory contexts such as the psychological refractory period (Meyer & Kieras, 1997a, 1997b) to complex real-world situations such as aircraft cockpit operation. The results of these simulations provide reaction time (RT) data that has excellent fits with empirical RT data, with response accuracy too in some situations. The framework and associated models therefore provide new testable predictions about wider aspects of multiple-task performance.

The basic principles of the EPIC architecture will be discussed briefly here, followed by discussion of an example of a model developed within this framework. The reader is directed to Meyer and Kieras (1997a) for further details.

Guided by recommendations made in the large body of information processing literature the framework has five heuristic principles.

1. Integrated information-processing architecture. That is, models are developed within an integrated information-processing architecture that has known characteristics of information processing and performance, extending the research that has previously strived towards unified theories of cognition.

2. Production-system formalisation. This allows for the specification of exactly what procedural knowledge is used to perform certain tasks separately and in various combinations.

3. Omission of limited processing capacity assumptions. This model does not impose an obligatory upper-bound on the number of tasks for which information is processed centrally at the same rate as in the single-task situations.

4. Emphasis on task strategies and executive processes.

5. Detailed treatment of perceptual-motor constraints.

1.1.2.1 An exemplar of this category of model

The EPIC framework consists of complementary memory stores and processing units that interact with each other. There are three fundamentally different memory stores. Declarative long-term memory represents knowledge that is expressed as propositions that embody the essence of verbal descriptions of where, when, why, and how to perform particular tasks. Procedural memory contains production rules that relate to procedural knowledge. Working memory contains control information needed for testing and applying production rules that are contained in procedural memory.

Visual, auditory, and tactile processing units receive inputs from simulated physical sensors, sending outputs to working memory, which is then used by a cognitive processor to perform tasks. The cognitive processor relies upon a production rule interpreter, which tests the conditions and executes the actions of the production rules in procedural memory.

In short, this framework consists of components that simulate various functional parts of the human information-processing system. Software modules incorporate perceptual, cognitive, and motor information processing. Other simulated sensors (eyes, ears) monitor the external displays of a virtual task environment. After a specific delay, the perceptual processors send symbolic stimulus codes to the declarative working memory of the cognitive processor. The cognitive processor maintains the contents of working memory, executes procedures for performing the tasks, and instructs the motor processors. The motor processors prepare and produce movements by simulated effectors (eyes, hands) that operate transduction devices (keyboard, joystick) in the task environment. As such EPIC and the task environment provide a basis for simulating multiple-task performance in a variety of contexts.

1.1.2.2 The role of assumptions in formulating these class of models

Some of the core assumptions concern the structure and function of the cognitive processor and its sub-components whose interactions allow for a high degree of parallel processing. These sub-components include the on-line declarative working memory, procedural memory, and the production-rule interpreter. According to Meyer and Kieras (1997b) the processing capacities are greater and more flexible than those proposed in unitary resource theories (e.g., Kahneman, Ben-Ishai, & Lotan, 1973).

The declarative working memory (within the cognitive processor) has partitions that store different types of symbolic information: a) identities of external stimuli sent through the perceptual processors; b) identities of selected responses waiting for transmission to the motor processors; c) task goals; d) sequential control flags; e) notes about the current status of other system components. This information evolves systematically over time and allows for the performance of one or more tasks to proceed efficiently from start to finish.

Efficient performance is achieved by applying production rules in accordance with the parsimonious production system (PPS) (Covrigaru & Kieras, 1987, as cited in Meyer & Kieras, 1997a). These production rules are expressed as condition-action statements, such as 'if x then y', where x refers to the current contents of working memory, and y refers to the actions executed by the cognitive processor. There would be a set of production rules stored in procedural memory for each task that an individual had learned to perform successfully. Executive process rules in production memory would help to co-ordinate the contents of working memory.

Task and executive rules are applied by the production-rule interpreter of the cognitive processor using the PPS. Under the PPS the interpreter operates through a series of processing cycles. At the beginning of each cycle the interpreter tests the conditions of all rules currently in procedural memory and determines which rules match the contents of declarative working memory. At the end of each cycle, for each rule whose conditions are completely matched by the contents of working memory, all of the rule's actions are executed by the cognitive processor.

Within the EPIC framework the PPS allows for substantial parallel processing (Meyer & Kieras, 1997a). It is assumed that there is no limit on the number of production rules that can have their conditions tested and actions executed at any one time. In this sense the cognitive processor does not have any decision or response selection bottleneck. Response selection and operation of concurrent tasks may occur simultaneously without between-task interference at a central level. For further detail and a rationale for these assumptions the reader is directed to Meyer and Kieras (1997a).

1.1.2.3 Formulation of models

Computational models of human multiple-task performance are formulated in terms of production-rule sets which guide the operation of the cognitive processor. For each task at hand a specific set of production rules that perform the task within the architecture must be specified. The task production rules translate intermediate stimulus codes to intermediate response codes and perform other record keeping unique to that task. Next, a set of production rules for a supervisory executive process must be specified. These rules co-ordinate progress on various tasks so that instructions about the relative priorities of tasks are adhered to and so that they do not disrupt each other at the peripheral level (in which perceptual-motor resources are limited). This co-ordination is achieved by monitoring working memory and inserting or deleting task goals and other control items at appropriate points.

Models are then evaluated by simulating multiple-task performance under test conditions that mimic those in which empirical data from human participants has (or will) been collected.

As stated earlier, it is not clear at this stage what implications such a model may have for human performance and workload related issues that are relevant to road safety. The discussion of this model does serve to illustrate that research is continuing to strive towards the development of improved models to account for human performance in multiple-task situations. Perhaps the major implication for these types of models would be for training skills related to divided attention and multiple-task performance. The fact that this model has been published in a premier Psychological journal, Psychological Review, is perhaps testament to the role that it may play in the future.

1.1.3 Cognitive, psychomotor, and perceptual skill development

1.1.3.1 Training issues

The ability to perform multiple tasks simultaneously is critical for a task such as driving. The acquisition of these skills is therefore a key area to be researched. There is evidence that dual-task training may be more beneficial than single task training for a dual-task situation (Peck & Detweiler, 2000). For example, reaction time and accuracy were improved when subjects had dual-task practice compared to comparable single-task practice (Detweiler & Lundy, 1995).

The type and duration of training has also been discussed in relation to highly automated and reliable systems. Metzger, Duley, Abbas, and Parasuraman (2000) looked at the effects of various training methods in reducing operator complacency resulting from system automation. The participants were trained with one of three attention allocation strategies; whole task, part task, or variable priority. The task was a low fidelity flight simulator that comprised compensatory tracking and fuel management tasks. Metzger et al. (2000) found that this variable priority training reduced complacency (improved performance) for the flight simulation task. Variable priority training has also been found to improve time-sharing abilities in complex environments compared to whole or part task training (Gopher, 1996; Kramer, Larish, Weber, & Bardell, 1999).

Singh, Sharma, and Parasuraman (2000) also examined the effects of varied training regimes using a flight simulation task. Firstly it was found that the duration of manual training (as distinct from automated training) did not influence rates of detection, suggesting that increased manual training did not improve automation-induced complacency. Secondly, training was performed when the system was running at both constant and variable reliability. The monitoring task was less than 100% reliable, and participants were required to manually detect malfunctions in case of automation failure. Training with variable reliability was found to have positive effects on detection rates.

Also in the context of aviation, Crew Resource Management (CRM) training has been developed in the recent literature, which has the broad aim of improving performance and teamwork in the cockpit (Salas et al., 1999; Salas, Rhodenizer, & Bowers, 2000). CRM training is also intended to ensure that cockpit crew utilise all resources available to them, and ultimately aims to reduce human error in the cockpit (Salas et al., 2000). CRM courses frequently incorporate tools to empower flight crew members to speak up and to communicate more effectively with each other, especially under heavy workloads. Specific details about CRM training procedures are published elsewhere (Wiener, Kanki, & Helmreich, 1993).

It is worth noting that some of the principles of CRM training could potentially be applied to road safety. For example, the tools to empower flight crew members to speak up and to communicate more effectively with each other may be appropriate in enhancing communication between young passengers and drivers (Regan & Mitsopoulos, 2001). One such tool, the "CRM assertiveness tool" could be used to empower passengers to "speak up" by using a hierarchy of verbal statements to bring safety concerns to the attention of the driver. For example, if the passenger thought that the driver was exceeding the speed limit, he/she could first issue a "query" (e.g. *do you know what the speed limit is here*?). If this had no effect on the driver's behaviour, they could issue a "statement" (e.g. *we're going a bit fast for my liking*). If this had no effect on the driver's behaviour, they could issue a "request" (e.g. *would you mind slowing down a little*). Finally, if this had no effect on the driver's behaviour, the passenger could issue a "demand" (e.g. *look, either you slow down or you can stop the car and I'll get out*). A hierarchy of communication such as this is more likely to achieve the desired effect than an initially blunt demand. Special consideration should be given to incorporating CRM tools such as these into educational materials and programs (Regan & Mitsopoulos, 2001).

A recent review of training programs in the road safety domain was published by Christie (2001). There are two leading-edge approaches to training in the road safety literature that will be mentioned here. The first is the 'insight' program (Gregersen, 1996). A significant issue with young novice drivers is that they are poor at estimating their own ability and therefore at estimating risks adequately. The over-estimation of novice drivers' perceptions of their own abilities is well documented in the literature (e.g., Finn & Bragg, 1986; Matthews & Moran, 1986). The aim of the insight training program is to address the issue of skill over-estimation by making novice drivers aware of the (probable) discrepancy between their actual and perceived levels of driving skill. So in that sense, driver training not only focuses on improving driving skills, but also should focus on calibrating the drivers' self-assessments of their own driving skills and to encourage them to drive with greater safety margins. To achieve such insight, a training program was designed so that novice drivers were placed in demanding situations that provided them with practical experience that (ideally) reinforced the fact that their driving skills are limited and cannot be relied upon in critical situations (Gregersen, 1996). The evidence for the success of this type of training program, in terms of reducing over-estimation and reducing crash involvement, is equivocal (Christie, 2001).

Another recent approach used technology as a training tool in learner drivers. The final product was a CD-ROM based training product designed to accelerate the development of risk perception, attentional control, and time-sharing skills in novice car drivers (Regan, Triggs, & Wallace, 1999). Twenty-two simulator experiments were conducted in the development of the training product. These experiments investigated the perceptual and cognitive differences in driving skills between novice and experienced drivers, and techniques for training these skills (Triggs & Regan, 1998). The outputs of this research formed the basis for design specifications for the training product. Further details of processes involved in developing the package, and of the product itself, are published elsewhere (Regan, Triggs, & Godley, 2000a; Triggs & Regan, 1998).

The training program was evaluated using the MUARC driving simulator (Regan, Triggs, & Godley, 2000b). The findings from this study suggest that DriveSmart is effective in training both attentional control and risk perception skills and that these skills, once acquired, persist for at least 4 weeks after training. The product appears to be equally effective in preparing young novice drivers to safely handle risky traffic situations similar to those encountered during training (near skill transfer) as well as potentially hazardous situations that are new and novel (far skill transfer). To the knowledge of the authors, this is the first time the effectiveness of a driver training program in facilitating both forms of skill transfer has been demonstrated (Regan et al., 2000b).

Historically, many driver training programs have failed to enhance novice driver safety because they have not focussed on the development of safety-critical skills and/or have had the effect of making novice drivers over-estimate their driving ability and, consequently, making them accept greater levels of risk. This MUARC research shows that, at least within the virtual environment, the instructional strategies embedded within DriveSmart are effective in training safety critical skills in a manner which does not induce over-estimation of driving ability (Regan et al., 2000b).

1.1.3.2 Learning from performance errors in skill acquisition

Ohlsson (1996) describes a theory and model that attempts to explain how people are able to detect and correct their own performance errors. The basic principles of this theory are that errors are caused by overly general knowledge structures, that error-detection requires domain-specific declarative knowledge, and that errors are experienced as conflicts between what the learner believes ought to be true and what he or she perceives to be the case, and that errors are corrected by specialising faulty knowledge structures so that they become active only in situations in which they are appropriate. This theory is limited to the acquisition of complex skills that have significant cognitive component (such as driving a car).

Two major cognitive functions involved in learning from errors are error detection and error correction. With regard to error detection, in order to learn from an error one must be able to detect it, or be aware of the error. In many training situations immediate feedback is available via learning software or tutors. It is less clear how learners in unsupervised situations evaluate their work and are able to detect errors. Whilst not a new idea in psychological research, Ohlsson develops the idea that errors are detected in novices by comparing actual with expected outcomes (cf. Allwood, 1984). The emphasis here is on the subjective view of errors rather than the objective view of errors (whereby errors are deviations from the correct action). Errors are recognised via particular features of the situations they produce. Error signals is the term given to describe the features or patterns of features that indicate incorrect actions. An example of an error feature would be when a learner driver heard grinding noises in the gearbox of an automatic vehicle. The recognition of error signals requires domain-specific knowledge. The learner must have some knowledge about the range of reasonable actions or responses in a given situation in order to recognise an action as being incorrect or unreasonable. As such, errors appear subjectively as conflicts between what the learner believes should be true and what the learner perceives to be the case.

Briefly, Ohlsson also discusses the distinction between practical and declarative knowledge. This distinction is necessary to account for the fact that if a learner has sufficient knowledge to recognise an action as being incorrect, then why was that incorrect action performed in the first place. If an error is started but then recognised and corrected, then there many be a monitoring mechanism of behaviour that is separate from the mechanisms responsible for the selection and execution of the action (Norman, 1981). The dissociation between execution/action and monitoring/evaluation can be understood by considering the distinction between practical and declarative knowledge. The function of practical knowledge is to generate and organise action. The functions of declarative knowledge include explanation and prediction. Ohlsson suggests however that declarative knowledge is prescriptive rather than descriptive, and that the cognitive function that supports it is not explanation or prediction, but judgement, which allows the learner to evaluate the outcomes of their actions.

With regard to error correction, Ohlsson's theory describes displacement errors, which are errors caused by overly general practical knowledge. Initially a learner's behaviour is controlled by general methods and rules that are non-restrictive and do not take into account the structure of the particular task environment. These rules are minimally restrictive and so will be active in many situations and therefore have a high probability of being active in situations in which they are not appropriate. Individuals engage in complex reasoning (error attribution) considering how and why an error occurred, and then revise rules, making them more specialised, and limiting their application to situations that will produce desirable outcomes. Ohlsson concedes that these hypotheses are tentative due to a lack of empirical evidence, but that a conceptual advance is that the processes of error attribution and knowledge revision are cognitive functions that must be specified to explain how novices unlearn performance errors.

1.1.4 System automation and operator performance

There are many psychological influences of increasing levels of system automation on operator performance. One area in which the psychological influences of increasing automation is being examined is Intelligent Transport Systems (ITS). There are a number of psychological issues that have been thoroughly addressed in the psychological literature and are yet to be fully explored with respect to ITS and vehicle automation. These issues include; locus of control (the extent to which removal of control from the driver affects vehicle performance), trust, situational awareness, mental representations (that the driver builds up about the automated system), mental and physical workload associated with automation, feedback (concerning human and automated intervention), and driver stress and its implications for automation (Stanton & Stevenage, 1998; Stanton & Young, 2000). Some of these psychological issues will be discussed briefly here.

1.1.4.1 Locus of control

According to Stanton and Young (1998), in this context, locus of control refers to the extent to which drivers attribute their own activities as being responsible for the behaviour of the vehicle (internal locus of control) or whether the behaviour of the vehicle is due to automated systems (external locus of control). As a result, some drivers may feel that they are in overall control of an automated vehicle whilst others may not (Stanton & Stevenage, 1998). For example, rather than feeling in control while driving with an adaptive cruise control system, some participants felt that the system forced the pace of their driving. People with internal locus of control may take a more active role with automated systems, whereas people with external locus of control may take a more passive role. These differences may help to explain why some people effectively take control in situations where there is an automation failure whereas others fail to react (Stanton & Stevenage, 1998).

1.1.4.2 Situational awareness

If automation takes control away from the driver, then it is questionable how well prepared the driver will be take over when required. As discussed in another section of this report, an approach to human-centred automation, that is, automation that is designed and implemented to be compatible with human capabilities and capacities, may benefit performance. By keeping the human involved in system operations and having an intermediate level of automation, it is possible that it may provide better human-machine performance and higher situation awareness than that found with a high level of automation (Endsley & Kaber, 1999). The concept of situation awareness is discussed in detail in the following section on decision-making.

1.1.4.3 Indirect modification of behaviour

ITS applications indirectly modify road user behaviour in many, largely unknown, ways. There are a number of human factors issues relevant that are discussed below.

1.1.4.3.1 <u>Behavioural adaptation</u>

The driver will adapt to the changing situation brought about by the introduction of Intelligent Transport Systems (ITS) and this is usually referred to as behavioural adaptation. Behavioural adaptation does not often appear immediately after a change but may show up later, and is very hard to predict in advance. Behavioural adaptation may manifest itself in different ways (e.g., by change of usage of the car, by the adoption of longer or shorter headways in a car following situation, by change of expectation of the behaviour of other road users, and so on). Counterproductive behavioural adaptation occurs when drivers start behaving in riskier ways as a result of a perceived increase in safety provided by an ITS technology. Very little research has been done to understand these effects, referred to traditionally as risk homeostasis effects, mainly because so few on-road studies of ITS applications have been undertaken over a sufficiently long time frame to allow the effects to become evident. Drivers of vehicles equipped with Anti-lock Braking System (ABS) brakes, for example, have shown negative behavioural adaptation to the system by driving faster under adverse conditions. As Rumar et al. (1999) point out, ABS has therefore changed the type of crash rather than having decreased the number of crashes. It is also possible that, as the handling characteristics of vehicle improve with the advent of new ITS technologies, there may be an increased use of these vehicles in adverse driving conditions such as in heavy rain, ice, snow, and so on. It is not until large-scale demonstration studies are implemented and evaluated that many of these effects of behavioural adaptation will be discovered and better understood (Regan, Oxley, Godley, & Tingvall, 2001).

1.1.4.3.2 <u>Effects of Automation</u>

Systems that intervene in vehicle control, and hence partially or fully automate human control functions, create a completely new driving situation, for which the behavioural consequences are difficult or impossible to predict in advance. There are several human factors sub-issues relevant here, as discussed by Regan et al. (2001):

- It is possible, for example, that as more control is taken from the driver, the less demanding the driving task will become. This, in turn, may lead to a lower level of alertness and a consequent reduction in driving performance (Cairney & Green, 1999).

- How control should be transferred from the driver to the ITS and from the ITS to the driver is an interesting issue. As noted above, drivers may not necessarily be alert and attentive to the driving task while a vehicle is under fully automated control and protocols will need to be developed for assessing whether the driver is fit to resume manual control of the vehicle and for handing back authority to the driver.

- Another issue relates to the complexity of automation. As complexity increases, the driver may not fully grasp the workings of this system and arrive at faulty predictions or expectations. This can lead to dangerous situations.

- Erosion of skill is an important human factors and safety issue. Human controllers, such as drivers, who have developed certain manual control skills and are then placed in a role of essentially supervising more automated systems will perform better than human controllers who have never developed specific skills (Endsley, 1995b). The introduction of more automated ITS applications mat result in a long-term deterioration in driving skills and, hence, safety. If future generations of drivers are trained solely in vehicles with all possible ITS support technologies, they will not develop the skills associated with manual control that are required without support or with failing support. This is a critical human factors issue that will need to be addressed very early in the evolution of ITS.

Automation can have negative consequences, such as:

1. The loss of Situation Awareness (SA) due to the removal of the system operator from the feedback loop governing the task.
2. Alteration, addition, or loss of task feedback due to the interface with technology rather than direct access to the task.
3. The exclusion from task exposure to develop new skills, and the atrophy of existing skills due to the transfer of task functions from the driver to the automated technology.

