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INTELLIGENT TRANSPORT SYSTEMS AND MOTORCYCLE SAFETY

by

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Abstract:
The current study aimed to identify existing and emerging Intelligent Transport Systems (ITS) that have the potential to enhance motorcycle rider safety. A review of the literature revealed that very few commercially available ITS currently exist specifically for motorcycles, although several emerging technologies were identified. Consultations with international experts in ITS, motorcycle safety, motorcycle manufacturers and various road safety research organisations confirmed this. However, there are emerging and existing technologies for other vehicles that have the potential to address key motorcycle safety issues. Each of these technologies was described, and those deemed most directly relevant to these key safety issues were ranked in a prioritised list. Systems which addressed the stability and braking properties of the motorcycle were given the highest priority on this list, as these systems have potential to enhance motorcycle safety in almost all crash situations. However, this list was based on safety relevance only. In the absence of more definite data regarding the causal factors of motorcycle crashes and the actual effectiveness of each of these systems, this list should be regarded as tentative. Recommendations are made for further research and for stimulating the early development of ITS which have the potential to enhance safety and are acceptable to riders.

Key Words:
Intelligent transport systems (ITS),
motorcycle, motorcycle safety, crash types

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Preface

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LIST OF ACRONYMS

ABS	Australian Bureau of Statistics
ACC	Adaptive Cruise Control
ACEM	Association des Constructeurs Européens de Motorcycle ("Motorcycle Industry in Europe")
ACN	Automatic Crash Notification
ADAS	Advanced Driver Assistance Systems
ANCAP	Australian New Car Assessment Program
APROSYS	Advanced Protection Systems
ASV	Advanced Safety Vehicle
BAC	Blood Alcohol Concentration
BMF	British Motorcyclist Federation
BTE	Bureau of Transport Economics
CAPS	Combined Active and Passive Systems
CBS	Combined Braking Systems
CPU	Central Processing Unit
DCA	Definitions for Classifying Accidents
DRL	Daytime Running Lights
ESP	Electronic Stability Program
FARS	Fatal Accident Reporting Scheme
FEMA	Federation of European Motorcyclists Association
GPS	Global Positioning System
HMD	Helmet Mounted Display
HMI	Human-Machine Interface
HUD	Heads-Up Display
INRETS	Institut National de Recherche sur les Transports et Leur Sécurité ("French National Institute for Transport")
ISA	Intelligent Speed Adaptation

ITS	Intelligent Transport Systems
MSF	Motorcycle Safety Foundation
MUARC	Monash University Accident Research Centre
NRMA	National Roads and Motorists' Association
OEM	Original Equipment Manufacturers
TAC	Transport Accident Commission
VACC	Victorian Automobile Chamber of Commerce
VMS	Variable Message Sign

EXECUTIVE SUMMARY

The current report was undertaken to inform VicRoads of Intelligent Transport Systems (ITS) that could reduce the incidence and/or severity of motorcycle casualty crashes. In order to do so, a number of activities were undertaken.

A comprehensive review of motorcycling safety issues was conducted. This encompassed crash statistics and research from both Australia and other developed nations, and considered the different crash patterns of serious injury and fatal crashes. Overall, it was found that running off-road crashes on both straight and curved sections of road were the most commonly occurring types of single-vehicle crashes; crashes involving vehicles travelling in opposing directions or intersection crashes were the most commonly occurring type of multiple vehicle crashes. Alcohol, speed and motorcycle conspicuity were consistently cited as either causal or contributing factors in motorcycle crashes.

Following this, a review of all known literature regarding ITS in motorcycles was undertaken. This review included any literature that reported the development or testing of an ITS technology in motorcycles, as well as any discussion of potential future applications and implementation issues of ITS in motorcycles. Very little literature was available for this review, highlighting the relatively small effort that appears to have gone into the research and development of ITS to enhance motorcycle safety.

Expert consultations were then conducted with ITS and motorcycling experts. Academics, manufacturers and industry leaders from both national and international organisations, were contacted via telephone and email, and in person. The purpose of these communications was to discuss and identify emerging ITS technologies for motorcycles that may not yet have been published. While few additional technologies were identified, this process proved invaluable in that the information provided by several of these contacts has not been, and most likely will not, be published. For example, several contacts within Europe have been involved in small trials of Intelligent Speed Adaptation (ISA) in motorcycles that had either been abandoned or undocumented. The expert consultations also highlighted that compared to the extensive research involving ITS for cars and commercial vehicles, research and development specific to ITS in motorcycles is relatively scarce.