Some work has been done showing the negatives of 1 and 2 above, but little has been done looking at skill development and acquisition. The consequences of automation for skill development was examined using a driving simulator game (Ward, 2000). Participants operated the task in an ABA order, where B represented the manipulation of automation (none, semi, full). Substantive skill development was observed without any automation. The introduction of full automation did improve task performance, and the level of automation did influence the degree of improvement, with approximately twice as much improvement observed with full automation. However, the introduction of full automation may interfere with skill development, as evidenced by the worsened performance seen after the removal of full automation. The change in the task feedback and demand by the insertion of the automated task may retard the development of skill that may otherwise develop from exposure to manual control.

As the driving task becomes more automated, existing drivers will become less dependent on their own skill, and novice drivers may never experience certain phases of skill development (Ward, 2000). This is critical in the event of a system failure - drivers may be less equipped to resume manual control and maintain safe driver behaviour. Automation of vehicle systems does have implications for driver skill. The development of such technologies must be closely monitored, and driver training must accommodate changes to the driving task resulting from the introduction of technologies.

- As ITS support systems become more complex, they may present the driver with the additional task of always knowing and understanding what the system is currently doing. The driver that misinterprets the action of a complicated system may end up 'fighting' the system, which demands considerable attention and is potentially dangerous. This problem has been at the core of several recent aviation incidents.

- As difficult or dull aspects of the driving task become automated, driving may become more attractive which may lead to an undesirable increase in driving, and hence in exposure to risk.

Recovery from automation failure is a critical issue, as it is unlikely that all automated systems will be flawless. As discussed by Young and Stanton (2000) there have been several simulator studies that have addressed the issue of automation failure. In evaluation of ACC, Nilsson (1995) found that most crashes occurred in the ACC rather than the manual driving condition. Stanton and Marsden (1996) found that one third of drivers faced with ACC failure were not able to regain control effectively. De Waard, van der Hulst, Hoedemaeker, and Brookhuis (1999) simulated failures on an automated highway system and found that only half of the drivers regained control of the vehicle. Desmond, Hancock, and Monette (1998) found that recovering from failures in lateral control was more effective under manual conditions (e.g.: wind gusts) than when the vehicle was fully automated. The explanations for the above results concerned the expectations about the automation, mobilisation of effort, complacency, and mental workload.

As suggested by Ward (2000), increasing levels of automation may have implications for levels of driver skill and skill development. Few studies have examined whether driver skill has a role in recovery from automation failure. Young and Stanton (2000) examined the role of driver skill in automated vehicles. Learner and experienced drivers operated a simulator, maintaining a constant headway with a lead vehicle which varied its speed. Drivers responded to ACC failure in ACC only and ACC with AS conditions. Experience was only beneficial when the driver retained some control of the vehicle (i.e.: steering, in the ACC only condition). Full automation had a detrimental effect on reaction times of both skill groups. So, while the experienced drivers were more able to respond to automation failure, full automation degraded performance in both groups. These results suggest that driver skill will continue to be of great value in more advanced and automated vehicles.

1.1.4.3.3 Automation in aviation

Some work has been done in the aviation domain to examine the effects of increasing automation on pilot performance, and in particular, on crew co-ordination. While the positives of automated systems, such as increased reliability and reduced operator workload, are assumed to contribute to flight safety, there is some evidence that automation can also lead to negative outcomes (Bowers, Deaton, Oser, Prince, et al., 1995). Some examples of these are increased complacency (Morgan, Herschler, Wiener, & Salas, 1993) and decreased vigilance (Wiener, 1987). As highlighted by Bowers et al. (1995), one area that seems at high risk of negative effects of automation is crew co-ordination, and in particular: a) physical difficulty observing the actions of other crew members, b) reduced cross-monitoring, c) changes in traditional roles and responsibilities, d) redistribution of authority, and e) changes in the way the crew members attempt to help each other (Wiener, 1989).

To this end, Bowers et al. (1995) examined the effects of automation on crew communication. Participants operated a flight simulation in pairs in either manual or automated mode. The most interesting finding relates to the changes in the roles of each crew member. The role of the pilot as a communicator of intended actions was greater in the manual condition compared to the automated condition. The role of the co-pilot as a delegator of responsibilities (reflected by rate of commands) was increased in the automated condition. As such it appears that the introduction of automation was associated with changes in the communication patterns initiated by each crew member.

While at this stage it may not be possible to suggest how to best develop training to improve the performance of crews using more fully automated systems, it is worth taking note of the (sometimes subtle) effects that automation has on the patterns of crew communication (Bowers et al., 1995).

1.1.4.3.4 Complacency

As drivers adapt to ITS, they may become 'complacent', believing that they can rely totally on the system to warn them of danger and to even intervene to prevent a crash if necessary. It has been shown, for example, that drivers readily adapt to the use of collision avoidance devices and rely on them completely after only a brief period of time. In one study, when such a device was made to fail, more than half of the drivers tested failed to take effective action and crashed (Stanton & Marsden, 1996).

1.1.5 Summary

Visual scanning studies have continued to be prevalent in the literature since the well known studies of the early 1970's (e.g. Mourant & Rockwell, 1970, 1972). One reason for this continued research is that there is an inherent assumption associated with the interpretation of findings from visual scanning studies; that is, that attention is directed to the point that is the focus of vision. The recent studies have continued to demonstrate differences in visual search strategy between novice and experienced operators, and have shown that experienced operators have a more efficient and flexible search strategy than novices. In an attempt to reduce specific crash types, countermeasures such as speed humps have been used successfully to alter drivers' visual search patterns in the field.

In terms of models of human performance, the EPIC model was published in one of the premier psychological journals, Psychological Review, which would suggest that the model has much credence. It is likely that this model will be empirically tested and validated in the very near future. Validation of the model may help us to gain a better understanding of how the model operates and how it may potentially apply to performance in a road safety context.

In regard to skill acquisition and training, recent studies have confirmed the benefits associated with variable priority training over whole or part-task training, and benefits associated with training on systems with variable reliability. There are a number of promising training techniques that could have significant implications for road safety. The DriveSmart driver training program is a CD-ROM based training product designed to accelerate the development of risk perception, attentional control, and time-sharing skills in novice car drivers. This MUARC research shows that, at least within the virtual environment, the instructional strategies embedded within DriveSmart are effective in training safety critical skills in a manner which does not induce over-estimation of driving ability. Training techniques used in aviation, such as CRM, may be applied to road safety in the future.

Finally, with regard to automation and operator performance, research is continuing to examine the psychological and behavioural impacts of automation on human performance. Psychological constructs such as locus of control and situation awareness continue to be the subject of further research. Behavioural adaptation and recovery from automation failure are key elements that are beginning to be better understood, however with increased levels of automation likely to continue to emerge both within vehicles and in the road infrastructure system as a whole, it is even more critical that the understanding of the effects of automation on behaviour continues to grow. Increasing levels of automation may also impact upon driver workload and vigilance, thus the tradeoffs between increasing automation and possible decreases in vigilance should be monitored carefully.

1.2 DECISION MAKING

In the previous decade there has been a paradigm shift in decision-making research, with a shift towards the study of decision-making in naturalistic settings (Naturalistic Decision Making; NDM). This shift is away from classical decision-making research which was seen as often focussing on sterile and contrived decision-making situations, with results that were of little consequence to real world decision makers (Beach & Lipshitz, 1993). The focus has shifted to study decisions that are embedded within complex tasks and that are made by competent and experienced decision makers.

A number of factors have been identified that characterise decision making in naturalistic environments (Orasanu & Connolly, 1993). Some or all of these factors need to be present for a decision to be considered naturalistic. These factors are:

- ill-structured problems;
- uncertain, dynamic environments;
- shifting, ill-defined, or competing goals;
- multiple event-feedback loops;
- time constraints;
- high stakes;
- multiple players; and
- organisational norms and goals that must be balanced against the decision makers' personal choice.

The NDM approach has made some important contributions to the study of decision making (Klein & Woods, 1993). It has emphasised how decision makers bring their experience to the fore in making a decision; it broadens the focus of decision-making research; and the models associated with NDM emphasise the different cognitive strategies and processes that are used when a decision situation is viewed as a temporal (rather than static) event. Moreover, NDM has provided researchers with a new method for studying decision-making processes.

To benefit fully from this new approach it is necessary to define the nature of the decisions that are of interest. A recent paper has developed a list of variables that are central to NDM research, and had expanded the concept of NDM (Cannon-Bowers, Salas, & Pruitt, 1996). Some of these factors are similar to those described by Orasanu & Connolly (1993), whilst others have also been addressed in classical decision making. These factors are; uncertain, dynamic task; multiple event feedback loops; meaningful consequences; ill-structured decision; multiple goals; time constraints; decision complexity; multiple players; congruent organisational norms and goals; quantity of information; level of expertise. Furthermore, these variables are broken down across three categories depending on whether each is a feature of the decision or task, the decision maker, or of the environment in which the decision is being made. These factors are described in detail in the article (Cannon-Bowers et al., 1996). It is believed that more prescriptive NDM approaches will increase the probability that results can be applied to improve human decision making.

1.2.1 Recognition-primed decision making

Klein (1993) presents a recognition-primed decision model (RPD) which describes how experienced people make decisions in natural settings. The decision maker identifies the situation as typical, which allows the person to know certain points, such as which goals make sense, which cues are relevant, what to expect, and which actions typically work. The decision maker can then implement an appropriate course of action without further deliberation. For more complex situations, the decision maker can appraise the possible courses of action by choosing the first one and running mental simulations and evaluating how that action will unfold in the given context. In most cases it is the first chosen course of action that is simulated and accepted to be put into action. Support for Klein's RPD model is found in studies examining decision making of pilots (Endsley & Smith, 1996) and offshore oil workers (Flin, Slaven, & Stewart, 1996) to name a few.

Klein's RPD model emphasises the importance of situation awareness for successful decision making in field settings. A recent examination of Naval Officers' decision making in complex situations highlighted the relevance of situational awareness in decision making (Kaempf, Klein, Thordsen, & Wolf, 1996). For these experienced decision makers, the most important decisions were judgements about the nature of the situation rather than selections between alternative courses of action. Situation awareness was developed through two strategies, being feature matching and story general. With regard to feature matching, the decision makers match features observed in the environment with the interpretations that they have learned to assign to specific patterns of cues to derive an understanding of the situation that is evolving around them. Kaempf and colleagues proposed an extended version of the RPD model. This extended model describes the strategies used for situation awareness, allows for cases where several (not single) diagnoses are possible, and the evaluation of courses of action (Kaempf et al., 1996).

This model does have applied implications, particularly for training interventions to facilitate the transition from novice to expert decision maker. Since pattern recognition is a key element in the decision making process (Klein, 1993), it has been suggested that interface training interventions support the development of highly effective and robust heuristic strategies rather than the development of abstract and cognitively intensive strategies (Kirlik, Walker, Fisk, & Nagel, 1996). These authors were able to show the benefits to decision making skill acquisition from training techniques that involved concrete situational patterns in the task environment, and from augmented displays that enhance critical perceptual properties and relationships during training.

As discussed by Klein (1993), there are a number of features of the RPD model that distinguish it from the classical decision models. These can be summarised as follows in that the RPD model:

- focuses on situation assessment rather than judging one option to be superior to another;

- describes how people bring their own experience to bear on a decision;
- asserts that experienced decision makers can identify a reasonably good option as the first one they consider, rather than treating option generation as a semi-random process requiring the decision maker to generate many options;
- focuses on serial evaluation of options and thereby avoids the requirement for concurrent deliberation between options; and
- relies on a recognitional strategy that enables the decision maker to be continually prepared to initiate action by committing to the option being evaluated.

The RPD model has recently been invoked within the road safety context (Fitzgerald & Harrison, 1999; Haworth, Symmons, & Kowadlo, 2000). Specifically, the situation recognition phase of the RPD model has been invoked in the context of hazard perception, that is, deciding whether or not a given situation is novel or familiar (Fitzgerald & Harrison, 1999). Further research should be directed towards further use and evaluation of these types of models in road safety contexts.

A recognition/metacognition (RM) model of decision making was also proposed (Cohen, Freeman, & Wolf, 1996). This model appears to be an extension (of sorts) from Klein's model of decision making which was based largely on recognitional processes (Klein, 1993). This model highlights two strategies; recognition of expectations and associated responses; and the critiquing and correcting of those responses. This latter point is linked with the concept of metacognition, that is, processes that monitor and regulate other thought processes (such as memory and attention). Metacognitive skills also include verifying and improving the results of pattern recognition as part of the decision making process in uncertain situations. According to the RM model, as decision makers become more familiar with a domain, they acquire abstract knowledge about the types of events and relationships between events that are relevant in particular situations. As such, when confronted with a new situation, decision makers can draw upon this generic knowledge to integrate the new information and subject the results to repeated modification and evaluation.

O'Hare, Wiggins, Williams, and Wong (1998) discuss Cognitive Task Analysis (CTA) in a framework based upon Klein's RPD model and the Critical Decision Method (CDM) form of CTA by Klein (2000). The CDM is a retrospective interview strategy that applies a set of cognitive probes to actual non-routine incidents that required expert judgement or decision making. The results of O'Hare et al. (1998) have implications for training. Training needs to focus on recognition of pertinent cues. This may be done via multi-media packages, such as the one they developed for rafting guides. This package aims to enhance perceptual learning.

1.2.2 Situational awareness and decision making

There has been much research and discussion about the concept of situation awareness (SA) in the past decade, and particularly in the last five or so years. SA is founded on the assumption that the first critical step for successful task performance is an evaluation of the 'situation' (Wickens, Gordon, & Liu, 1998). The concept of SA and its importance in operator performance has developed to such a point that, for example, in military aviation, SA is evaluated on nearly every training event because it is seen to be critical to mission success (Oser, 2000).

The definition of SA has also evolved over the last ten years. According to Endsley (1995b), SA is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995b, p. 36).

SA describes a variety of cognitive processing activities that are crucial to dynamic, event-driven, and multitask fields of practice. Some of the cognitive processes that may be invoked under the label of situation awareness are control of attention, mental simulation, directed attention, and contingency planning (Sarter & Woods, 1995).

According to Smith and Hancock (1995), SA is defined as adaptive, externally directed consciousness, and as such SA generates purposeful behaviour in a specific task environment. SA is more than performance, it is the capacity to direct consciousness to generate competent performance given a particular situation as it unfolds. SA is seen to be directly related to stress, mental workload, and other energetic facets of consciousness (Smith & Hancock, 1995).

The need for SA applies in a wide variety of environments. Most research concerning SA has focussed on aviation, however as vehicle systems and displays become more complex, the issue of SA is becoming more important in the context of driving.

Acquiring and maintaining SA becomes increasingly difficult as the complexity and dynamics of the environment increase. In dynamic environments many decisions are required across a narrow space of time, and performance is dependent upon an ongoing and up to date analysis of the environment. The state of the environment is constantly changing, often in complex ways, and so a major part of an operator's role is obtaining and maintaining a high level of SA. Operators must also understand what they are perceiving, and so SA incorporates the operators understanding of the situation as a whole, forming the basis for decision making (Endsley, 1995b). Endsley also presents a comprehensive model of SA.

Endsley's model of SA in dynamic systems highlights the role of SA in system performance. This model clearly shows that the attainment of SA occurs prior to any decision being considered or made. According to Endsley, SA is comprised of three levels. The first level involves perceiving the status, attributes, and dynamics of the key elements in the environment. For example, drivers would need to perceive elements such as other vehicles or obstacles on the road, and their dynamics, relative to the status and dynamics of their own vehicle. Level 2 SA involves a comprehension of the current situation that extends beyond being aware of the key elements that are present in the environment to gain an understanding of the significance of those elements in light of the current goals. This model suggests that synthesis of the elements from level 1 allows the operator to form patterns between the elements, and to comprehend the significance of the objects and events within the environment. An example provided by Endsley is that a military pilot must comprehend that the appearance of enemy aircraft within a certain proximity of each other and in a particular location indicates certain things about their objectives. Operator experience becomes more critical for level 2 SA. An inexperienced operator may be able to identify the key elements in the environment (level 1), but may be less able to integrate those elements with the current goals to form an adequate comprehension of the situation. The third and highest level of SA is the projection of future status. The ability to project the future action(s) is achieved through the knowledge of the status and dynamics of the elements (level 1) and comprehension of the situation (level 2). Referring again to the pilot example, knowing that an enemy aircraft is in a particular location and proximity allows the pilot to project that the aircraft is a threat and is likely to attack (level 2). This awareness provides the pilot with the knowledge necessary to decide upon the most appropriate course of action. Analysis of Endsley's model shows clearly that SA goes far beyond merely perceiving information in the environment. SA does impact upon decision making, and also affects performance.

There are a number of factors that can affect SA, which can be classified in two broad categories, and will only be mentioned briefly here. Human properties that underlie SA include pre-attentive processing, attention, perception, working memory, long term memory, the development of mental models, confidence, automaticity of processing, and goals. There are also task and system factors that may affect SA, which include system design, interface design, stress factors (heat, noise, etc), workload, complexity, and level of automation (Endsley, 1995a). The issue of system automation and SA is addressed further by Endsley (Endsley & Kaber, 1999) and will be discussed shortly.

Managing the attentional and conceptual processes that permit strong SA involves significant cognitive resources, and as such, acquiring and maintaining SA must be appreciated as an integral part of the operator's mental workload (Adams, Tenney, & Pew, 1995).

A new approach focuses on the various levels of automation (LOA), that is, the degree to which a task is automated (Endsley & Kaber, 1999). LOA may provide an approach to human-centred automation, that is, automation that is designed and implemented to be compatible with human capabilities and capacities. By keeping the human involved in system operations and having an intermediate LOA, it is possible that it may provide better human-machine performance and higher SA than that found with a high LOA.

Endsley and Kaber (1999) describe a 10-level taxonomy of LOA that is intended to have applicability to a wide range of cognitive and psychomotor tasks requiring real-time control across a range of domains. They examined the effects of each of the 10 LOA on performance on a multitask simulation. This task was a target identification task (with a complex reward and punishment system) similar to the displays used by air-traffic controllers.

Endsley and Kaber (1999) found that LOAs that distribute the roles of option generation and implementation between human and/or computer servers have a significant impact on automated system performance. Specifically, LOAs that combine human generation of options with computer implementation produce superior overall performance during normal conditions, as compared to purely manual control and to higher LOA. SA did not seem to vary significantly with LOA, although this result was not in accordance with their previous research (Endsley & Kiris, 1995) (the present study didn't provide much opportunity for vigilance declines, which reduce SA). Ratings of mental workload did vary with LOA, and the lowest ratings of workload were associated with the highest LOA. This research has implications for driver performance as the level of system automation increases with the development of ITS.

An alternative computational model of SA is offered by Shively et al. (see Burdick & Shively, 2000). The key elements of this model are situational elements (SEs) and situation-specific-nodes. Similar to Endsley's (1995a) model situational elements are the relevant information in the environment, such as aircraft and obstacles. Each SE has a mathematical weight attached to it based upon its importance to the situation. Again, similar to Endsley (1995a), the nodes refer to semantically related collections of SEs. The nodes are also given mathematical weightings based upon importance to the situation. The models prediction of the perceived SA was accurate in predicting operator SA in a flight simulation task, where SA was measured by the Situational Awareness Rating Technique (SART) (Burdick & Shively, 2000).

1.2.2.1 Measurement of SA

It is difficult to measure SA directly without it being contaminated by the actual decision making and performance tasks (Wickens et al., 1998). Major categories of measurement of situation awareness include: subjective ratings, explicit performance measures, and implicit performance measures (Sarter & Woods, 1995). Adams et al. (1995) review measurement techniques in categories of on-line indices, indirect probes, and model-based approaches. The most comprehensive 'review' of measurement techniques was provided by Endsley (Endsley, 1995a).