The information gathered from the review of motorcycle safety, the review of ITS literature, and the additional information yielded from the expert consultations were then combined. All ITS technologies that had been identified as having the potential to enhance motorcycle safety were briefly described in terms of their functional and technical aspects, and their relevance to motorcycle safety.

The final step of this review was to create a list of all technologies identified, prioritised according to the potential for each to address critical crash problems. This chapter also included a discussion of other criteria that should be considered in the evaluation of the viability of ITS technologies in motorcycles.

On the basis of the material reviewed, there are 15 ITS that, in the opinion of the authors, have the greatest potential to address critical motorcycle crash problems. There are, in addition, other conclusions that can be drawn from this study.

- Very few ITS have been developed specifically for motorcycles, and all of those that do exist are in-vehicle systems.
- Some motorcycling groups have expressed concern about the potential for ITS technologies to automate aspects of the riding task or to compromise motorcycle rider safety. It is critical that the views of the motorcycling fraternity be properly researched and understood, and that this knowledge be used to inform the design and deployment of technologies which are acceptable to them. There have been no formal studies of the acceptance to riders of ITS in motorcycles.
- Of those systems that have been developed, very little evaluative data exists. Hence, the effectiveness of these systems in improving safety and user performance is as yet largely unknown.
- Many ITS exist or are emerging for other classes of vehicle that have potential to enhance motorcycle safety directly or indirectly.
- Whilst the types of fatal and injury crashes that motorcycles have are known, the causal factors which underlie these crashes are less well known, especially the role of human error.
- There is no known national strategy for the design, development, deployment and evaluation of ITS in motorcycles. Indeed, it is pertinent to note that Victoria's Vehicle Safety Strategy and Action Plan 2004-2007 makes no reference to motorcycles.
- Motorcycles pose particular problems when it comes to the technical adaptation of certain ITS systems, particularly those that have not been custom-designed for motorcycles.
- The bulk of research and development of ITS systems for motorcycles has been undertaken in Japan, largely as part of the national ASV program in that country.

The present work should be regarded as preliminary given the paucity of information currently available about the estimated and actual safety benefits of ITS technologies for motorcycles.

Research needs

The following are regarded as immediate research needs deriving from this project.

- The views of the motorcycling fraternity must be properly researched and understood in order to inform the design and deployment of technologies which enhance safety and are acceptable to them.
- No attempt has been made to estimate the relative harm reductions associated with deployment of ITS in motorcycles. This is an important research priority.
- In-depth identification and prioritisation of motorcycle safety problems that are amenable to ITS intervention, which would serve to stimulate industry to develop ITS that address those problems is desirable (in addition to, as at present, identifying existing and emerging technologies and searching for crash problems that they might solve). To do so requires a far better understanding of the causal factors that underlie motorcycle crashes and incidents, including human error.
- Establish the effectiveness of ITS technologies through the collection and evaluation of crash data, field operational testing and analytical modelling of estimated risk.
- Fundamental research on the effects on rider performance and behaviour of human-machine interaction with new technologies that deals with issues such as distraction,

cognitive workload, over-reliance on technology, training requirements, situational awareness, and so on.
- Further research, development, and evaluation, of emerging systems which appear to have great potential to enhance safety, such as ISA, inter-vehicle communication etc.
- Research to determine the cost-benefits of deploying ITS relative to other countermeasures in addressing intractable rider safety problems. For example, research could be undertaken to determine whether rear-view displays are more effective than the optimal use of side mirrors.

General issues

Conspicuous by its absence in the literature is any reference to the roles that key stakeholders, including governments, can play in facilitating the early deployment of ITS technologies for motorcycles which are capable of enhancing safety. The following are general recommendations that, if implemented, will optimise the potential for ITS to enhance motorcycle rider safety.

- There should be an Australian New Car Assessment Program (ANCAP) -equivalent system to encourage manufacturers to equip motorcycles with safety critical ITS.
- Like ITS technologies for other vehicles, there is a need to stimulate rider demand for systems that provide the greatest safety benefits.
- There is a need for the development of standards for the design of ITS technologies for motorcycles, as there is for the design of ITS technologies for other vehicles.
- Targeted research on specific safety technologies, particularly those with high estimated benefit-cost ratios requires funding and support.
- The effectiveness of ITS technologies, through the collection and evaluation of crash data, field operational testing and analytical modelling of estimated risk needs to be established.
- Demonstrate to riders that systems with high safety potential work and that there are no unintended or adverse consequences associated with their use.
- Leverage previous research and development, here and overseas, in facilitating the deployment of candidate systems.
- Facilitate the development and dissemination of system architectures and standards for the design, deployment and evaluation of future technologies.
- Provide infrastructure support for emerging cooperative and infrastructure-based systems.
- Introduce and support fiscal incentives to stimulate system demand, such as tax incentives, reductions in insurance premiums, reduced road user charges and access to parts of the road network at reduced cost.
- Provide an effective legal and regulatory framework to support system deployment and remove regulatory barriers
- Initiate and support cross-industry activities, such as the European "e-Safety" forum and its working groups, to harmonise system development and deployment.
- Ensure that new systems entering the market, both OEM (Original Equipment Manufacturers) and aftermarket products, do not distract or otherwise compromise rider safety in unintended ways.
- Promote an industry-wide approach to the development of standard tests and methods for evaluating new ITS safety technologies.