Endsley (Endsley, 1995a) discusses various techniques for measuring SA. The present review does not discuss these techniques in much detail, but the techniques include:

1) physiological techniques such as the P300. This approach has been used as a measure of mental workload, but is unlikely to be of significant value in the measurement of SA as a state of knowledge. Heart rate and eye blink data have been used to measure SA in aviation (Vidulich, Stratton, Crabtree, & Wilson, 1994).
2) performance measures, which are usually objective and unobtrusive including:
    a) global measures of SA, which, like global measurements of mental workload, often suffer from lack of diagnosticity and sensitivity. An overall measure of performance provides the output from a number of cognitive processes, and is often masked by other factors.
    b) external task measures typically involved removing aspects of the operator display and measuring the time it takes the operator to respond to that change.
    c) imbedded task measures involved measuring performance on a subtask that is of interest.
3. subjective techniques (self-rating, observer rating), e.g.: Waag and Houck (1994).
4. questionnaires, which include:
    a) post test, e.g.: the SA adaptation of the Subjective Workload Dominance Technique (SA-SWORD). Looking at pilot performance it was found that the link between subjective SA (using SA-SWORD) and performance was tenuous (Snow & Reisling, 2000).
    b) on line
    c) the freeze technique, which involves stopping a simulation at random points in time and questioning the operator about their perceptions of the situation at that time. This approach will be discussed further.

The Situation Awareness Global Assessment Technique (SAGAT) was developed to measure SA across all its elements based on a comprehensive assessment of operator SA (Endsley, 1987). It incorporates queries about SA across all three levels (in accordance with Endsley's (1995a) model), and considers system functioning and status and relevant features of the external environment. Two experiments are reported which provide data for the validity and unobtrusiveness of the SAGAT (Endsley, 1995a).

A recent study has found that the task interruptions associated with SAGAT do not affect performance (this is a concern with the SAGAT approach to SA measurement) (Snow & Reisling, 2000). SAGAT is however only as good as the questions asked, and good questions require a task analysis and pilot testing to ensure the relevance of questions.

SA has also been measured in helicopter pilots (Entin, 2000). A detailed measure of SA was developed that was based upon the SAGAT, and focussed on specific aspects of the situation. A second high-level measure assessed more general knowledge of the situation. Not only were they able to measure SA, but they were able to provide empirical support for the hypothesis suggesting a relationship between SA and performance [Note. This has been a hotly debated topic. Endsley suggests that SA should be separated from performance, whereas others suggest that SA implies the ability to respond appropriately, and as such should include the ability to execute tasks. It is however difficult to measure SA without incorporating performance measures, perhaps because the elements of SA are not always easy to identify and quantify, and so SA has often been inferred from task performance rather than being measured in its own right (Entin, 2000). The relationship between SA and performance is dependent upon the measures of both SA and performance that are used.]

1.2.2.2 Training for SA

Most research into SA has focussed on measuring SA and designing better systems. While research is continuing in this direction, there does appear to be a shift towards improving SA via training. For example, Endsley & Garland (2000) has made some recommendations for training in general aviation. First, a SA error taxonomy was developed (Gibson, Orasanu, Villeda, & Nygren, 1997; Shook, Bandiero, Coello, Garland, & Endsley, 2000), which identified types of SA errors (level 1-3) in accordance with Endsley's (1995a) model. From this error taxonomy it was possible to identify the key problem areas for high SA in general aviation. Finally, it was possible to identify key areas where SA could be improved through training. For general aviation, these areas were: task management, development of comprehension, projection and planning (level 3 SA), and information seeking (seeking out the critical information) (Endsley & Garland, 2000).

Another approach is an event-based assessment of SA called SALIANT (SA linked indicators adapted to novel tasks). It is based upon observed behaviours, and can be used to identify if an operator has difficulty with a specific task component related to SA. Since it is based on a list of behaviours, it can be used to standardise training in any number of situations. This approach has been used for pilot flight training (Fowlkes, Merket, & Oser, 2000; Milham, Barnett, & Oser, 2000; Sheehan & Oser, 2000).

1.2.2.3 Mental model and SA

Mental models have been defined as "mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states" (Rousse & Morris, 1995, as cited in Endsley, 2000). Similarly, Wickens et al. (1998) suggest that mental models are internal representations of objects, actions, situations or people, built on experience and observation, and are simulations that are run in operators mind that allow them to describe, predict, and explain behaviour. As such, the mental model, as a concept, has much in common with SA.

Human factors and ergonomics specialists have developed a heavy reliance upon mental models. The belief is that if the mental models from operators in particular situations can be communicated to the system designers, then the systems can be designed with interfaces that better match the needs and expectations of the operators (Wilson, 2000). Similarly, training systems can be designed to build up mental models consistent with that of the expert.

As discussed earlier, SA can be measured, and a popular method for measuring SA involves the SAGAT technique. The collection of SA data for particular situations provides snapshot situation models. It may be possible to construct mental models by reconstructing a series of situation models, although Endsley does concede that this approach needs further exploration and development (Endsley, 2000).

1.2.3 Other models of decision-making

While there have been several decision-making models discussed in the human factors literature, there are also mathematical models that are utilised and being developed in other disciplines such as in the economic and memory-based literature.

1.2.3.1 Memory process model

One such model is based upon the MINERVA2 memory model (Hintzman, 1984, 1988). Modification of this mathematical memory model has allowed this model to explain judgement and decision phenomena (Dougherty, Gettys, & Ogden, 1999). Basically this is a complex model that incorporates decisions involving conditional probabilities that will not be explained here. It provides a coherent theoretical explanation of the cognitive processes underlying many of the heuristics and biases and other likelihood judgements.

1.2.4 Summary

In the previous decade there has been a paradigm shift in decision-making research, with a shift towards the study of decision-making in naturalistic settings. The focus has shifted to the study of decisions that are embedded within complex tasks and that are made by competent and experienced decision-makers. Models to account for decision-making in naturalistic settings have been prevalent in the recent literature. It would seem however that further empirical testing of these models is required. Within the framework of decision-making the concept of situation awareness has received much attention, and was in fact the subject of a special issue of the journal Human Factors in 1995.

Noteworthy is the observation that virtually none of this research has been conducted in the driving domain. Clearly, there is considerable scope to apply recent knowledge in this area to better understand decision making by vehicle drivers.

1.3 MENTAL WORKLOAD

The concept of mental workload is crucial in the successful operation and integration of human-machine systems. Mental workload is rarely defined and is used in different ways by different authors. Mental workload describes some type of burden upon the central processor and reflects the difficulty associated with decision-making (Moray, 1979). The theories underlying the measures of mental workload are primarily based upon the concept of capacity; that is, the total amount of *resources* or effort that an individual can expend (Kahneman et al., 1973). It is also assumed that the total amount of available capacity is limited, and that executing specific functions demands a finite amount of capacity. As such, resources not committed to task performance are deemed as *spare capacity*. Resource theory, as described in various forms (e.g., Kahneman et al., 1973; Navon & Gopher, 1979; Wickens, 1984), has dominated the attention literature for several decades. In the material reviewed for this report, no major advances on resource theory were found.

1.3.1 Direct and indirect costs models for vigilance tasks

The examination of mental workload has been used to better understand the demands associated with different tasks. An example is vigilance tasks. Vigilance tasks usually involve long duration, monotonous tasks in which the likelihood of a response being required is very low. The Macworth clock is a well-known example of a vigilance task that is used widely in the performance literature. However, while vigilance tasks by nature have been interpreted as being fairly simple and low in workload demands, some recent studies have shown that workload ratings on the NASA-TLX have been in the upper levels for vigilance tasks (Deaton & Parasuraman, 1993; Warm, Dember, & Hancock, 1996). Two models have been put forward to account for the high levels of mental workload associated with vigilance tasks.

The direct-cost model of workload for vigilance tasks puts forward that vigilance tasks are associated with high workload due to the need for continuous observation and decision-making in discriminating signals from neutral events (Warm et al., 1996). The indirect cost models attribute the high workload to the effort to combat the boredom associated with performing monotonous vigilance tasks (Scerbo, 1998). Hitchcock, Dember, Warm, Moroney, and See (1999) conducted an experiment which provided reliable cueing (meaning that observation was necessary only when a low-probability event occurred), or knowledge of results (KR), which we assume was used to alleviate boredom. It was predicted that the direct-cost approach would result in high boredom and low workload. Results supported the direct-cost view (Hitchcock et al., 1999). These results suggest that more emphasis should be placed on the role of mental workload for tasks or jobs that involve continuous monitoring.

1.3.2 Model of driver performance, demands, and mental workload

De Waard and Brookhuis (1997) propose a region model that describes the relationship between task demands, performance, and workload, whereby the region describes the interaction between (subjective) workload and performance. This model is an extension of an earlier model proposed by Meister (1976). The implications of this model are that constant levels of performance are not necessarily indicative of constant levels of workload. For example, a driver may experience increasing levels of workload during times of fatigue or increasing task difficulty in an effort to maintain consistent performance. This model describes regions in the performance-workload relationship for which different categories of workload measurement (self-report, performance-based, and physiological measures) are likely to be sensitive. De Waard (1996) has examined the sensitivity of performance, physiological, and self-report measures of workload in the field, and emphasised the need to incorporate multiple measures of workload, as not all measures are equally sensitive to all regions of performance in the model.

As discussed by De Waard and Brookhuis (1997), there are many factors that complicate the measurement of mental workload in the field. There are different sources for increased workload (fatigue, increased task difficulty, use of a secondary task), the different measurement techniques are differentially sensitive to changes in workload, and for self-paced tasks such as driving, performance is not only influenced by external demands but also but the individual's own goals and motivations.

1.3.3 Mental workload and perception

Peripheral vision plays a critical role in human behaviour, and particularly the performance on visual search and monitoring tasks. The size and shape of the visual field are known to affect peripheral visual performance. Rantanen and Goldberg (1999) examined visual fields (primary task was visual detection – visual vigilance) alone and in a dual-task situation (whilst subjects performed an auditory detection task). Primary task performance was improved in the absence of the additional auditory task, but more interestingly, the size of the visual field was reduced (and changed shape) when the low demand secondary task was introduced, and reduced further when the high demand secondary task was used. If the shape and size of the visual field change shape under conditions involving higher workloads, then clearly there are implications for design recommendations and the positioning of controls within a drivers environment.

Research by Lamble et al. also has implications for the positioning of attention-demanding in-car controls (Lamble, Laakso, & Summala, 1999). They examined driver's ability to detect a decelerating car ahead when they were also asked to direct their attention to visual stimuli within the interior of the vehicle and at different foveal locations. It was expected that visual detection ability would decrease as the eccentricity of the task from the normal line of sight increased. Their study confirmed this hypothesis, and also found that there were greater decrements (in terms of time to collision) for similar eccentricities in the vertical periphery compared to the horizontal periphery.

1.3.4 Measuring mental workload

The three most commonly used categories of mental workload measurement are performance measures, physiological measures, and subject reports. The category of performance measurements can be divided further to include analysis of primary and secondary task techniques. It is beyond the scope of this document to provide a thorough analysis of the positive and negatives of each category of workload measurement. Primary task measures are the most obvious measures of driver workload, and include measures of lateral position, speed, and steering control. Most recent research however has been directed towards the examination of various secondary task techniques on aspects of performance and driver workload, and so they will form the focus of this section.

The purpose of this section is merely to provide some examples of how these techniques have been utilised in recent research. Further information about the different categories of workload measurement can be found elsewhere (De Waard & Brookhuis, 1997; O'Donnell & Eggemeier, 1986; Wierwille & Eggemeier, 1993).

1.3.4.1 Secondary tasks

The secondary task approach measures mental workload through the performance of a second (additional) task that is performed concurrently with the primary task. This approach is used to assess the amount of resources, and hence workload, that are demanded by the primary task performance.

Secondary tasks are still used as measures of primary task performance, both inside and outside the domain of road safety. For example, two secondary tasks (delayed-digit recall & random digit generation) were used in four year long field trials of van drivers. These tasks (2 min periods) were sensitive to traffic density and ratings of task difficulty (Zeitlin, 1995). In another recent study an auditory addition task (sensitive to mental workload) and a visual detection task (sensitive to visual workload of driving) were performed while driving an instrumented car (Verwey, 2000). Both of these tasks were found to be sensitive secondary task measures and showed changes across road situation and driver age.

Other studies have used mobile telephones as secondary task activities in order to measure the influence of the secondary task on primary task performance (Lamble, Kauranen, Laakso, & Summala, 1999; Reed & Green, 1999). Another study looked at the effects of working memory load, using semantic tasks supposed to simulate mobile phone use, on driving simulator performance. Increasing difficulty in driving scenarios did not impair performance on the semantic tasks (Radeborg, Briem, & Hedman, 1999). Use of a mobile phone also slowed driving speeds in an on-road driving task, and subjective workload was also higher than without the phone (Waugh et al., 2000).

Stanton and Young (1998) also describe a study where they examined driving ability using automated cruise control in a car following scenario. Primary and secondary task data were collected. While primary task (driving simulator) measures did not vary, workload as measured by the secondary task was lower when using the automated cruise control. These studies were extended by Young and Stanton (1997, as cited in Stanton & Young, 1998) to examine driver behaviour with automated cruise control, active steering, and the two combined. Differences in primary and secondary task measures were found.

Recent research has continued to examine some of the cognitive deficits associated with ageing. Elderly people have more limited processing resources than young and middle aged people, particularly when performance in multi-task situations. When driving, the elderly also have greater difficulty performing additional tasks that are not related to driving (Verwey, 2000).

A number of studies have examined the nature of the performance differences between older and younger adults. A key aspect of driving is being able to perform several tasks concurrently, and so the study of multiple-task and secondary task performance and ageing is an important one. Older adults have been found to exhibit larger multiple-task performance decrements than younger adults, however the age-related gap in performance is reduced with training. The age-related performance difference increased again when the task emphasis (not demand) changed, but again, the difference diminished with additional experience. Give that older adults may allocate attention differently than younger adults, it is suggested that enhanced usability testing be included for even moderately complex products (Sit & Fisk, 1999).

Older drivers do have difficulty performing secondary tasks while driving. For example, older drivers consistently showed decreases in driving performance (more large steering reversals, more lane deviations, driving slower & taking longer to reach a destination), and had longer eye fixation durations and less efficient scanning behaviour, when required to navigate while driving an instrumented vehicle. Older drivers had greater difficulty when full route information was provided, but did benefit when turn-by-turn guidance was provided. It seems therefore that older drivers may benefit from route guidance functions using the Advanced Traveller Information System (Dingus et al., 1997).

Outside of road safety, subjects performed the Stroop task while performing secondary tasks (verbal time estimation and concurrent-duration-production (CDP) task) (Zakay & Shub, 1998). The CDP task was sensitive to changes in Stroop task difficulty. Similar results were also found when the primary task was a flight simulation – that is, CDP correlated with workload difficulty, and CDP did not interfere with primary task performance. Zakay then discusses the theoretical basis for using CDP as a workload measure.

An important issue with the use of secondary tasks is their global sensitivity, or the ability to generalise across operator tasks (Wierwille & Eggemeier, 1993). Ideally a secondary task would be sensitive to changes in mental workload across a range of tasks, situation, and design manipulations. Colle and Reid (1997) provided an alternative theoretical basis for the development of secondary task measures of mental workload. The Cancellation axiom of mental workload measurement theory (Colle, Amell, Ewry, & Jenkins, 1998; Colle & Reid, 1997; Colle & Reid, 1999) is a theory that is derived from the need for globally sensitive secondary tasks, that is, secondary tasks that detect changes in mental workload across a wide variety of tasks and situations. In contrast to resource theory, mental workload in their model does not have a one-to-one relationship with resources (attentional capacity). Through manipulating the cognitive processing similarity of tasks, Colle and Reid (1999) believe that it is possible to develop standardised secondary task techniques for the practical measurement of mental workload.

1.3.4.2 Physiological measures

While many studies continue to use physiological measures such as heart rate as indicators of mental workload (e.g.: Backs, 2000), these techniques are generally not widely used as measures of workload. Other types of physiological measures that are still used include EEG, blink rate, and respiration rate.

For example, EEG spectral features (frontal theta activity and alpha activity) were found to be sensitive to increasing working memory load on computer-based tasks (stimuli recognition, verbal and spatial components) (Gevins et al., 1998). Heart rate and blink rate (as well as driving speed) were used to measure workload on rural road (curve) segments. These measures varied as a function of the curvature change rate for rural road segments (Richter, Wagner, Heger, & Weise, 1998). Finally, respiration rate was the most sensitive physiological measure of mental workload/effort (but not necessarily task difficulty) on a flight simulator task (Veltman & Gaillard, 1998). Respiration rate also reflected changes in task demands in a simulated air traffic control task (Backs, Navidzadeh, & Xu, 2000).

1.3.4.3 Subjective measures

Subjective measures such as the NASA-TLX are still widely used, particularly in experimental settings (for example, Fildes, Godley, Triggs, & Jarvis, 1997). New subjective measures continue to be developed. Pauzié and Pachiaudi (1997) recently developed a new technique for measuring subjective mental workload. It is based on the NASA-TLX, and has advantages over the Subjective Workload Assessment Technique (SWAT) (Pauzié & Pachiaudi, 1997). It was used in an examination of the effects of a new guidance system and mobile telephone use on driving behaviour (simulator and on-road). The Driving Activity Load Index (DALI) has six subscales; effort of attention, visual demand, auditory demand, interference, and situational stress, as well as providing one global score.

Subjective measures of mental workload are likely always to play a role in workload measurement. Their high levels of face validity and ease of implementation make these measures very acceptable for operators. An issue is that often operators are merely asked about perceived difficulty which is assumed to represent workload. While subjective scales are continually evolving, as described above, for the time being it appears that their high face validity is sufficient to overshadow theoretical concerns about what exactly it is that subjective measures of workload actually measure.

1.3.5 Summary

In summary it would have to be said that there have not been any major developments in the understanding or measurement of mental workload in the recent literature. The recent techniques used to measure mental workload are similar to those used over the past 10-20 years, namely performance measures (primary and secondary), physiological measures, and subjective measures. A key area of research that continues to be undertaken is the development of globally sensitive secondary task measures of mental workload.

A major application of this research may be in measuring and quantifying the degree of workload imposed by emerging ITS systems.

1.4 HUMAN ERROR

Recent research into human error has considered the issues of error classification and explanation. Reason (1990) described a taxonomic approach that has enabled the development and formal definition of several categories of human error, and an attempt to understand the psychological processes that combine to cause errors. Reason argues that it is critical to understand the activities of the individual if we are to identify what may go wrong. Errors are seen as predictable events based on the analysis of the individual's activities rather than being viewed as unpredictable events (Reason, 1990).

This section will begin by discussing error and violations within the road safety context, followed by a more detailed discussion of approaches adopted in other domains such as the nuclear industry and aviation.

There has been limited research within the road safety domain that has attempted to examine the role of errors/violations with accidents (Lawton & Parker, 1998; Parker, Manstead, Stradling, Reason, & Baxter, 1992; Parker, Reason, Manstead, & Stradling, 1995; Parker, West, Stradling,

& Manstead, 1995; Reason, Manstead, Stradling, Baxter, & Campbell, 1990). Driver behaviour has been measured using the Driving Behaviour Questionnaire (DBQ) which provides scores on three subscales: errors, violations, and lapses (Parker, West et al., 1995). This research has provided some evidence that people who score highly on these DBQ subscales are associated with both active and passive accident involvement (DBQ scores are linked with accident records) (Parker, West et al., 1995). As will become apparent in the following sections, there is certainly scope to engage in more complex analyses of human error in the road safety domain.

1.4.1 Fundamental concepts in human error

Reason (1990) describes a conceptual framework, the generic error-modelling system (GEMS), that defines three basic error types. This work is an extension of the work by Rasmussen, and distinguishes between two types of error; slips and lapses, and mistakes.

Skill-based slips and lapses reflect errors whereby the action deviates from the intended action due to failures in execution and/or storage. Slips describe attention failures and may take the form of (for example) interference errors, omissions following interruptions (intrusion), order reversals, and mistiming. Lapses describe more covert memory failures and include errors such as omitting items in a checklist, forgetting intentions, and losing place within a given action(s). For example, an individual grabs his coat while walking out the door, the telephone rings, and then the person ends up leaving the house without the coat. These two types of skill-based error occur mainly at an automatic skill-based level of processing, and are particularly sensitive to monitoring failures by the individual.

Mistakes occur when the action matches the intended action, but the intended action is not sufficient to achieve the desired outcome. Mistakes are further classified as being rule-based or knowledge-based. While in general skill-based slips precede the detection of a problem, the rule-based and knowledge-based mistakes arise during subsequent attempts to find a solution. This assertion defines that for rule-based and knowledge-based mistakes there must be an awareness that the problem exists.

Rule-based errors are viewed as either constituting the misapplication of good rules or the application of bad rules. A good rule is seen as one with proven utility for a given situation. These rules however may incorrectly be applied to situations with similar common features with the appropriate good rule situation. In other words pre-programmed rules and behaviours, while appropriate in the situation in which they were learned, prove inadequate in a new or different situation. This error typically occurs when a new situation shares similar elements with the usual problem environment, but counter indications are overlooked and so an inappropriate action is taken.

1.4.2 The assessment of human error

Human Reliability Assessment (HRA) aims to determine the impact of human error and error recovery on system performance. Human Error Identification (HEI) techniques typically form part of HRA. The predictions from HRA are incorporated into risk assessments known as Probabilistic Safety Assessments (PSA) which determine the risk for systems such as nuclear and chemical power plants for all potential causes of risk, including human error. Error Reduction Analysis

(ERA) can then be employed to identify methods to reduce the likelihood of error and its impact on the system.

Kirwan (1998a; 1998b) has reviewed a number of different HEI techniques, and the following discussions are based upon this review. These techniques have been used to determine the risks of systems such as nuclear power plants, chemical plants, and so on. These techniques are discussed in a number of categories. Firstly though, it is necessary to identify the error types that are of interest in risk assessment (Kirwan, 1998b).

1.4.2.1 Error types in risk assessment

The major error types of interest in risk assessment, as reviewed by Kirwan (1998b) are discussed briefly here.

1. Slips and lapses. These error types have been discussed earlier, but usually concern the quality of performance, errors of omission, or sequence errors, and are the most predictable of all error types.

2. Cognitive errors: diagnostic and decision-making errors. These errors relate to misunderstandings by the system operators, and include misdiagnosis, partial diagnosis, and diagnostic failure.

3. Maintenance errors and latent failures. Errors due to slips and lapses during maintenance and testing activities. These errors may lead to immediate failures, or latent failures (in which the consequences of the failure are delayed).

4. Errors of commission. This is when the operator performs an action that is incorrect and not required. These types of errors are an increasing concern because they have a substantial impact on system risk, and are very difficult to identify which makes it difficult to anticipate a problem.

5. Rule violations. As per Reason (1990), there are routine and extreme violations. While extreme violations are associated with great risk, they are quite rare. Routine violations are associated with negligible risk and are seen as acceptable.

6. Idiosyncratic errors. These errors relate to an individual's emotional state and other social variables during task performance. These errors relate to covert social factors that are not obvious from an examination of the work context, and are therefore extremely difficult to predict. These errors are not covered in HRA.

7. Software programming errors. There are very few techniques that can predict software programming errors, and these types of errors should be the focus of future research in HEI techniques (Kirwan, 1998b).

1.4.2.2 HEI approaches

Kirwan (1998b) has reviewed thoroughly the range of HEI techniques that are available, and has discussed the merits of each approach. The approaches will be mentioned briefly here but the reader is referred to the work by Kirwan for further detail.

1.4.2.2.1 Taxonomies

There are a number of HEI techniques that incorporate error taxonomies and provide checklists of error modes. It is then up to the analyst to interpret these checklists within the context of interest.

The most used approach is the Technique for Human Error Rate Prediction (THERP) (see (Kirwan, 1998b). This type of approach can either be generic (like THERP), or for a specific industry or a specific error type. This approach is experience-based, reflecting a combination incident experience with assessor experience. This approach demands few resources if the assessor has experience with and an understanding of the context of interest. These checklist-based approaches are used as prompts for the experienced assessor. The assessor may however overlook some of the interactions and error types in novel situations. These checklists are often not very cognitive in nature.

1.4.2.2.2 Psychologically-based tools

Stanton and Stevenage (1998) evaluate one such technique, SHERPA (Systematic Human Error Reduction and Prediction Approach), using the scenario of buying an item from a vending machine. SHERPA was later modified to Predictive Human Error Analysis (PHEA) (see Kirwan, 1998b). Techniques such as SHERPA are flowchart-based approaches which provide considerable structure to the assessor, which is of particular benefit to novice assessors. As a result of the high degree of structure, assessments tend to be more consistent and reliable between assessors. This technique relies on a detailed task analytical approach.

Task Analysis for Error Identification (TAFEI) is another technique of this type, and employs a combination of flowchart (hierarchical task analysis) and state space diagrams (Baber & Stanton, 1996). In their study using a ticket vending machine, TAFEI and PHEA compared favourably with the actual errors in machine use. They concluded that these HEI techniques have a role in product design.

1.4.2.2.3 Cognitive modelling

In the field of HRA a model based upon Cognitive Reliability and Error Analysis Method (CREAM) has been described (Hollnagel, 1993). CREAM is meant to be more theoretically valid than the two approaches discussed previously, and it attempts to model cognitive behaviour.

Evaluated by Hollnagel, Kaarstad, and Lee (1999), this method allows the operator to identify the types of incorrect performance that are possible (error modes, cognitive failure modes) for the given task or scenario, and to qualitatively rank the likelihood of the possible error modes and thereby identifying those that are more likely to occur.

The first step in this process is to gain a detailed description where the performance takes place and the specification of the critical aspects of the performance (i.e.: the target for the predictions). This starts with a description of the expected performance, since errors are basically deviations from the expected. Hollnagel et al. (1999) describes the basic steps of the prediction method, which includes: constructing event sequences; describe the situation (common performance factors); select performance segments; describe actions and cognitive activities; determine time windows; determine cognitive functions; identify likely error modes. These steps are described in detail by Hollnagel et al. (1999). A study was conducted using a simulated (nuclear) water reactor plant. There was high (mean around 70%) match between predicted and observed errors (Hollnagel et al., 1999).

1.4.2.2.4 Cognitive simulations

Cognitive simulation approaches aim to develop computerised simulations of operator performance, and as such, these models can predict errors in tasks. They tend to be aimed at knowledge-based behaviour, which is one of the more difficult error domains to predict. It takes years and great expertise to develop these types of simulation, but these systems can predict performance and errors across a range of scenarios and thus can be validated against human performance (Kirwan, 1998b).

An example of this type of simulation is The System for the Behaviour of the Operating Group (SYBORG) (Hasegawa & Yoshimura, 1996). This model attempts to incorporate emotional aspects of performance. It aims to predict the emotions that a person will experience while performing certain actions in a nuclear power plant, and how these emotions will affect attention, thoughts, and actions. Research is being directed toward determining how emotions interact with each other and with error forms. These relationships and interactions are based on empirical observations from subjects performing these tasks in simulated experiments.

While this is the most sophisticated approach to predicting human error, they are rarely fully developed due to the high time and resource demands of this approach.

1.4.2.2.5 Reliability-oriented techniques

The two main reliability style approaches to HEI are Failure Mode and Effects Analysis (FMEA) and Hazard and Operability (HAZOP). FMEA is a structured single-assessor detailed analytical approach that is seen to be seeking to identify failure possibilities systematically and in great detail. The HAZOP approach however is a semi-structured, group technique, and is more incisive and similar to brainstorming at times.

1.4.2.2.6 Evaluation of these HEI approaches

Kirwan has also developed a list of criteria by which each of the above HEI techniques were evaluated. These criteria are:

1. comprehensiveness of human behaviour – the degree to which the techniques address the performance error types (skill-based, rule-based, etc);
2. consistency;
3. theoretical validity 1 – whether the technique is based upon a model of human performance;
4. theoretical validity 2 – whether the technique assesses external or psychological error mechanisms;
5. usefulness – the degree to which the technique can generate error reduction mechanisms, and includes diagnosticity or the insight into the causes or error;
6. resources 1 – resource usage applying the technique;

7. resources 2 – training required (it is an expert's tool?);
8. resources 3 – requirement for an expert panel or task-domain experts;
9. documentability – degree to which to technique lends itself to auditable documentation;
10. acceptability 1 – PSA usage of the technique in the real world (i.e.: prototype versus extended usage), and
11. acceptability 2 – the availability of the technique (i.e.: unavailable, linked to an organisation).

Kirwan concluded that there was no technique available that was optimal on all of the qualitative criteria, and as such, that there was no clear best technique. In a subsequent paper Kirwan outlines a framework that attempts to overcome some of the weaknesses of available techniques while addressing all error types.

1.4.2.3 Human error in aviation

The reduction in human error-related accidents has not matched the reductions in accidents related to environmental or mechanical factors (Shappell & Wiegmann, 1996). More effort needs to directed towards preventing the occurrence of human error and the design of more error-tolerant systems.

Wiegmann and Shappell (1997) briefly review the three major theoretical frameworks of human error. These include the four-stage model of information processing, a model of internal human malfunction derived from Rasmussen's (1982) Skills-Rules-Knowledge model, and a model of unsafe acts as proposed by Reason (1990).

The analysis of post-accident data remains the predominant means of investigation of the causal role of human error. However, since many accident reporting systems are not designed around any theoretical framework, the scope for identifying the human factors remains limited (Wiegmann & Shappell, 1997).

Wiegmann and Shappell (1997) applied these three traditional error frameworks to the analysis of post-accident data with limited success. These taxonomies generally do not consider the potential adverse mental or physiological condition of the individual (fatigue, illness, etc) when describing cognitive failures. They also often fail to consider latent errors committed within the management hierarchy that influence operators decision making (Reason, 1990). A taxonomy that takes the multiple causes of human error into account is needed.

As such, Shappell and Wiegmann describe a conceptual taxonomy of accident causation, called The Taxonomy of Unsafe Operations (Shappell & Wiegmann, 1997; Shappell, Wiegmann, & Schmidt, 1996). This taxonomy draws upon several well established theoretical frameworks and so is applicable to accidents in a variety of settings. This taxonomy draws heavily upon the work by Edwards (1988), Reason (1990), and Rasmussen (1986). This taxonomy is designed for use in accident investigation and post accident data analysis, although it is claimed that it can be used in the early identification and prevention of potential hazards (Shappell & Wiegmann, 1997).

Errors are the result of an interaction between many factors. This relationship was described by Edwards' (1988) Software-Hardware-Environmental-Liveware (SHEL) model of system design. The four components necessary for the successful integration and design of a system are: software

– the rules, regulations, and governing operations; hardware – physical resources; environmental conditions; and the liveware, or the human. The reliability of a system is determined by its least reliable component, which is often the human element.

The Taxonomy of Unsafe Operations describes three levels of failure within the human component of the SHEL model: a) unsafe supervisory practices; b) unsafe conditions of operators; and c) the unsafe acts operators commit. A failure at any one or all of these levels can lead to some form of accident or injury (Shappell & Wiegmann, 1997).

1. Unsafe supervisory practices

This category of failures is divided into two categories. The first is unforeseen unsafe supervision which is described as unsafe supervision or management practices that go unnoticed yet are not the result of negligence or unsafe behaviour. *Unrecognised unsafe operations* are likened to a loss of situational awareness. For example, when the signs of fatigue or illness are not recognised by an inexperienced supervisor. *Inadequate documentation and procedures* is typical of most systems, but particularly of new ones where bugs have yet to be discovered. The accounting for all possible contingencies through technical specifications, instructions, regulations, and standard operating procedures is very difficult. *Inadequate design* accounts for design flaws that are built into systems without the supervisors knowledge and for reasons beyond their control.

The second type of failure is this category is known unsafe supervision. *Inadequate supervision* refers to mismanagement of individuals on a personal level, and includes aspects such as improper training, professional guidance, and leadership. It is viewed as some form of action or purposeful inaction by the supervisor. *Planned inappropriate actions* describes situations where it is planned that individuals are placed at risk, for example, inappropriate crew scheduling that may compromise rest periods. The *failure to correct known problems* describes instances where shortfalls in equipment, training, and other safety related areas are known to the supervisor but are allowed to continue uncorrected. *Supervisory violations* refer to situations where rules and regulations are intentionally disregarded by supervisors.

Table 1. Classification of Unsafe Supervision (adapted from Shappell & Wiegmann, 1997, p. 278)

Unforeseen Unsafe Supervision	Known Unsafe Supervision
Failure to recognise unsafe operations	Inadequate supervision
Loss of supervisory situational awareness	Improper training
Unseen of unsafe conditions and hazards	Lack of professional guidance
Life changes (personal issues)	
	Planned inappropriate operations
Lack of documentation and procedures	Improper work tempo
Inadequate instructions, regulations, etc	
	Failure to correct known problems
	Failing to correct inappropriate behaviour
Inadequate design	
Design flaws that contribute to accidents	Failing to correct safety hazards
	Supervisory violations
	Violating rules and regulations
	Disregard for authority by supervisor

2. Unsafe conditions

In some cases the standard conditions of the operator may have a role in accident causation. Within this classification, *adverse physiological states* encompasses the medical and physiological conditions that may impact upon normal operations. Some examples within aviation are presented below. *Adverse mental states* encompass loss of situational awareness and mental fatigue, but also includes personality traits and attitudes such as overconfidence, as these traits often influence decision-making. The *physical or mental limitations* of the operator describe situations where the necessary sensory information is not available, such as in a situation where a pilot's combat performance may be impeded if there was interference to auditory cues. Alternatively, the operator may neither have the time nor the ability to respond adequately (e.g.: the time required to evaluate and respond to a problem may exceed the human limit).

The second group of unsafe actions falls under the class of substandard practices of the operator. *Mistakes and misjudgements* describe situations whereby an operator has performed a behaviour that does not necessary violate rules but does compromise the capabilities of the operator. Shappell and Wiegmann (1997) provide the example of a pilot who goes for a long run prior to piloting an aircraft. While not breaking any rules, the demands on physical and/or mental capabilities by the run may impair pilot performance. Crew resource mismanagement simply refers to errors caused by insufficient communication and co-ordination between operators. Finally, violations of rules and regulations that promote unsafe behaviour are classed as *readiness violations*. Ignoring alcohol restrictions may negatively affect operator performance and is an unsafe condition. This is distinct from violating a flight parameter (such as altitude restrictions) which is an unsafe act.

Table 2. Classification of Unsafe Conditions of the Operator (adapted from Shappell & Wiegmann, 1997, p. 275)

Substandard Conditions of the Operator	Substandard Practices of the Operator
Adverse Physiological States	Mistakes and Misjudgements
Spatial disorientation	Poor diet
Physical fatigue	Overexertion while off duty
Visual illusions	
Motion sickness	
Intoxication	
Adverse Mental States	Crew Resource Mismanagement
Loss of situational awareness	Not working as a team
Drowsiness	Poor aircrew coordination
Overconfidence	Inadequate briefing
Complacency	
Physical and/or Mental Limitation	Readiness Violations
Lack of sensory input	Not adhering to regulations about rest, drug use, etc.
Limited reaction time	
Insufficient intelligence	

3. Unsafe acts of the operator

The taxonomy incorporates directly Reason's (1990) classification of unsafe acts. Reason indicates that the investigation of an unsafe act should begin with an investigation of the operator's intentions. If the behaviour proceeded as planned then the error is unintentional, and if the behaviour was not planned then the error is intentional. Reason's work was discussed earlier and so only a brief summary in the context of this taxonomy is presented here.

Table 3. Classification of Unsafe Acts of the Operator (adapted from Shappell & Wiegmann, 1997, p. 273)

Unintended Actions	Intended Actions
Slips (attention failures)	Mistakes
Intrusion	Rule-based
Omission	Misapplication of a good rule
Reversal	Application of a bad rule
Mistiming	Knowledge-based
	Incomplete mental model
Lapses (memory failures)	Violations
Omitting planned items	Routine
Place-losing	Habitual departures from rules that are condoned
Forgetting intentions	Exceptional
	Isolated departures from rules not condoned

1.4.2.4 Performance shaping factors and human error

Performance Shaping Factors (PSF) are factors that affect performance in complex human-machine systems and can be classified as being external, internal, and stressor PSF. External PSF include the work environment, system design, and procedures. Internal PSF refer to individual characteristics, skills, motivations and expectations that affect performance. Stressor PSF are psychological and physiological stressors placed on the operator that result from the work environment.

In a nuclear reactor simulation Mackieh and Cilingir (1998) examined the effects of some external and internal PSF on the type and frequency of human error. The external PSF used were task and equipment characteristics such as the motor requirement, the complexity of decision-making, and the complexity of the information presented to the operator. The internal PSF were; the locus of control, the sense of personal or internal control over one's actions; state anxiety, the degree of stress that a person experiences when in a situation where risk or stress is present; trait anxiety, the degree of stress that the operator experiences when no risk or stress is present; and intelligence.

The results of this study suggest the PSF do have an impact on the occurrence of error, but also on the type of error. The error types examined were timing errors, errors of omission and commission, inadequate responses, and errors from incorrect decisions as a solution to a problem. While information complexity and complexity of decision-making were influential factors for all error types, intelligence, state and trait anxiety, and locus of control did differentially affect the occurrence of the various error types. These results confirm that improvements to system design (in accordance with human factors principles) will help to alleviate errors to an extent, but also highlight the role of individual characteristics, suggesting that attention to personnel selection may also reduce the incidence of error in complex systems.

1.4.3 Summary

The work of James Reason still features prominently in the recent approaches in the study of human error. For example, the prominent methods for examining the role of human error in the aviation domain rely heavily on Reason's classification of unsafe acts. The two developing areas of human error are cognitive modelling and cognitive simulation. In particular, cognitive simulations have the potential to simulate operator performance and therefore predict the occurrence and type of errors for a given system. A recent model has even attempted to incorporate emotional aspects of performance. While having the most potential, cognitive simulations are yet to be fully developed and tested due to intensive time and workload involved. It is highly likely that much future research will be directed in this area.

FITNESS FOR DUTY ISSUES ARISING FROM RECENT BEHAVIOURAL RESEARCH

Fitness for duty issues are becoming increasingly important in the context of road safety. While fatigue has been an important issue in road safety over the last decade, drugs other than alcohol are an emerging issue. Unlike the areas reviewed in this report to this point, the significant majority of leading edge work in the areas of fatigue, drugs, and performance, is conducted within the road safety domain, hence these areas are reviewed here.

1.5 FATIGUE

It is well documented that fatigue is a major risk factor for accidents, and not just road accidents. To illustrate the scope of fatigue as a cause of accidents, a recent survey of 29,600 accident-involved drivers in Norway found that sleep or drowsiness was a contributing factor in 3.9% of all accidents, as reported by drivers who were at fault for the accident (Sagberg, 1999). Similarly, comprehensive analysis in the United States and United Kingdom shows that between 1-3% of highway crashes involve fatigue (Horne & Reyner, 1995b; Lyznicki, Doege, Davis, & Williams, 1998; Maycock, 1996).

While falling asleep at the wheel is thought to be a common precursor for fatigue-related accidents, there is some research that indicates that fatigue-related driving accidents are not caused by drivers falling sleep *per se* but rather by the inattention and distractibility associated with sleep loss. In a simulator study it was found that sleep-deprived drivers became less able to detect other vehicles in their own lane and in their blindspot, and less able to recall the location of these vehicles (Gugerty, 2000). These results support the hypothesis that the effects of fatigue and sleep loss on driving are related to difficulties in allocating attention (Gugerty, 2000; Peters et al., 1998).

The time of day and task duration are important determinants of sleepiness when performing monotonous tasks such as highway driving (Horne & Reyner, 1997). In relation to driving, both levels of driving ability and subjective sleepiness have been found to vary significantly across the 24 hour day (Lenné, Triggs, & Redman, 1997). This is important to consider in light of the fact that sleep related accidents are mainly the result of circadian or non-pathological sleep loss factors rather than the result of sleep abnormalities (Horne & Reyner, 1997).

While much is known about the prevalence of fatigue in accidents, the types of effects fatigue has on performance, and the factors which can exacerbate the fatigue-induced decrements, little is known about how the duration of fatigue or sleep loss corresponds to subsequent performance impairments. If further progress is to be made in developing improved fatigue-related countermeasures, it is important to have a better understanding about how the duration of prior wakefulness and sleep restriction influence performance. These two issues will be discussed in turn.