CHAPTER 1 – LITERATURE REVIEW

1 INTRODUCTION

1.1 PROJECT BACKGROUND AND OBJECTIVES

VicRoads has commissioned MUARC to identify and assess the potential benefits of emerging transportation technologies that may enhance motorcycling safety. In recognising the recent emergence of numerous Intelligent Transport System (ITS) technologies for other vehicles, VicRoads has also noted the lack of ITS developments that are specifically designed for motorcycles. Therefore, MUARC has been asked inform to VicRoads of all ITS technologies that have the potential to either reduce the occurrence, or minimise the severity, of motorcycle crashes.

The need for enhanced motorcycle safety in Victoria is evident in the over-representation of motorcyclists in the national and state-wide road tolls. VicRoads has noted the high proportion of motorcycle crashes that occur at intersections, and the high proportion of crashes that involve other vehicles. In light of these crash patterns, any countermeasure that addresses road safety issues, either applied to the motorcycle or other road users, is of particular interest to this review.

The study aimed to investigate the role of ITS technologies in enhancing motorcycle rider safety in two ways. Firstly, an extensive review of the literature was undertaken. This review encompassed all existing and emerging ITS technologies that have either been developed specifically for motorcycles, as well as those that have been developed for other vehicles but have been noted for their potential to be adapted for motorcycle use. Furthermore, any discussion in the literature of issues specific to ITS in motorcycles was reviewed.

Secondly, consultations with international experts in the fields of ITS and motorcycle safety were conducted. Such experts included ITS suppliers, motorcycle manufacturers, academics and industry group leaders both nationally and internationally. These consultations were conducted either in person, via telephone conference and/or electronic correspondence. The information gathered from these sources was then combined with what was already known from the literature review to provide an extensive list of current ITS developments relevant to motorcycling safety.

The final goal of the report was to create a prioritised list of ITS. This list was driven by the key safety issues of motorcycling, where those ITS that address the most pertinent safety issues were given highest priority. The report concludes with recommendations for further research and for the stimulation of the development of ITS which have both the potential to enhance safety and are acceptable to riders.

1.2 STRUCTURE OF THE REPORT

The current report consists of five chapters. Chapter 1 provides an overview of the key safety issues relevant to motorcycling and the prevalence of various types of motorcycle crashes. It identifies the safety issues specific to motorcycle casualties in order to enable a better understanding of which ITS technologies will be most beneficial to motorcyclists. Chapter 1 also provides a review of the literature concerning what is currently known about safety-enhancing ITS in motorcycles.

Chapter 2 describes and reports the processes of and information gathered from the informant interviews and communications with various industry experts. Chapter 3 combines all the available information from the literature and experts, and describes all emerging and currently available ITS technologies that have an immediate or potential benefit to motorcycling safety. All reviewed technologies are further described in terms of their relevance to the key safety issues as identified in Chapter 1, and includes information about their function, purpose and potential safety benefits. Where available, diagrams and pictures of the relevant systems are also included.

Chapter 4 then provides a prioritised list of those technologies (both emerging and existing) that are most relevant to the safety issues discussed in Chapter 1, and therefore present the greatest potential safety benefits to motorcyclists. Criteria that should be considered when evaluating ITS technologies are also discussed here. Chapter 5 contains conclusions and recommendations of future actions to stimulate research and growth in ITS for motorcycles.