Some recent research has examined the link between the duration of sleep loss and performance, and this research highlights the role of time of day in considering the effects of fatigue. For example, Monk and colleagues have employed a continuous wakeful bedrest routine in attempts to examine the interaction between duration of prior wakefulness and time of day (Monk et al., 1997; Monk, Buysse, Reynolds, Jarrett, & Kupfer, 1992). Participants were deprived of sleep for 36 hours, from 0900 hours on day 1 until 2100 hours on day 2. During this time, participants were confined to bed, in order to reduce the potential confounding effects of activity upon body rhythms. Manual dexterity, verbal reasoning, and serial search performance were measured every two hours. Monk et al. (1992) found that performance on these tasks (for participants aged 21 to 28 years) decreased throughout the night, with a trough at approximately 0600 hours, but then improved across the following day. These findings were replicated in a later study (with the same methodology), which also included a vigilance task (Monk et al., 1997). Subjective mood also showed a similar pattern across the day.

The pattern of driving performance across the day following prolonged wakefulness is similar to the pattern of performance reported by Monk and colleagues above. Using a time of day matched control condition and a driving simulator, Lenné, Triggs, & Redman, (2000) found that performance after 24 hours without sleep (8 am) was 0.84 percent of control performance, but after 36 hours without sleep (8 pm) performance improved to 0.93 percent of control performance. This type of research suggests that the relationship between the duration of prior wakefulness and performance is not a linear one. After one night without sleep, the morning period between 8 am and midday is more risky than the period between 12 noon and 8 pm.

While several studies have examined the effects of restricted sleep times on performance, a recent study is perhaps the most comprehensive evaluation of the effects of varied levels of sleep restriction on performance, and has documented for the first time the relationship between hours of sleep and subsequent daytime performance (Balkin et al., 2000). The effects of sleep restriction (3, 5, 7, or 9 hours per night over 7 nights) were measured across a range of performance (including driving) and physiological measures. After seven nights of sleep restriction the participants were given three nights of recovery sleep (8 hours sleep per night).

The greatest decrements in cognitive performance (addition, 10-choice RT, 4-choice RT) occurred in the 3 hour sleep group, and declined to virtually no decrement in the 9 hour group. For RT speed and accuracy measures, performance in the 3 hour sleep group declined below baseline levels after two or three days of sleep restriction. Performance rarely returned to baseline levels after one night of recovery sleep, but rather after the second or third night. In some cases in the 3 hour sleep group, three nights of recovery sleep was still not sufficient to return performance to baseline levels.

Physiological measures such as saccadic velocity, sleep latency and microsleeps were not indicative of the performance decrements seen in the various sleep restriction groups. The majority of crashes (93%) were also not immediately preceded by microsleeps suggesting that simulator accidents were not caused by drivers falling asleep at the wheel. Sleep restriction did not result in a relative increase in the number of microsleep events. This finding has implications for alertness monitoring devices that rely upon polysomnographic recordings – such devices will not necessarily predict accidents.

Balkin et al. (2000) then tested the Walter Reed Sleep/Performance Model (SPM). Unlike other models that correlate alertness levels with sleepiness, this model relates performance levels with sleep, and then describes a method for displaying a person's current level of fatigue via a Sleep Watch Actograph (SWA). After inputting basic information about a person's sleep characteristics, the SWA can display the wearer's current level of sleep debt, circadian phase, and through the use of the SPM it can indicate the implication of this information for subsequent performance. A sleep scoring algorithm built into the SWA takes a minute-by-minute activity score to determine if the wearer is awake or asleep. The SPM, also built into the SWA, uses the information from the sleep-scoring algorithm to predict changes in performance in real time. The level of ambient light is used to define the circadian phase (with 2000 hours being the peak, or acrophase). The display is in the form of a fuel gauge that indicates the current levels of predicted performance (by the SPM). While promising, this device does need to be evaluated rigorously.

While only a few paragraphs have been devoted to the Balkin et al. (2000) study in this report it is worth noting that it is a hugely significant project in the study of fatigue.

1.5.1 Modelling fatigue

Some recent research has been undertaken by the United States Air Force in an attempt to model the effects of fatigue on the performance of military personnel (Neville, Takamoto, French, Hursh, & Schiflett, 2000). Two experiments were conducted that examined the effects of 52 and 46 hours of sleep loss on volunteers and military pilots respectively. Performance was measured using a set of computerised cognitive tasks such as decision-making, visual search, and attention switching. Based on the findings of these studies, the Sleepiness-Induced Lapsing and Cognitive Slowing (SILCS) model was formulated. This model does not predict an overall level of performance efficiency, but rather it predicts characteristics that were found to be associated with sleepiness, which are:

1. A general slowing of responses,
2. An increasing occurrence of delayed responses (i.e.: lapses),
3. Increasing duration of lapses,
4. Production of errors by lapses during work or event-paced task performance, and
5. Combined effect of general slowing and lapses on average RT responses.

The SILCS model functions also consist of a linear and cyclical components (24 hour and 12 hour). This model therefore clearly takes into account the duration of sleep loss and circadian (24 hour) and ultradian (12 hour) rhythms.

It is important to note that this model represents an extension of over thirty years of work in the area of sleep loss and performance. It extends on the lapse hypothesis (Williams, Gieseking, & Lubin, 1966; Williams & Lubin, 1967) and work showing that sleep loss induces a gradual slowing that is independent of lapses (Dinges, Orne, Whitehouse, & Orne, 1987; Kjellberg, 1977a, 1977b, 1977c). With a sound theoretical underpinning and with a range of performance output characteristics, this model has the potential to be extremely beneficial in providing predictions of the effects of sleep loss for different tasks in different situations. Neville and colleagues (2000) suggest that this model could be used strategically to great advantage by the United States military in times of combat.

1.5.2 Approaches to detecting fatigue

A recent report released by the National Road Transport Commission reviewed the available fatigue detection devices (Hartley, Horberry, Mabbott, & Krueger, 2000). It was suggested by Hartley et al. (2000) that with such devices there should be a guarantee that validity, reliability, etc of the device be thoroughly tested and reported. The criteria were adapted from Dinges & Mallis (1998), and were:

1. Validity: Does the device measure what it purports to measure, both operationally and conceptually?

2. Concurrent validity: The extent to which one variable predicts another at the same point in time. Can one variable be used to predict the other at the same point in time?

3. Predictive validity: The extent to which one variable predicts another variable at some point in the future. Can one variable be used to predict the other at some point in the future?

4. Reliability: Does the device measure the same construct consistently?

5. Generalisability: Does the device measure the same events in everyone?

6. Sensitivity: How often will the device miss detecting a fatigue event of fatigued operator?

7. Specificity: How often will the device give an alarm that is false?

Fatigue detection devices that are currently available and being developed can be categorised into different classes. There are a number of fitness-for-duty type devices which are primarily devices that measure performance levels prior to work. One example of such a task was developed by OSPAT systems, and is a computer-based measure of psychomotor hand-eye coordination. While this system has been used to equate performance deficits due to sleep loss and alcohol (Dawson & Reid, 1997), there is no validation data describing how performance on this task correlates to on-road driving across a wide range of hours of sleep loss.

A test battery is being used in Sydney to compare the effects of sleep loss and alcohol on performance (Williamson & Feyer, 2000). This test battery has also been linked with possible roadside fatigue testing, and is discussed in more detail in a later section (Education).

The effects of fatigue on performance and mood manifest in a variety of ways. In relation to driving, differences between fatigued and rested drivers are apparent in measures of lane weaving behaviour, lateral placement, mean speed and speed variability, steering wheel movements, reaction time to secondary tasks while driving, and also subjective mood as measured by sleepiness and motivation (e.g., Huntley & Centybear, 1974; Lenné, Triggs, & Redman, 1998). While there are many other situations that can lead to similar types of changes in driver behaviour, it is possible to go a long way towards identifying the fatigued driver on the basis of driver behaviour. The problem here is to define what constitutes as a normal variability in driving behaviour for these measures.

Some fatigue countermeasures are based on the detection of fatigue by devices that monitor control inputs such as steering. Driver Status Monitoring (DSM) systems measure driver fatigue purely on the basis of pattern recognition of vehicle control inputs that are indicative of performance impairment (Ward & Fairclough, 1997). Those authors reported that field dependent and independent subjects are differentially affected by fatigue. Their results lead to the suggestions that, a) the performance feedback by DSM systems will be interpreted differently by the two groups, and b) different strategies to combat the effects of fatigue may be need for the different cognitive styles.

An ambitious project is being undertaken in Europe to develop a system that will detect driver impairment (in real time) and engage emergency handling manoeuvres. This system is called SAVE, or the System of effective Assessment of the driver state and Vehicle control in Emergency situations (Brookhuis, De Waard, Peters, & Bekiaris, 1998). Aside from the driver, vehicle, and environment, the SAVE systems has five subsystems.

1. The Hierarchical Manager (HM) is the central processing unit of the system whose major function is to control the other subsystems. A multisensor approach is necessary to adequately detect and diagnose driver impairment, and includes Principal Component Analysis, Artificial Neural Networks, and Fuzzy Logic.

2. The Integrated Monitoring Unit (IMU) collects data from various sensors that monitor the driver (e.g.: head position, eyelid closure), the vehicle (e.g.: headway, lateral position), and the environment (e.g.: time of day) that would be helpful in determining when a driver is impaired.

3. On the basis of the IMU data, if the HM determines that the driver is impaired (but still able to stop the vehicle), the warning system is activated in one of three ways. Yellow, orange, and red warnings are used with increasing severity. Coinciding with the red warning, or the vehicle coming to a stop, the car to car warning system informs other vehicles of the possible health problems on the driver.

4. The Human Machine Interface consists of a smart card reader, visual and auditory warning and information devices, and an LCD screen and alarm button. The screen is designed to provide textual and symbolic information to the driver. The warning devices operate via warning lights and the cars speaker systems.

5. If driving safety is jeopardised the HM will initiate the Automatic Control Device (ACD). This would usually occur when no response to the warning systems is detected or when the situation is critical. When initiated the ACD stops the car safely on the side of the road without driver action.

While the integrated SAVE system has the potential to severely reduce driver impairment and accidents, it is still in prototype stage. No validation report is available at present and so commercial applications are likely to be several years away (Hartley et al., 2000).

Another approach to identifying the fatigued driver is to monitor changes in physiological state. A popular method is the use of eye monitoring devices (based on research showing that blink rate & pupil size change when the driver is fatigued). As evaluated by Dinges, Mallis, Maislin, and Powell (1988), the most promising method is Percentage of Eyelid Closure (PERCLOS) which is based upon slow eye lid closure when 80% of the pupil is covered. While Dinges et al. (1988) report high correlations between PERCLOS and performance on a psychomotor vigilance task, there are concerns about this approach. The concerns include the potentially high frequency of warnings, the extent to which it can detect signs of fatigue versus the presence of fatigue, and the fact that it has only been validated against the psychomotor vigilance task (Hartley et al., 2000). More recently however PERCLOS values were found to be significantly higher in local short haul truck drivers prior to at fault critical incidents compared to other critical incidents (Hanowski, Wierwille, Gellatly, Early, & Dingus, 2000).

Eye blink duration (EBD) has also been used as a measure of sleepiness (Hakkanen, Summala, Partinen, Tiihonen, & Silvo, 1999). Those authors used EBD to evaluate the effects of treatment for sleep apnoea, and found that sleepiness and sleep latency improved post-treatment. Since EBD is an effective measure of sleepiness in this instance, perhaps it can have applications for fatigue detection.

Alm (2000) has suggested that visual sensitivity be used (to some degree) as an indictor of impending fatigue-induced impairments. Sleep deprived and alert subjects operated the VTI driving simulator. This test is essentially a measure a reaction time to the presence of an object appearing in the environment. The results showed that RT predicted about 50% of the variance in the standard deviation of lateral position (SDLP). Since increasing variance in SDLP is indicative of early signs of losing vehicle control, perhaps the task could be incorporated into vehicle design to be used as an indicator of the ability to control the vehicle in a safe manner.

1.5.3 Approaches to manage fatigue

The best way to manage fatigue is to sleep. Where this is not possible a number of approaches have been explored to reduce to magnitude of fatigue-induced decrements in performance.

Much effort is being devoted to develop in-vehicle monitors of driver sleepiness that alert the driver when a critical level of psychological or physiological state is reached.

1.5.3.1 Naps

The use of naps as a strategy to overcome fatigue-induced performance decrements has been prevalent in the literature. For example, the use of short naps has been shown to improve both mood and performance. It was found that a 30 minute nap increased subjective alertness and decreased sleepiness in subjects who had both a normal sleep and a night of restricted sleep (Gillberg, Kecklund, Axelsson, & Akerstedt, 1996). Other studies have also reported positive affects of naps on alertness (Bonnet, 1991; Hayashi, Ito, & Hori, 1999; Takahashi & Arito, 1998; Takahashi, Fukuda, & Arito, 1998). These positive effects on mood often translate to positive effects on performance (Gillberg et al., 1996; Hayashi, Watanabe, & Hori, 1999; Rosekind et al., 1995).

Recently naps have been used effectively in the driving domain. Horne and Reyner (1996) restricted subjects to five hours of sleep, and then asked them to drive for two one hour sessions, separated either by a short nap or no nap. Whilst performance remained at high levels for the first 15 minutes after the break with no nap, performance was sustained for the full 60 minutes post-nap. Furthermore, in a second study, the effects of caffeine in combination with a short nap in sleepy subjects was found to be more effective than caffeine alone (Reyner & Horne, 1997).

There are many issues that need to be further addressed when examining the potential benefits of napping. These issues concern the optimum timing of the nap and nap length, and further investigation of the effects of sleep inertia following a nap. Sleep inertia refers to the impairment in performance and mood that occurs for a period of time after waking. While the duration and intensity of the effects of sleep inertia depend upon many factors such as the length of nap, duration of prior wakefulness, and the type of task, the effects of sleep inertia usually do not last for more than about 30 minutes (Bruck & Pisani, 1999; Dinges et al., 1987; Gillberg et al., 1996; Muzet, Nicolas, Tassi, Dewasmes, & Bonneau, 1995; Rosekind et al., 1995; Salame et al., 1995).

The positive benefits of naps have been endorsed to the point that taking 15 minute 'power' naps is now recommended by VicRoads as a major fatigue countermeasure for both professional and non-professional drivers (Dr Philip Swann, TWU Fatigue Seminar, 1999).

1.5.3.2 Auditory-based countermeasures

Landström, Englund, Nordstrom, and Astrom (1999) examined the effects of auditory stimuli on the alertness ratings of truck drivers. The auditory tones were presented for 3-7 seconds at intervals between 1 and 15 minutes. This 'measure for raised wakefulness' showed positive effects on drivers' ratings of alertness (both short-term and long-term).

Verwey and Zaidel (1999) examined the effectiveness of a more complex interactive auditory game on driving simulator ability at times of reduced alertness (11pm to 6.15am). The auditory countermeasure is called CarMate, manufactured by Dimyon Brain Storm Ltd. Drivers can play games with the CarMate based on either measuring speed, time, or distance; auditory analogues of the game Tetris, and activities based on recording and playing back the driver's voice. The CarMate decreased drowsiness, and produced fewer long (greater than one second) eye closures. Drivers in the CarMate condition also showed fewer lane crossings and accidents, as well as delayed onset of errors.

The use of auditory stimuli has been found to overcome fatigue-induced decrements in vigilance performance, and the auditory stimuli also halted the decline in alertness that was observed in a no-sound control condition (Kalsher, Fleshman, & Chiang, 2000). Positive effects of the stimuli were also evident for subjective mood. Although this study was discussed in terms of countermeasures to drowsiness, it should be said that subjects performed the task for only 24 minutes. It is unclear if benefits to performance and mood would be evident if subjects were in a genuinely fatigued state.

While such devices (that promote mental activity) appear promising in situations involving fatigue (i.e., underload), to be truly effective requires that all drivers be convinced of their utility. These devices are not likely to be effective if used very often, and may in fact overload the driver. Hence it is important that they are only used in times where the driver is under loaded, and so drivers need to be able to detect signs of fatigue so that such countermeasures can be activated. It has been stated however that (for a number of reasons) drivers do have a tendency to continue to drive when fatigued, even in the presence of warning signals (Summala, Haekkaenen, Mikkola, & Sinkkonen, 1999). Summala and colleagues suggest that fatigue monitoring systems should take control of the car, perhaps by stopping it smoothly with all lights flashing, when drivers continue driving while fatigued and ignoring several warnings.

1.5.3.3 Drugs

1.5.3.3.1 Caffeine

It has been known for many years that caffeine in a range of doses can improve performance and subjective mood (Bonnet, 1991; Bonnet & Arand, 1994; Buysse, 1991; Gibson, Mascord, & Starmer, 1995; Horne & Reyner, 1995a; Mitchell & Redman, 1992; Penetar et al., 1993; Regina, Smith, Keiper, & McKelvey, 1974), including psychomotor performance (Rees, Allen, & Lader, 1999; Reyner & Horne, 2000). The effects of caffeine only usually persist for a couple of hours. Caffeine (250 mg) has also been shown to be particularly effective in halting the decline in psychomotor performance over time in older subjects (Rees et al., 1999).

The effects of caffeine are intuitively dependent upon the degree to which a person is fatigued. For example, Reyner (2000) asked participants to operate a driving simulator from 0600 to 0800 hours after normal sleep, restricted sleep (five hours from 1200 to 0500 hours), and no sleep. Driving performance was measured in terms of incidents, defined as lane drifting. Caffeine (200 mg) improved performance and reduced levels of subjective sleepiness for two hours in the restricted sleep condition but only for 30 minutes in the no sleep condition.

A new slow release caffeine formulation has recently been used in performance studies. Slow release caffeine improved performance (improved RT and Stroop performance) and physiology (EEG) in subjects deprived of sleep for 36 hours. Sedation was also reduced. The effects peaked 4 hours post-dose, and were evident for 24 hours post-dose. Slow release caffeine has reduced improvements in alertness in rested participants (Sicard, Perault, Enslen, Chauffard, et al., 1996).

Given that caffeine and naps have independently been found to have (limited) positive effects on performance and mood it is not surprising that a small number of studies have examined the effects of both in combination. In the context of driving, Horne and Reyner have examined the influences of naps in combination with 150 mg and 200 mg of caffeine respectively (Horne & Reyner, 1996; Reyner & Horne, 1997). While driving incidents were reduced by caffeine alone, the combination of a 15 minute nap with 200 mg caffeine dramatically improved performance during a two hour driving period in the early afternoon (Reyner & Horne, 1997). While the combination of a short nap with caffeine seems beneficial, the effects of caffeine alone appeared more consistent that the benefits provided by a short nap alone (Horne & Reyner, 1996).

1.5.3.3.2 Stimulants

Caldwell and Caldwell (1997) examined helicopter pilot performance during about 33 hours of sleep loss. They reported that 10mg of dextroamphetamine improved many aspects of pilot performance, as well as decreasing feelings of fatigue and confusion, and increasing vigour.

When considering the potential benefits of stimulants it is important to consider what effect the substance may have on behaviour after the work period has ended, such as the effect on subsequent recovery sleep. A recent study has shown that low doses of the stimulant pemoline (10, 20 mg) improved night time performance between 2200 and 0800 hours (Nicholson &

Turner, 1998). Performance was measured for 90 minutes every two hours on a range of ten performance tasks. Without the stimulant, performance began to decline from 0200 hours. Importantly, while doses from 10 to 40 mg improved performance, the effects of the 30 and 40 mg doses persisted beyond the work period (2200 to 0800 hours) and disrupted the morning recovery sleep (from 0800 hours). The 10 and 20 mg doses however did not disrupt recovery sleep. These results therefore suggest that a moderate dose of pemoline (20 mg) may be suitable for maintaining overnight performance without interfering with recovery sleep. The stimulant modafinil has also been found to improve performance during the night, however it was recommended for use when there was no real opportunity for recovery sleep (Batejat & Lagarde, 1999).

1.5.4 Overcoming fatigue in the trucking industry

Research into truck driver fatigue is more focussed on long haul truck drivers, however the largest segment of the trucking industry (in the United States at least) is the local short haul truck drivers. In response to the lack of knowledge of safety issues in this group of drivers, the United States Department of Transportation recently sponsored an on-road field study of these drivers to determine the extent to which fatigue was a critical factor for them (Hanowski et al., 2000). The driving behaviour of forty-two local short haul drivers was monitored over a two-week period via instrumentation placed in their trucks. The data set contained 249 critical incidents, defined as near misses.

Fatigue was certainly an important factor for these drivers, being a contributing factor in 21% of at fault incidents. However, analyses suggested that much of the fatigue was brought with the driver to the job rather than being induced by the driving task. Younger and less experienced drivers were significantly more likely to be involved in critical incidents than more experienced drivers. However, inexperienced drivers were also showed higher levels of on-the-job drowsiness, as measured by the PERCLOS and OBSERV methods (OBSERV is based on observer ratings of fatigue based upon facial expression). Finally the majority of at fault critical incidents were committed by a small number of drivers.

Although the findings have only been mentioned briefly here, several guidelines were put forward that may lead to a reduction of at fault critical incidents:

- Driver education - it was suggested that drivers be educated on the need to arrive to work well rested and that a good night of sleep will reduce fatigue levels during the day. In addition drivers should be made aware of the dangers of driving while fatigued. This guideline also suggested that research should be directed towards developing an on-site random fatigue tester.
- Driver training – at a minimum trucking companies should conduct mandatory training programs for all young and/or inexperienced drivers. In the USA, and in Victoria, no special licences are required to drive vans and smaller trucks, and so some training and education should be given to drivers in how to safety operate a larger vehicle.
- Driver screening – all drivers should be screened prior to hiring so that unsafe drivers can be identified, although further research needs to be directed towards methods for identifying unsafe drivers.

Hanowski et al. (2000) conclude that adoption of these types of guidelines would lead to a reduction in the number of at fault local short haul driver near misses.

1.5.5 Education

There has been much advertising in Victoria alerting the public of the dangers of driving while fatigued. The 'Fatigue Kills' campaign would be familiar to the vast majority of Victorian drivers. One of the problems in highlighting the risks of fatigued driving is that it is difficult to quantify the magnitude of fatigue-related impairments, and therefore while the average person would have some awareness that fatigue does impair performance, he/she would have very little idea to what extent their performance was impaired. This issue also has implications for enforcement, that is, at this point in time there is not a quantifiable measure of fatigue that could be used for enforcement purposes.

To this end, several recent studies have attempted to define fatigue-induced performance decrements with decrements caused by the consumption of alcohol. While the concept of comparing performance to an established reference point, such as impairments due to alcohol, is not totally new (Kennedy, Dunlap, Turnage, & Fowlkes, 1993; Kennedy, Turnage, Dunlap, & Drexler, 1995; Kennedy, Turnage, Rugotzke, & Dunlap, 1994), only in the last four years has the alcohol benchmark been equated with fatigue-related impairments. The most prominent of these studies have been conducted by Drew Dawson (Dawson & Reid, 1997; Lamond & Dawson, 1999).

To achieve their aim, 40 participants were sleep-deprived for 28 hours, from 0800 hours on day 1 until 1200 hours on day 2 (Dawson & Reid, 1997). Computer tracking performance was measured every 30 minutes. In a second session, participants consumed an amount of alcohol every 30 minutes, beginning at 0800 hours, until their mean Blood Alcohol Concentration (BAC) reached 0.10%. Again, tracking performance was measured every 30 minutes. The order of testing conditions was counterbalanced across participants.

Regression analysis showed that an additional hour of sleep loss produced decrements in relative performance at the rate of 0.74% per hour, and an additional 0.01% increase in BAC produced decrements of 1.16% per hour. These values were calculated for between 10 and 26 hours of sleep loss (approximately 1800 hours on day 1 until 1000 hours on day 2), and for BACs up to 0.13%. On the basis of these regression analyses, it was claimed that 17 hours of sleep loss produced the same level of impairment as a BAC of 0.05%, and that 24 hours of sleep loss corresponded to a BAC of 0.10%.

The equating of fatigue-induced decrements in performance with an equivalent BAC is an excellent idea because it can be used to provide people in the community with a familiar but rough guide as to their levels of performance impairment during periods of sleep deprivation. There are however a number of issues associated with the approach that should be raised. Firstly, there seems to be an assumption that performance decrements during sleep deprivation and alcohol intoxication are qualitatively similar. This may be the case for the tracking task used by Dawson and Reid (1997), but differences may be apparent with other dependent variables. Secondly, in calculating the 0.74% per hour decrement due to sleep loss (between 10 and 26 hours of sleep loss), regression analysis was performed only on the data for between 10 and 26 hours of sleep loss (approximately 1800 hours through until 1000 hours). It was reported that the linear component accounted for about 90% of the variance. Therefore, it could be claimed with a high degree of confidence that the calculated decrement per hour (0.74%) was quite valid. However, the range of data selected here is very limited. Although performance does decrease almost linearly throughout the night, there is much evidence showing that performance on a wide range of tasks varies in a different way across the day (Folkard, 1983). Consequently, the percentage decrement in performance may not be equal for each additional hour of sleep loss beyond 26 hours. Similarly, there was an assumption that the effects of alcohol on performance did not differ with the time of day.

More recent studies have been conducted in this area that have utilised a wider range of tasks, including a driving simulator (Arnedt, Wilde, Munt, & MacLean, 2001; Williamson & Feyer, 2000; Williamson, Feyer, Mattick, Friswell, & Finlay-Brown, 2001). These studies have generally confirmed the relationship between sleep loss and alcohol reported by Dawson (Dawson & Reid, 1997; Lamond & Dawson, 1999). There are however several aspects of the methodology of these studies which remain suspect.

While there has been some discussion in the media that the test battery used by Williamson et al. (2001) may potentially be used for roadside fatigue testing, more research is need before such a test battery could be used with any significant degree of confidence. Furthermore, while the research by Dawson and colleagues (Dawson & Reid, 1997; Lamond & Dawson, 1999) does provide some useful information about the relationship between fatigue and alcohol-induced decrements in performance, the methodological limitations suggest that these results should be interpreted with caution, and while of educative value could not be used in any way for enforcement.

1.5.6 Summary

Further research that extends and improves upon the research by Dawson and colleagues, needs to be conducted. This information would be valuable for educative initiatives that raised awareness of dangers of driver fatigue while at the same time providing the general community with a reference points (alcohol impairment) to help provide a context with which to interpret fatigue-related impairments in driving ability. There are certainly significant research efforts being directed towards the development of models that relate current level of fatigue (using circadian phase, sleep debt, and activity levels) with subsequent performance impairments.

In terms of enforcement, it is likely in the near future that a type of performance battery could be used on the roadside to measure the extent of any fatigue-related impairments. It should be noted that such a test battery is likely to also detect impairments from other sources, such as age, drugs, etc. Further research needs to be conducted if a fatigue test is to be developed.

1.6 ALCOHOL AND OTHER DRUGS

As was the case with the fatigue research, the vast majority of the recent applied psychology research relating to specific forms of impairment such as drugs has been conducted within the domain of road safety. For example, in the drugs area, it is no longer of significant interest to examine the effects of a particular drug on simple task performance in the laboratory. There has been a definite shift in the recent drugs research towards examining the effects of drugs on complex task performance. The task of driving has been the complex task of choice in recent literature.

This section begins with a brief comment about the types of effects that various drugs have on performance. The discussion then shifts to the prevalence of drugs in drivers and accidents, and the culpability studies. Having established that the use and effects of drugs is a major road safety issue, the focus shifts to discussing how drugged drivers can be detected on the roadside, and finally some ideas about how to reduce the role of drugs in road accidents.

A point to bear in mind when considering the effects of drugs on performance is that different classes of drugs and have different types of effects and different pharmacological properties. As a result it is not valid to talk generally about 'intoxication' when discussing the effects of drugs, particularly in a legal sense (Rajaratnam, Redman, & Lenné, 2000). It is important to consider each drug class separately when examining the effects of drugs on performance.

1.6.1 Effects of drugs

There has been a considerable research effort that has addressed the issue of drugs and driving in the past five or so years, particularly in Europe. This research has found that many licit and illicit drugs do impair driving ability (see Maes, Charlier, Grenez, & Verstraete, 1999; Tunbridge, Clarke, Ward, Dye, & Berghaus, 2000, for excellent reviews). These effects will be mentioned briefly here, and the reader is directed to these comprehensive European reviews for further details.

The research reviewed here in the period 1998-2002 has been directed towards establishing the effects of particular drugs on driving (such as cannabis, ecstasy, and opioids), in addition to determining the prevalence of drugs in various samples of drivers and the role of drugs in crashes. Methods of screening for drugs of abuse in the field have also been a focus of recent research.

1.6.1.1 Illicit drugs

The most high profile illicit drug currently in Victoria is cannabis. While much research has shown that cannabis impairs performance on simple tasks in the laboratory (Berghaus, Scheer, & Schmidt, 1995), even recent reviews show that there is relatively little research on the effects of cannabis on driving (O'Kane, Tutt, & Bauer, 2002). The more comprehensive studies have been conducted in Europe. For example, Robbe (1994) found that 100 to 300 ug/kg cannabis impaired driving performance (as measured by SDLP), and this effect was heightened in city traffic. RT was also increased in unexpected emergency situations. As is often the case with cannabis, Robbe (1994) reported that drivers tended to compensate for effects of cannabis by reducing speed, increasing following distance, and engaging in fewer overtaking manoeuvres. Findings from another simulator study conducted by Sexton et al. (2000) also suggested that drivers were aware of their impairment and compensated by driving more cautiously. This study also reported that cannabis (100-150 ng/ml) produced significant increases in SDLP.

There are a number of methodological concerns that continue to manifest in some studies of the effects of cannabis on driving. For several years there has been concern that the levels of cannabis used in experimental research are much lower than those used by moderate to heavy recreational users. Furthermore, different measures of driving performance show different effects. For example, while impairments in lateral deviation have been found (Ramaekers, Robbe, & O'Hanlon, 2000; Robbe, 1998), no effect of marijuana was found on brake reaction time (Liguori, Gatto, & Jarrett, 2002). However, because in this latter study, as in many others, levels of cannabis in the body are not measured, it is difficult to reach a firm conclusion about the level of cannabis in the body, impairments in performance, and thus accident risk. There is no doubt however that the more recent evidence certainly does indicate that cannabis impairs measures of driving ability (Ramaekers et al., 2000; Robbe, 1998).

The other major illicit drug of current interest in ecstasy. Using an advanced driving simulator, researchers in the Netherlands assessed a number of driving measures, including crashes, and judgement, measured by gap acceptance when crossing a junction (Brookhuis, De Waard, & Pernot, 2000; De Waard, Brookhuis, & Pernot, 2000). Twenty subjects were tested on the simulator under three conditions: 1) at night, one hour after self-administering an ecstasy tablet, before going to a dance party, 2) after the party between 4 and 8am having taken either just ecstasy or a combination of drugs, and 3) on a control night at the same time as condition 1), supposedly drug-free. Most participants in the study (70%) reported multiple drug use at the dance party, mainly alcohol and cannabis in addition to ecstasy but no blood or urine samples were collected to verify reports. Under the influence of ecstasy alone basic driving skills were not significantly affected, however, a trend towards increased driving speed and more crashes suggested that users of ecstasy alone may accept higher levels of risk. When the driving of multi-drug users was assessed, speed and judgement were adversely affected, and again the number of crashes increased. But overall effects were only moderate. Two points are of particular note in this study: first, the design of this study is problematic and the interpretation of the multi-drug effects on driving are confounded by sleep deprivation, time of day and possibly by physical exertion. In the analysis the multi-drug condition (early morning testing, post-party) was compared with the control condition (night, pre-party). It is well established that sleep deprivation impairs driving performance especially when testing after sleep deprivation takes place in the early hours of the morning (e.g. Lenné et al., 1998), a time the circadian (daily) rhythm in arousal is near its lowest point (Moore-Ede, Sulzman, & Fuller, 1982). Secondly, the mean age of participants was 27 years. Although participants driving experience is not reported, it is likely that most were experienced rather than novice drivers so they may have been able to compensate for drug-induced decrements.

In the second field study, Krueger and Vollrath (2000) reported that consumption of high concentrations of amphetamines/ecstasy alone impaired performance on a secondary task that required attention and fast response time, and resulted in increased speed but no change in lane position (lateral deviation). Ecstasy in combination with alcohol or cannabis impaired performance further. Subjects were tested outside the party venue, at one time only (post-party, 4-6am) and performance was compared to an independent control group who had also attended the dance-party but used no drugs, so possible sleep deprivation and physical exertion confounds were avoided. Blood sampling enabled the researchers to identify the type and amount of drugs consumed. The major shortcoming of this study as far as a test of driving performance was the less than realistic driving simulation. The simulator consisted of a PC with 15" monitor and joystick for steering. Despite having a series of secondary distractor tasks incorporated, the ability to extrapolate from these results to on road performance is limited.

Research on other illicit drugs such as cocaine and heroin is virtually impossible to conduct due to ethical constraints. Available evidence suggests that these drugs have effects that would be likely to affect driving ability (Maes et al., 1999).

1.6.1.2 Licit drugs

Despite the recent focus on illicit drugs such as cannabis, alcohol remains the primary drug of concern for road safety. There is an abundance of literature demonstrating the deleterious effects of alcohol on driving skills and risk taking, and showing the over-representation of alcohol in accident statistics.

Rather than further documentation of the effects of alcohol on driving performance, more recent research has been directed towards enhancing our understanding of why people drink and drive, and in identifying target groups of drink drivers for countermeasure development and targeting. The effect of drink-driving countermeasures is understood in terms of deterrence theory, and it is assumed that the greatest benefits are achieved by using general countermeasures that would impact upon the largest number of drivers (Bornewasser & Glitsch, 2000; Dunkel & Glitsch, 2000; Guppy & Albery, 1997). However recent research has attempted to identify the psychological characteristics of drink-drivers in order to further enhance to targeting and development of countermeasures (Donovan, 1993; Guppy, Clay, & Albery, 2000; Harrison, 1996; Harrison & Fitzharris, 1999; Siegrist & Bächli-Biétry, 2000). While psychological characteristics associated with drink driving have been identified in preliminary research, future research needs to follow through with the development of countermeasures for the target groups, and evaluate their efficacy.

It is important to consider that drink driving is one of many risk-taking behaviours, and that risk-taking behaviours in general do not occur in isolation. For example, people who use alcohol are more likely to use other drugs, less likely to use seat belts, and more likely to engage in unsafe sexual practices (Sommers, Dyehouse, Howe, & Manharth, 2000). It was suggested that interventions targeted only at reducing drink driving may be ineffective in managing a broader spectrum of risk-taking. More comprehensive health policy programs would be more likely to reduce to future risks of injury and death in the at-risk population of drinking drivers (Sommers et al., 2000).

Of all prescribed medications, benzodiazepines represent the greatest road safety risk. According to Maes et al. (1999), benzodiazepines are the most solidly documented drug group with regard to the influence on driving behaviour.

For example, in a study of elderly drivers (>65 years), Ray, Fought, & Decker (1992) found that the relative risk of injurious crash involvement for benzodiazepine users was 1.5. The risk increased with dose and was substantial at high doses (2.4 for ≥ 20 mg diazepam). Hemmelgarn (1997) examined records of 5579 elderly people involved in crashes (1990-93) and 13256 controls. There was a significant increase in rate of crash involvement within the first week of long half-life benzodiazepine use (1.45); the rate ratio for continuous use up to one year was lower but still significant (1.26). There was no increased risk after initiation or continued use of short half-life benzodiazepine. Oster, Huse, Adams, Imbimbo, & Russell (1990) compared 4554 persons who had been prescribed benzodiazepine tranquillisers with 13662 controls with prescriptions for other drugs. The probability of an accident-related medical encounter was higher during the months following the prescription of a benzodiazepine (1.15. vs. control; 1.28 vs. the same person in period when he/she was not exposed to drugs). The reader is also directed to Neutel (1998).

Little is known about how other medications such as antidepressants affect driving performance. Maes et al. (1999) do suggest that single doses of the more sedative medications is likely to induce more impairment. In a series of seven driving studies, Ramaekers (1998) found that specific antidepressants did impair driving and sustained attention whilst others had no impact. The prevalence of antidepressants in the driving population is unknown, and incidence in accident-involved drivers or in drivers suspected of drugged-driving are typically below 1.5% (Maes et al., 1999).

Opioid analgesics may also have a detrimental impact on driving skills, however it is accepted that the risk is far less than for benzodiazepines. A recent review of the effects of opioid analgesics on performance suggests that patients are only likely to be at potential risk when in the few weeks of treatment, and when increasing their dose markedly (Lenné, Dietze, Rumbold, Redman, & Triggs, 2000). Experimental studies with morphine in cancer patients have shown no increase in accident risk is associated with the long-term morphine treatment (Zacny, 1995, 1996).

Much research has focussed on the effects of methadone on driving, as methadone is the primary treatment for heroin dependence in most countries. While acute doses of methadone do impair cognitive performance in naïve subjects, measures of psychomotor performance for clients in methadone treatment do not seem to differ from controls (Lenné, Dietze, Rumbold, Redman & Triggs, 2000). Research in Melbourne also suggests that the driving behaviour of clients in treatment for heroin dependence (methadone, LAAM, and buprenorphine) does not differ from controls (Lenné, Dietze, Rumbold, Cvetkovski et al., 2000).

1.6.2 Prevalence

In a recent review of 69 epidemiological studies, Krueger and colleagues reported data on the median percentages of positives for alcohol, illicit drugs, and licit drugs in drivers at the roadside, injured drivers, and fatally injured drivers (Kruger, Schulz, & Magerl, 1995).

Table 4: Median exposure rates from 69 epidemiological studies (adapted from Maes et al., 1999, p. 9)

	Roadside (% positive)	Injured (% positive)	Fatalities (% positive)
Drugs	1	17	19
Medicines	4	13	10
Alcohol	6	35	52

It is critical that substantial data be collected on the prevalence of drug use in the general driving population. Roadside surveys conducted in Germany and The Netherlands suggest that the prevalence of drugs is as follows: alcohol (6-12%), cannabis (1-5%), amphetamines (0.8-1.4%), opiates (0.7-1.4%), and benzodiazepines (0.3-2.6%) (Maes et al., 1999).

The incidence of alcohol and drugs increases when data from drivers suspected of drugged driving and injured drivers are considered. Table 5 shows European data on the prevalence of drugs in drivers suspected of driving under the influence. Alcohol is clearly the most common drug, followed by benzodiazepines, cannabis, and amphetamines. The data below is from Norway (Christophersen & Morland, 1997; Skurtveit, Christophersen, & Morland, 1995), Switzerland (Augsburger & Rivier, 1997), Denmark (Steentoft, Worm, & Toft, 1997), and Finland (Lillsunde et al., 1996).

Table 5: Drivers suspected of driving under the influence (adapted from Maes et al., 1999, page 12).

	Norway	Switzerland	Denmark	Finland
Period	1994	1982-1994	1995	1993
Number of subjects	2529 (total of 2819)	641 (40 % involved in accident)	221 (46 % involved in accident)	332
Biological sample	Blood	blood, urine		blood
Analytical methods	Immunoassay GC-MS	Emit, RIA, TLC, GC, HPLC		Emit, GC
RESULTS				
Alcohol	89%	35.9%		95.5%
Alcohol only	30%	7.8%		73.2%
Drugs	59% (in 2529 cases With BAC < 1.5 g/l)	85.0%	86.0% (in 221 cases with BAC < 0.5 g/l)	26.8%
Drugs only		56.9%		
Drugs + alcohol		28.1%		24.1%
Amphetamines	21.1%	4.2%	10.0%	2.7%
Benzodiazepines	30.6%	14.8%	53.0%	22.9%
Cannabinoids	26.1%	57.3%	17.0%	2.4%
Cocaine	0.04%	10.5%	6.0%	1.2%
Methadone	7.6%	10.3%	13.0%	
Opiates	4.1%	36.3%	27.0%	0.0%

Again, prevalence of drugs is higher in (European) drivers who are injured or killed. The most prevalence drug is by far alcohol, again followed by benzodiazepines, cannabis, amphetamines, and opiates (Alvarez et al., 1997; Christophersen et al., 1995).

Table 6: Drug prevalence in drivers injured or killed in Norway and Spain (adapted from Maes et al., 1999, page 11)

	1.6.2.1.1.1.1 Norway	Spain
Period	1993	1992-1995
Number of subjects	394 (injured drivers)	979 (killed drivers)
Biological sample	Blood	Blood
Analytical methods	GC-MS,HPLC	Immunoassay GC-MS, HPLC
RESULTS		
Alcohol	62.9%	51.2%
Alcohol only	51.8%	44.3%
Drugs	24.1%	14.3%
Drugs only Drugs + alcohol	12.9% 11.2%	5,9% (2 % illicits+ 3,9 % medicines) 6.9%
Amphetamines	4.1%	0.9%
Benzodiazepines	13.7%	
Cannabinoids	7.6%	1.5%
Cocaine	?	5.0%
Opiates	4.3%	3.1%

Australian data is discussed in the following section.

1.6.3 Culpability studies

Australian studies have moved beyond stating the prevalence of drug types in accidents. Researchers in Melbourne and Adelaide have used methods for assigning culpability or responsibility for each accident.

Drummer (1994) collected data for 1045 drivers killed. Responsibility was determined according to the mitigating factors (independent of drug analysis), and drivers were classified as culpable, contributory, or not culpable. The proportion of culpable drivers (ratio) was calculated for each drug type, as is presented below. The majority of drivers were culpable (73%), while 18% were not culpable.

Table 7: Responsibility analysis for fatal accidents (Drummer, 1994).

Drug group	Prevalence	Relative risk (all cases)	Relative risk (drug alone)	Relative risk (drug + alcohol)
Drug free	51 %	1.0		
Alcohol Alcohol + drugs Drugs	27 % 9 % 13 %		**6.0** 1.4	**9.0**
Cannabis	11 %	1.6	0.6	**5.6**
Stimulants	3.7 %	**2.7**	1.6	8.7
Opiates	2.7 %	**5.0**	2.3	2.9
Benzodiazepines	3.1 %	**5.8**	1.9	**9.5**
Misc. Drugs	5.6 %	**4.0**		8.7

Note: Bold = statistically significant

The highest culpability ratios for any drug alone was found for alcohol, then opiates. Culpability ratios were considerably higher for all drugs in combination with alcohol, except opiates.

Data have also been reported on the prevalence rates for various drugs in non-fatal accidents in Australia (Longo, Hunter, Lokan, White, & White, 2000a, 2000b). Longo and colleagues collected blood samples from 2500 non-fatally injured drivers in South Australia in 1995-1996. Alcohol was the most common drug being present in 8.6% of cases. The next most prevalent drugs were cannabis only (7.1%), cannabis and alcohol (3.0%), benzodiazepines only (1.8%), and stimulants only (0.8%). Just over 75% of drivers tested were negative for alcohol and other drugs. Alcohol and cannabis were more prevalent in single vehicle accidents than multiple vehicle accidents. Culpability analysis was conducted and the results appear below.

Table 8: Percentage of drivers culpable for each drug type in an analysis of 2500 non-fatally injured drivers in South Australia (Longo et al., 2000b).

Drug combination	Percentage culpable
Drug free	52.8
Alcohol only	90*
THC only	47.7
Alcohol + THC	85.7*
Benzodiazepines only	69.6*
Stimulants only	68.8
Benzodiazepines + alcohol	93.8*

* significantly different from drug free group.

The trend continues in that alcohol was the most dangerous drug in terms of the percentage of drivers found culpable with one drug alone. Culpability was again much higher for drugs in combination with alcohol – particularly THC and benzodiazepines.

1.6.3.1 Summary

These studies clearly show that alcohol is still the major drug of concern for road safety. It is the most commonly detected drug in roadside and injured driver samples, and it is associated with a very high degree of accident culpability. The combination of other drugs particularly cannabis and benzodiazepines) with alcohol is also of great concern and associated with high culpability.

It is interesting to note that after reviewing all of the available experimental and epidemiological evidence, Tunbridge et al. (2000) classified alcohol and benzodiazepines as the two drugs that should be regarded as being the highest priority in terms the nature of their impairing effects and the frequency of their incidence in the driving population, and thereby represent the greatest risk to road safety. Amphetamines, cocaine, opiates, and cannabis were classified as medium priority.

It should be noted however that some reasons for the discrepancy between laboratory and epidemiological drug driving studies have been recently noted (Ramaekers, 2003). Namely it has been suggested that methodological concerns with epidemiological studies, such as misclassification of drug use, confounding by treatment duration and concentration, and statistical power, may contribute to the underestimation of crash risk.

1.6.4 Drug detection

1.6.4.1 Detection by observing behaviour change

The development of effective legislation around the driving-impairing effects of drugs has proven difficult in Victoria (Victorian Parliamentary Road Safety Committee, 1996). Presently American-style standardised field sobriety tests are being used as a mechanism for detecting drug-related impairment and empowering police to order the provision of bodily fluid samples from impaired drivers. These tests include the one-leg-stand, walk-and-turn and gaze nystagmus tests (see Grossman et al., 1996; Kennedy et al., 1994).

The introduction of these procedures represents one of the major countermeasures proposed in relation to drug-related impaired driving (Victorian Parliamentary Road Safety Committee, 1996). However, most research on standardised field sobriety testing has been conducted on alcohol in relation to legislative requirements in place in many parts of the United States. This research has shown that the tests are able to detect alcohol-related impairment at the 0.08% blood alcohol level (Stuster & Burns, 1998). In the United States the development of Drug Recognition Expert (DRE) programs utilise a series of additional tests in order to determine the involvement of illicit drugs in impaired driving (Heishman, Singleton, & Crouch, 1996, 1998; Page, 2000).

Undoubtedly future research will continue to evaluate the efficacy with which these tests can detect recent illicit drug use, and strive towards the development of alternative approaches.

1.6.4.2 Drug detection in alternative samples

There is currently a race worldwide to develop a validated measure of drug use that can be used in the field, and the majority of this research is taking place in Europe. The samples that can potentially be used to conduct drug analyses are blood, urine, sweat, saliva, and hair (Samyn, Viaene, Vandevenne, & Verstraete, 1999). There is no doubt that blood sampling represents that most accurate means for confirming recent drug use, however it is not a practical means of testing for drug use in the field, such as at mining sites or on the roadside. While much research is being directed towards researching these alternative samples, the majority of effort seems to be directed towards developing a saliva-based measure of drug use (Christophersen et al., 2000; Moeller, Steinmeyer, & Aberl, 1999; Samyn, 2000).

Two such saliva-based devices, the Rapiscan and Drugwipe, are currently being evaluated in Norway in drivers who are suspected of driving under the influence of drugs (Christophersen et al., 2000). Early results suggested that the devices may need further research to enhance the ease of operation by police on the roadside, and to refine the pharmacological cut-off levels for the drugs being tested.

Using a different approach., the Rapiscan unit was recently evaluated in Melbourne (Lenné, Dietze, Rumbold, & Drummer, 2000). Results from this device were compared with blood levels and self-reported levels of drug use in injecting drug users. While results were not encouraging for cannabis and benzodiazepines, the results for opioids were promising. Given that cannabis and benzodiazepines are more widely used, and so are more of a road safety concern, it was recommended that further work be done refining the device to improve the sensitivity to these drugs, and as such, that the device not be used for road safety purposes at present.

It is likely that an appropriate device will be available in the next couple of years. The availability of such a device will have huge implications for occupation health and safety, such as in the mining and transport industries, as well as providing Police with an additional means for quickly confirming drug use by drivers, pedestrians, and other road users.

1.6.5 Education

One of the major countermeasures to drugged driving will be education and increasing the awareness of the potential impairing effects of drugs on driving skills. There have a been a couple of studies conducted in Melbourne that clearly highlight the need for such educative initiatives.

Aitken and colleagues (Aitken, Kerger, & Crofts, 1998; 2000) conducted focus groups with heroin, stimulant, and cannabis users. This study documented in detail the issues concerning drugged driving amongst illicit drug users. While the majority of illicit drug users are not overly concerned about the their drug use and driving patterns, it was clear that the drug use and driving patterns were dependent upon the type of drug user. For example, heroin users reported driving under the influence of heroin on regular trips to work and social events, but also for specific drug-related travel. It was common for heroin users to report driving to buy heroin, using, and then driving home shortly after using. The patterns of drug use and driving behaviour were also similar for stimulant users, and driving to buy drugs, using, and then driving home was also a common occurrence.

Unlike heroin and stimulant users, cannabis users did not feel the urgent need to drive to buy drugs. Although users of these types of illicit drugs identified effects of each drug that could affect driving, these users felt that their drug use did not compromise their driving abilities. This belief was particularly strong for the cannabis users who felt that cannabis was a safe drug for driving. All of the illicit drug using groups believe that driving under the influence of alcohol was a more dangerous practice than driving under the influence of heroin, stimulants, and cannabis.

The drugged-driving attitudes and practices were further explored in a survey study of regular cannabis users. Similar to the Aitken et al. (2000) study, this study confirmed that cannabis users did perceive cannabis to be a safe drug for driving. Of particular interest was the finding that a majority of participants indicated that they would not change their drug-use and driving behaviour if tougher drug-driving legislation was introduced (Lenné, Fry, Dietze, & Rumbold, 2001). A discussion about legislative countermeasures appear below.

The attitudes of illicit drug users in Melbourne clearly highlights the need for long-term educative countermeasures targeted towards attitudinal change.

1.6.6 Legislation

One strategy that has been introduced worldwide to combat drugged driving has involved new legislation that provides police with the powers to prosecute drivers for driving under the influence of drugs other than alcohol. This approach is necessary because it is difficult to prove impairment (although some tests are now being developed). Countries that have adopted this type of approach include Germany, Belgium, and Sweden (Moeller, Steinmeyer, Bregel, & Wilske, 2000; Verstraete & Maes, 2000), although the law in Belgium does not include prescribed medications. The Drug Recognition Expert (DRE) program has been implemented in the United States since the 1970s. While it was originally designed to detect alcohol related impairment, it is now used to detect impairment resulting from the consumption of other drugs (Page, 2000).

Legislative countermeasures to drugged driving have recently been introduced in Victoria. From December 1st 2000, Victorian Police have the ability to prosecute drivers who are found to be driving under the influence of drugs other than alcohol, both licit and illicit (Wylie & Swann, 2000). This approach uses a combination of behavioural observations at the roadside, physical tests (standardised field sobriety tests), and blood drug screens to reach a conclusion about a driver's drug use.

1.6.7 Summary

Despite recent attention to illicit drugs such as cannabis, alcohol remains as the primary drug of concern for road safety. Recent research has been directed towards enhancing our understanding of why people drink and drive, and in identifying target groups of drink drivers for countermeasure development.

The driving task has increasingly been used as a complex task by which to measure the effects of drugs on performance. In the past five or so years research been directed towards enhancing our understanding of how drugs other than alcohol affect driving. In particular, advances in simulator capabilities have allowed for more comprehensive examinations of how illicit drugs such as cannabis affect driving.

Drug detection is an area of immense research activity in recent years. Some research has focussed on detection by observing behaviour change. Increased understanding of how drugs affect performance has informed the development of procedures such as the SFST. Research conducted in the previous year or so has been more directed towards detection in alternative samples such as saliva, sweat, and urine, as more objective indicators of drug use in the field.

IMPLICATIONS FOR COUNTERMEASURE DEVELOPMENT

The purpose of this report was to review developments and trends in the recent literature on applied experimental psychology, human factors and traffic psychology that might provide new directions for, and lead to the refinement of, existing road safety countermeasures. In the previous chapters, literature was reviewed from selected reports and journals published between 1997 and 2002. In the final chapter of this report, the implications for countermeasure development of the literature reviewed are discussed. While beyond the original scope of this report, some further key findings from papers published are included in this chapter to maintain the currency of the material reviewed.

1.7 PROCESSES USED TO DISTILL IMPLICATIONS FOR COUNTERMEASURE DEVELOPMENT

Described below is the process adopted by which the implications for countermeasure development were distilled from the material reviewed.

The literature review was sent internally to a number of MUARC colleagues, most of whom are highly experienced researchers with a broad appreciation of road safety issues. Those to whom the document was sent were invited to provide input to the development of countermeasures deriving from the material reviewed. The following colleagues were able to respond to this request:

Dr Narelle Haworth (Senior Research Fellow; MUARC);

Dr Tim Horberry (Senior Research Fellow, MUARC);

Professor Ian Johnston (Director, MUARC);

Dr Mike Regan (Senior Research Fellow, MUARC);

Dr Teresa Senserrick (Research Fellow, MUARC);

Professor Tom Triggs (Deputy Director, MUARC); and

Ms Michelle Whelan (Research Assistant, MUARC).

Each researcher was asked to read the literature reviewed and, as they came across a paragraph or cluster of paragraphs which triggered in their mind a recommendation for a road safety countermeasure (or a recommendation for the refinement of an existing countermeasure), to document it under one or more of the following headings:

- training;
- education;
- promotion/advertising;
- traffic engineering;
- legislation;
- enforcement;

- licensing;
- vehicle design; and
- ”other” countermeasures.

With the exception of the latter category, most countermeasures for injury prevention in the road safety domain fall under one or more of these headings.

The outputs from this process were then collated and distilled into a final set of recommendations for countermeasure development. These are outlined the paragraphs that follow.

1.8 RECOMMENDATIONS FOR COUNTERMEASURE DEVELOPMENT

In the following sections, some suggestions for countermeasure development are made which derive from the process described above. Some of the recommendations relate to the need for further research. These are grouped under one or more of the non-research headings noted above, in order to make these recommendations more accessible.

1.8.1 Training

The findings from the present review reveal some important developments in training research. Noteworthy, is that most of these have occurred outside the domain of road safety.

1.8.1.1 Visual Scanning

Safe driving relies critically on the ability to effectively scan visually both the internal (i.e., car cockpit) and external visual environments. This review highlighted three important developments in research on visual scanning: the identification of critical differences in the way novice versus more experienced vehicle operators (drivers and pilots) scan the visual environment; the identification of critical differences in the way younger versus older drivers scan the visual environment; and the use of road treatments to change search patterns to make potential hazards more conspicuous. The following recommendations were distilled from this research.

There is a need for fundamental research on differences in scanning strategies between young novice and experienced drivers and riders in Victoria, specifically in traffic scenarios which are known to pose the greatest crash risk to them. Similarly, there is a need for fundamental research on differences in scanning ability between younger and older drivers and riders, in traffic scenarios known to pose the greatest crash risk to drivers and riders of advancing age. The research should address, among other things, so-called “looked but not see” crashes that result in many injuries to the riders of motorcycles and bicycles.

In the meantime, there is enough general information known about deficits in novice driver scanning patterns and methods for optimising these to suggest ways in which methods might be developed to train efficient scanning in young novice drivers. It is recommended that current driver training programs in Victoria be examined to determine to what extent the scanning deficiencies known to exist in young novice drivers are being adequately addressed.

There is enough information known about general deficits in novice driver scanning patterns to enable an assessment of scanning ability to be made as part of the probationary licensing process. It is recommended that an examination of the VicRoads Hazard Perception Test be undertaken to determine how it can be enhanced to assess the presence of scanning skills known to be critical for safe driving.

There is evidence that the ageing process has a detrimental effect on visual scanning ability. There is also converging evidence that some skills that decline with age can be re-trained. It is recommended that fundamental research be undertaken to determine if scanning techniques can be optimised for older drivers and, if so, which training methods are most effective for doing so. This research would also yield insights into suitable methods for assessing scanning skills known to deteriorate as a function of the ageing process.

1.8.1.2 Multitasking

The ability to perform several tasks at the same time is critical for safe driving. There is evidence to suggest that the way in which people are trained to perform multiple tasks can have a profound effect on the ease and efficiency with which they can be performed together. Variable Priority Training, in particular, is a training technique that can be used to train drivers to multi-task efficiently. The DriveSmart CD-ROM product, developed by MUARC for the Transport Accident Commission, is currently the only known driver training product in the world to have incorporated this training technique. It is recommended that future development of training programs for road users draw on the knowledge and techniques derived from this area of research.

1.8.1.3 Crew Resource Management

CRM is a term for a form of training used to enhance safety, mainly in the aviation domain, by optimising teamwork, communication and decision making by flight crew. This form of training, if employed in the road safety domain, has potential to optimise the safety of drivers and passengers in car cockpits, particularly young drivers who are more at risk of crashing than older, more experienced, drivers in the presence of young passengers. There is currently enough known about CRM to adapt it for use in pre-driver education and driver training programs in Victoria. Work being undertaken by MUARC for the NRMA-Australian Capital Territory (ACT) Road Safety Trust is examining the potential role for this form of training for young drivers and passengers in the ACT. The outputs of this project should be closely monitored.

1.8.1.4 Virtual Reality

There is strong evidence in domains other than road safety to support the concept that training people in synthetic environments can lead to cost-effective training outcomes (e.g., Crane, Robbins, & Bennett Jr, 2001; Crane, Schiflett, & Oser, 2000). These synthetic environments can range from full-scale, dynamic, vehicle/cockpit simulations to PC-based environments which are represent some aspects of the operational environment. It is important to note that full-scale simulation, or full task fidelity, is not a requirement to obtain good training effectiveness. There are a number of examples of low fidelity devices achieving as good an outcome as high fidelity alternatives. There is in fact some evidence that increasing fidelity does not necessarily add to training effectiveness (Moroney and Moroney, 1999). Furthermore, high similarity (short of a perfect representation of the real environment) may be detrimental because it leads to conflicting response strategies and may divert attention away from the critical aspects of the task to be learned (Hawkins and Orlady, 1993). In fact, for some tasks initial learning may be better in a primitive device than in the real thing, although this would not apply to all situations.

In the road safety domain, there is evidence that CD-ROM based training can provide significant transfer of training in a cost-effective way, and is an effective simulation platform for training safety-critical driving skills such as visual scanning, hazard perception, risk assessment, decision making, and attentional control (e.g., Fisher et al., 2002; Regan, Triggs and Godley, 2000; Regan, Deery and Triggs, 1998; Triggs and Regan, 1998). Given that these skills are also critical for other road users to safely negotiate their way through the traffic management system, there appears to be potential to use this approach to train critical skills required to, for example, safely walk, cycle, and ride a motorcycle. In fact there is current activity in more than one of these areas. The CD-ROM is an effective tool for training certain skills required to walk safely and the Victorian Transport Accident Commission has recently commissioned a project that will culminate in the development of a CD-ROM training product for motorcycle riders. By comparison with full-scale, high fidelity, simulation, PC-based virtual training environments are far less likely to induce simulator sickness.

1.8.1.5 Decision Making

There has been a paradigm shift in decision making research, with a shift away from a focus on research in laboratory settings to the study of decision making in naturalistic settings. There is now a greater focus on the study of decisions which are embedded within complex tasks that are made by competent and experienced decision makers (e.g., Klein, 1993). A class of techniques falling under the rubrics of Cognitive Task Analysis (CTA) and Work Domain Analysis (WDA) has been developed to systematically "tease out" of experts the decision making processes used by them when performing complex tasks in domains such as aviation and process control. These techniques, if applied in the road safety domain, provide a powerful means for understanding the decision making processes that differentiate expert drivers from novice road users. Models of decision making in naturalistic settings, such as Klein's model of recognition-primed decision making, have also been developed from which have been derived techniques for facilitating the transition from novice to expert decision maker. It is recommended that future development of training programs for road users draw on the knowledge and techniques derived from this area of behavioural research.

1.8.1.6 Situation Awareness

SA refers to the perception of elements in time and space, the comprehension of their meaning, and the perception of their status in the near future (Endsley, 1995). Lack of SA has been causally linked to accident and incident involvement in the aviation and maritime domains. In the aviation domain, techniques have been developed to train SA and to measure it. With the exception of the DriveSmart CD-ROM novice driver training product developed by the Victorian Transport Accident Commission, the authors are unaware of any other driver training programs or products that have been designed directly, or indirectly, to enhance SA in the road safety domain. Research is needed in the road safety domain to determine to what extent lack of SA is a causal factor in road crashes, to identify factors which contribute to the loss of SA, and to develop techniques for measuring and training SA in drivers and other road users.

1.8.1.7 Ageing

Older adults have been found to exhibit larger multiple-task performance decrements than younger adults. There is converging evidence, however, that the age-related gap in performance can be reduced with training. It is recommended, therefore, that programs be developed which investigate the potential for re-training multi-tasking, visual scanning and certain other skills known to decline with age which appear, from the research reviewed, to be amenable to re-training.

1.8.1.8 Feedback

Feedback about task performance is critical in acquiring most skills. There have been recent advances in knowledge about the ways in which people detect and correct errors when acquiring complex skills with a significant cognitive component, such as driving. These findings have implications for the design of training programs and for the design of in-vehicle technologies which are capable of detecting performance errors and providing feedback to drivers in a manner which facilitates skill acquisition.

1.8.1.9 Variable Reliability Training

One study reviewed here examined the effects of varied training regimes using a flight simulation task (Singh et al., 2000). Training was performed when the system was running at both constant and variable reliability. Training with variable reliability was found to result in superior skill acquisition. Variable reliability training may be particularly beneficial in the road safety domain given that drivers do not drive in a predictable manner and in accordance with road rules.

1.8.1.10 Insight training

There appears to be support by some members of the road safety community for training programs that aim to improve "insight" into factors, including personal factors, that increase or decrease crash risk (e.g., Gregersen, 1996). The extent to which such self-awareness training actually reduces crash risk is, however, unclear and some (e.g., Christie, 2002) have argued that such courses may in fact strengthen or confirm optimism bias amongst those so trained. Further research is needed to trial and evaluate the effectiveness of this form of training as a road safety countermeasure.

1.8.1.11 Summary

In summary, the findings from this review reveal many important research findings of relevance to driver and road user training, the vast majority of which have occurred outside the domain of road safety. What this review has highlighted is that training research is progressing in a number of areas that have not yet influenced the ways in which driver training is accomplished in Victoria, or indeed elsewhere in the world.

A recent report, concerned with driver training, should be considered here. Christie and Harrison (2003) have reviewed research and developments in driver education and training, limiting their focus to developments within the road safety domain locally and overseas. Those authors argue that driver training of a "conventional" nature contributes little to reductions in accident involvement or risk among drivers of all age and experience groups, but conclude that ".. there is no clear blueprint for the development of leading edge driver training programs." (pi).

Based on the material reviewed in the present document, and that reviewed by Christie & Harrison (2003), we believe there is scope for developing a model driver training program in Victoria. While the specific features of such a program are yet to be defined, it is possible at this point in time to define some key elements that derive from the present research which might characterise the program:

- the program would not only focus on the driver, but also on the role that passengers may play in influencing driver performance and safety;
- The content of any such program should focus on the development of those skills that are known to be safety critical. The material reviewed in the present report highlights skill domains that might also form part of future training programs. Current European Union funded projects reviewed by Christie and Harrison (2003) also provide guidance in this area.
- It has been asserted elsewhere (Christie & Harrison, 2003) that associative learning is the predominant means by which safe driving skills develop. The present report, however, has identified instructional techniques, such as variable priority training, which have been demonstrated to result in skill transfer to operational domains. It is essential therefore that future driver training programs consider the full range of instructional methods that can be used to facilitate skill development.
- The present report has highlighted the gains that can be made from using training delivery modes that go beyond the sole use of vehicles. In particular, the use of virtual reality in young driver training has been shown to have good efficacy.
- Future training programs should focus not only on the initial development of skills, but in addition, the decline in skills that occurs as a consequence of the ageing process or declines in health.

We recommend, therefore, that a study be undertaken to review the efficacy of the current system of driver training in Victoria and to determine how these and other developments can be drawn on to enhance the effectiveness of driver training programs.

1.8.2 Education

There is evidence that heavy drug users are not aware of the potentially impairing effects of drugs, alone, and in combination, on driving skills, and that they would not change their drug use and driving behaviour if tougher drug-driving legislation were introduced. Clearly there is a need for the development of a long-term educational program targeted towards attitudinal change amongst drug users who drive. There is a need to research the drug-driving practices and attitudes of more recreational users. This is particularly important in the case of cannabis. Recent advances in drug detection approaches have been able to demonstrate increased crash culpability associated with the recent use of cannabis (Drummer et al., 2003). Furthermore, a recent review has also reported data that shows more conclusively that cannabis does impair aspects of driving performance (Ramaekers, Berghaus, van Laar, & Drummer, 2004).

Recent research has focussed on the effects that the use of stimulants has on performance after the work period has ended. For example, in one study it was found that, at optimal doses, the stimulant pemoline was suitable for maintaining overnight task performance without interference with recovery sleep. Whilst the use of stimulants by drivers vulnerable to the effects of fatigue is not condoned by the authors, there is a case for bringing knowledge of this kind to the attention of those who habitually consume stimulants in the road transport industry.

1.8.3 Licensing

The findings from this review suggest that there are many perceptual and cognitive skills, acquired through experience, and amenable to training, which are necessary for safe driving. Noteworthy, in this context, is that the VicRoads-developed Hazard Perception Test (HPT) assesses only a small sub-set of these skills. It is recommended that the HPT be upgraded to ensure that it assesses the full range of perceptual and cognitive skills required to drive safely, not just those relating to hazard perception.

The size of the visual field has been shown to reduce and change shape when people are required to perform a demanding task in addition to a primary visual detection task, such as driving. This effect may be particularly pronounced for young novice drivers, due to a lack of automatisation through practice of the driving task. Further research is needed to confirm this hypothesis. If confirmed, it is possible that currents tests of hazard perception, such as the VicRoads -developed HPT could be made more discriminating by embedding within it a secondary task. This would make the test better able to differentiate between license applicants who have, and have not, through experience automated driving to the point that their field of view is wider than that of less experienced drivers.

There is some evidence that people who score highly on the violations and errors sub-scales of the Driver Behaviour Questionnaire (DBQ) are more likely to offend and are at greater risk of having a crash than those who score less highly. It is recommended that, as part of a broader examination of human error and its role in crash causation (recommended in a later section of this report), further research be undertaken to determine the validity of instruments such as the DBQ as diagnostic tools for identifying driver training needs, for screening licence applicants who may be at higher risk of crashing, and in providing proxy measures which can be used for research purposes when more traditional sources of information (e.g., offences, crashes and actual driving data) are not available.

1.8.4 Promotion/Advertising

Recent research on fatigue suggests that time on task, time of day, amount of prior sleep and sleep recovery time interact to determine levels of driving performance degradation. It is recommended that existing publicity campaigns, which focus only on time spent driving, address the full range of factors that, in combination, contribute to the onset and presence of fatigue.

Several recent studies have attempted to equate fatigue-related performance decrements with those caused by equivalent BACs. Whilst it is concluded in this review that further research is needed that extends and improves upon this research, the information derived from these studies is nevertheless valuable in providing the general community with a reference point (i.e., alcohol impairment) as a context within which to interpret fatigue-related impairments in driving ability. It is recommended that educational programs incorporate information about the effects of fatigue in terms of equivalent doses of alcohol.

Whilst some road safety benefits exist for the safe use of caffeine in some situations, comparatively little publicity or advice on this matter has been made available to the general public. Recent research, for example, suggests that drivers ingesting one or two cups of coffee followed by a "power nap" might be a more effective strategy in maintaining alertness than a power nap alone. It is recommended that the motoring public be informed more widely about the benefits and limitations of using caffeine in overcoming and managing the effects of fatigue.

1.8.5 Traffic Engineering

Whilst research has been conducted in the past into the effectiveness of perceptual countermeasures in moderating a drivers' choice of speed, recent evidence (e.g., Summala et al., 1996) suggests that road treatments, such as speed humps, can be designed and deployed in a way that promotes effective visual scanning for hazards by motorists. Advanced driving simulators are suitable for prototyping and evaluating the effects on visual perception, including scanning, and other driving behaviours of introducing alternative road treatments (Godley, Triggs, & Fildes, 2002; 2004). Indeed, use of simulators in this way could form part of the existing Road Safety Auditing process, particularly in proactively evaluating design concepts. It is recommended that a program of research be initiated to examine, using advanced simulation, ways in which the traffic management system can be better designed to enhance the perception by drivers of potential hazards, including other road users.

Driving along quiet sections of a highway with little traffic can be regarded as a form of vigilance task. While vigilance tasks have been interpreted in the past as being fairly simple and relatively undemanding, recent research suggests that, paradoxically, such situations might in fact induce high levels of cognitive workload. As such, workload might, on occasions, be high (as the driver fights fatigue or boredom) and performance may decrease. Countermeasures to the potential problem of too little stimulation might include increasing the amount of global optical flow impinging on the driver from the road environment or, in general, increasing the complexity of simple highway environments. Increasing optical flow might also have additional benefits in terms of speed reduction.

As noted previously, the size of the visual field has been shown to reduce and change shape when people are required to perform a demanding task in addition to a primary visual detection task. This suggests that high workload (and high crash rate) segments of the road system, such as intersections, should be designed in a manner which does not, through a decrease in the size and shape of the visual field, prevent drivers from being able to scan for, detect, and perceive critical information. For example, wide carriageways at high workload intersections may restrict drivers' field of view so that they are unable to see pedestrians intending to cross the road from the sides. To date, research on field of view restriction whilst driving has been relatively limited. Because of its potential contribution to improved road design, further research on this topic is recommended.

Various methods have been developed to measure the degree of mental workload imposed on the human operator when performing complex tasks. These include non-invasive physiological measures, subjective measures and measures of secondary task performance. In principle, these techniques can be used to measure driver mental workload at different locations in the road environment. Where mental workload is deemed to be unacceptably high, alternative engineering approaches could be implemented to reduce the processing load on drivers. It is recommended that the various techniques referred to be trailed and evaluated to determine if they have potential to practically assist traffic engineers in designing and auditing the road network to avoid high workload "blackspots".

1.8.6 Legislation

There were no findings from the literature reviewed which suggest any obvious recommendations for changes to existing road safety legislation.

1.8.7 Enforcement

Since December 2000, Victorian Police have had the ability to prosecute drivers who are found to be driving under the influence of drugs other than alcohol, both licit and illicit. This approach has involved a combination of behavioural observations at the road side, physical tests (Standardised Field Sobriety Test), and blood drug screens to reach a conclusion about a driver's drug use. Research is needed to evaluate the effectiveness of these strategies in deterring people from driving under the influence of both licit and illicit drugs.

1.8.8 Vehicle design

1.8.8.1 Workload and distraction

There is converging evidence that the design of the human-machine interface (HMI) for emerging communication, entertainment and advanced driver assistance systems in vehicles can have a profound effect on the amount of time a driver spends fixating on displayed information. As noted elsewhere (Young, Regan and Hammer, 2003), fundamental research is needed in Australia to support local vehicle manufacturers in designing car cockpit display and control systems, such that use of them by drivers of varying age and experience levels does not compromise their ability to perform safely the primary driving task. In particular, there is a pressing need for the development of research tools for measuring and quantifying the degree of workload and distraction associated with the use of emerging in-vehicle technologies. The research on mental workload reviewed here suggests several methods that can be used for this purpose.

1.8.8.2 Auditory displays

Most of the information processed in order to drive safely is visual. The auditory modality, however, is under utilized by vehicle designers as a channel for conveying information to drivers. Auditory spatial cues - that is sounds, like the shaking of car keys, that can be localized by a person as coming from a particular direction - have been found in the laboratory and in military settings to facilitate the localisation of targets and other objects in space. As the visual environment inside and outside the vehicle becomes more complex and visually demanding, auditory cues which convey critical safety information to the driver or cue the driver where to look inside or outside the vehicle can be expected to reduce this visual burden. The use of the auditory modality to cue drivers to fixate on critical regions of the driving scene is a promising area of research, particularly for drivers with known visual scanning deficits, such as young inexperienced and older drivers. Fundamental research on the use of the auditory modality to facilitate safe driving in a manner acceptable to the driver is a very promising area for research in road safety.

1.8.8.3 Automation

Car cockpits, like aircraft cockpits, are becoming increasingly automated. Whilst there is a vast research literature pertaining to the human factors issues arising from increased automation in the aircraft cockpit, comparatively little is known about the effects on driving behaviour of intelligent transport systems and other technologies that will eventually partially, or even fully, automate driving tasks previously performed by humans. It is important at this early stage in the evolution of ITS to conduct research on the effects of automation on driver behaviour of emerging ITS, particularly maturing systems with known high estimated safety potential.

1.8.8.4 Interface design

Techniques such as Cognitive Task Analysis and Work Domain Analysis, which are used to understand decision making in naturalistic settings, provide a powerful means of understanding the decision making processes that differentiate expert drivers from novice drivers. This knowledge can be used to optimise the ergonomic design of the human machine interface (HMI) for modern road vehicles such that they are compatible with the full range of driver capabilities and limitations. It is recommended that efficacy of these techniques as tools for optimising HMI design in the driving domain be investigated.

The research reviewed here suggests that elderly drivers find it more difficult to perform multiple tasks (such as using a mobile phone whilst driving) and that they scan the internal and external driving environments less efficiently than younger drivers. It is critical that these and other perceptual and cognitive performance deficits associated with aging are further researched and incorporated into the development of standards and guidelines that are used to design the HMI for vehicle cockpits.

1.8.9 Other countermeasures

Some countermeasures do not lend themselves to consideration under the categories considered above. These are presented below.

1.8.9.1 Human Error

Outside the domain of road safety, significant research effort has been devoted to understanding the psychological principles underlying human error given the prominent role that it plays in accident and incident causation. An important theme running through this literature is that there are many factors that interact to affect human performance in complex systems: external factors, individual factors and stressor factors (e.g., fatigue). In domains such as aviation and process control, this research effort has led to the development of tools and methods for classifying human errors, predicting error occurrence, structuring crash and incident investigations, conducting post-accident data analysis and, ultimately, designing error-tolerant systems. In road safety the role of human error in accident causation as a focus for research has been almost negligible, even though human error is recognised as a major factor contributing to road crashes. The Vision Zero approach to traffic safety management in Sweden is the only risk management approach known to the authors which is based on the premise that the traffic management system should be error-tolerant. It is recommended that a large-scale program of research be undertaken to determine how existing knowledge of human and "organisational" error (the latter relates to breakdowns in safety climate, supervisory practices, communication, etc.) can be used to improve our understanding of the human factors involved in crashes and to support the development of countermeasures that address these factors.

1.8.9.2 Modelling human performance

Many theories and models have been developed by psychologists in an attempt to describe the psychological processes underlying human performance. In this review the so-called EPIC model, which attempts to model human behaviour in multiple-task settings, was cited as an exemplar of recent attempts to model human performance. Surprisingly, there has been little attempt by the road safety community to model the behaviour of road users in the traffic management system. This is unfortunate as, once validated, such models provide powerful tools for designing, auditing and evaluating the traffic management system and for predicting human behaviour within these systems. It is recommended that fundamental research be undertaken to develop models of road user behaviour which can be used a priori to predict where, when, and why crashes are most likely to occur on the existing road network, and to support the design and evaluation of future traffic management initiatives.

1.8.9.3 Fatigue Management

A recent theme emerging from fatigue research is the notion of "coping with fatigue". In many situations - such as military operations or, to a lesser extent, some long-haul truck or other transport operations - some degree of fatigue is unavoidable and, therefore, strategies need to be established to help maintain alertness. Although Hours of Service legislation, fatigue management programs, fatigue detection technologies, publicity campaigns and other enforcement measures by the traffic authorities can help target fatigue, there is still a need to examine fatigue coping strategies (taking into account the different ages and skill levels of road users). It is recommended that further research be undertaken in this area.

Whilst not advocating the use of stimulants in the driving task (with the possible exception, as noted above, of caffeine), there is good evidence that stimulants are widely used by many road transport sectors (e.g., in long distance truck driving). As the active effects of such stimulants can last for longer than driving shifts, they might have an impact upon drivers' off-duty recovery periods (including sleep disruptions). If sleep disruption is severe, this could have possible fitness-for-duty effects on subsequent driving shifts (perhaps with cumulative effects over several driving shifts). Further research on this issue could be beneficial to help develop appropriate countermeasures.

Fatigue management programs emphasise the importance of responsibility of drivers to be fit for work (including being appropriately rested beforehand). However, as noted in this review, overseas research suggests that differences in fitness for duty between drivers exist (especially between long and short haul drivers and between younger and older driver groups). Fundamental research is needed in Australia to establish how truck drivers prepare for work.

A number of in-vehicle technologies entering the market claim to be able to detect the presence of fatigue. However, the review identified a paucity of research evaluating these devices. It is recommended that a list of known available devices be compiled and that an independent evaluation of these devices be performed to assess performance of them against a range of criteria, including predicted safety benefit, validity and reliability. It is also important to gauge the acceptability of these devices to both ordinary motorists and commercial vehicle drivers.

Even if such in-vehicle technologies are capable of detecting the presence of fatigue, a critical, unresolved, issue for human factors research is how this diagnosis should be conveyed to the driver and/or the vehicle. What the driver should do in response to receiving a fatigue alert is also another issue that remains to be resolved. For example, are such devices to be used as management devices to penalise drivers susceptible to fatigue, or to schedule journeys so that fatigue remains within acceptable limits? Clearly, further research is needed in these areas.

Recent research on the effects of sleep restriction on driving performance has shown that physiological measures such as saccadic velocity, sleep latency and so-called "microsleeps" are not indicative of performance decrements brought on by various levels of sleep restriction. In one study, the majority of crashes in a simulator were not immediately preceded by microsleeps, suggesting that the crashes were not caused by drivers falling asleep at the wheel. This research suggests that the conceptualisation of the role of fatigue in crashes should be extended from falling asleep at the wheel to a better understanding of the performance deficits, such as inattention and distractibility, associated with sleep loss. An implication of this is that existing fatigue detection technologies based on detection of sleep onset can prevent only a sub-set of fatigue-related crashes; other technologies and approaches will need to be developed to complement these technologies in addressing known performance deficits associated with fatigue.

Research by the United States Air Force has resulted in the development of the Sleepiness-Induced Lapsing and Cognitive Slowing Model (SILCS) which is capable of predicting the effects of varying levels of sleep loss on performance for different tasks in different situations at different times of day. It is recommended that further research be undertaken to determine the applicability of this model in predicting the effects of sleep loss on driving performance in the road transport domain.

1.9 CONCLUSION

In this final chapter of the report, implications for countermeasure development of the literature reviewed were discussed.

An important outcome of this review was confirmation that there exist developments in behavioural research, not widely known in the road safety domain, which have the potential to lead to the development of new countermeasures. In addition, some of the information gleaned can be used to refine existing countermeasures.

There has been no attempt in this report to prioritise the various recommendations concerning possible research or countermeasures deriving from the material reviewed, as it is difficult to estimate in the behavioural domain the likely impact of associated countermeasures. However, the following are some of the more important conclusions that can be drawn from this study.

At a time when many in the road safety community are sceptical about training as a road safety countermeasure, this review identified some important research and developments in training techniques and methodologies that have potential to enhance the effectiveness of the driver training regime in Victoria. In particular, converging findings suggest that virtual reality, of various levels of fidelity, can be used to effectively train safety-critical skills, including driving skills.

The review suggested that there is great potential to enhance the effectiveness of the VicRoads-developed HPT as a device for screening for the presence of the full range of perceptual and cognitive skills required to drive safely. In addition, there is scope for making an enhanced HPT a more discriminating test than it currently is.

There are significant opportunities for the use of advanced simulation to support improved design and evaluation of vehicle cockpit interfaces and of traffic management systems. Currently, advanced simulation is used very little for these purposes in Victoria or elsewhere in Australia.

The review identified various tools and techniques that are being developed to support and optimise the design of the vehicle HMI, in ways that reduce driver reduce workload and distraction. A particularly promising area is the use of the auditory modality to present safety-critical information and to facilitate the visual search process.

The road safety domain is lacking in predictive models of human behaviour and error causation. Understanding human error provides an important basis for the development of new and innovative countermeasures.

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