2 REVIEW OF MOTORCYCLE CRASHES AND SAFETY ISSUES

According to the Australian Bureau of Statistics (1996), motorcyclists are far more likely to be involved in crashes that result in either fatality or hospitalisation than car drivers. While 279 per 100,000 cars were involved in crashes in 1993, 986 per 100,000 motorcycles were involved in crashes for the same period. The over-representation of motorcyclists in the road toll is a trend that is continuing in Australia, with 14% of the 2005 national road toll being made up of motorcyclists (TAC, 2006), even though motorcycles made up only 3% of the registered vehicles in Australia in 2005. Road crashes cost Australian society billions of dollars each year. The Australian Bureau of Transport Economics (BTE, 2000) estimated the average cost of a fatal vehicle crash to be $1.5 million dollars, a serious crash to be $325000 and minor injury $12000, and property damage crashes at $6000 on average. It was also estimated that 18,222 motorcycles were involved in road crashes in 1996 Australia-wide, of which 207 were fatal and 2431 were serious injury. The disproportionately high number of motorcycle crashes and the associated costs of motor vehicle crashes warrant the development of motorcycle safety enhancing systems.

In order to understand which technologies will be most beneficial to motorcycling safety, it is important to identify the types of crashes that present the greatest risk to motorcyclists, the factors commonly associated with these crashes, and their causal factors. The TAC (2006) has grouped motorcycling crashes into seven main types, with their relative contribution to the 2004 Victorian motorcycle road toll. Table 1 summarises these crash types in order of greatest proportion of fatalities.

Table 1 Analysis of Motorcycle Crashes in 2004.

Crash Type	Description	Fatalities	Serious Injuries	Minor Injuries
Single vehicle	Involve one vehicle only. This category includes collisions with stationary objects, running off the road, and being thrown from the motorcycle	43%	56%	53%
Multiple vehicle	*Head on:* Two vehicles colliding from opposite directions	27%	4%	2%
	Vehicles from opposing directions: Differ from head-on crashes, in that one or both vehicles are turning at an intersection	14%	8%	7%
	Vehicles from same direction: Lane changing, side-swiping and rear-end crashes	8%	13%	17%
	Vehicles from adjacent directions: Collisions between vehicles at intersections when one or more are turning, and cross-traffic collisions at an angle	5%	10%	10%
	Manoeuvring/ overtaking: Includes collisions from u-turns, parking, emerging from driveways, and collisions resulting from overtaking other vehicle	3%	8%	10%
Miscellaneous	Collisions involving trams, trains, pedestrians or object or person falling from the vehicle	1%	1%	1%

It can be seen from Table 1 that according to TAC data from 2004, single vehicle crashes were the most common crash types involving of fatality or injury to motorcyclists. Crashes involving vehicles travelling in opposing directions and intersection crashes were the most commonly occurring type of multiple vehicle crashes involving motorcycles. Head-on crashes were more likely to result in fatality than injury, while multiple vehicle crashes involving vehicles from adjacent or same directions, or manoeuvring, tended to be associated with injury more than fatality.

Further examination of the characteristics of motorcycle crashes in Victoria during the period of January 2000 December 2004 revealed a similar pattern (Crash Stats, 2006). A total of 9,383 motorcycle crashes was reported for this period. Of these, 4046 were serious injury crashes and 239 were fatal. These were grouped within the Definitions for Classifying Accidents (DCAs), as devised by VicRoads, allowing analysis of the types of crashes that are most likely to be fatal or result in serious injury. The data for this five-year period are as follows, with DCA codes in brackets:

- Pedestrian crashes (100-109): 1.3% of all motorcycling crashes, 0.4% of fatal, 1.0% of serious injury. The most commonly occurring crashes involving pedestrians were those emerging from behind parked cars (101), and being struck from the near (100) and far (102) sides.
- Vehicles from adjacent directions, at intersections only (110-119): 9.6% of all crashes, 8.3% of fatal, 9.2% of serious injury. The majority of these involved cross-traffic (110) or right-near (113) crashes, where one vehicle turns into the path of the other.
- Vehicles from opposing directions (120-129): 11.8% of crashes, 32.2% of fatal, 13.0% of serious injury. These were most commonly head-on crashes that did not involve overtaking (120) and right through crashes (121), where one vehicle turns across the path of the other.
- Vehicles from same direction (130-139): these accounted for 13.6% of crashes, 6.2% of fatal, 11.4% of serious injury, with rear-end collisions (130) being the most frequently reported type.
- Manoeuvring crashes (140-149): 7.5% of all crashes, 4.8% of fatal, 6.6% of serious injury. Crashes from u-turns (140) and striking another vehicle when emerging from a driveway (147) were the most common types.
- Overtaking crashes (150-159): 2.6% of crashes, 5.4% of fatal, 3.0% of serious injury. The most common type was crashes from pulling out when overtaking (152).
- On-path crashes (160-169): 8.2% of all crashes, 3.0% of fatal, 8.5% of serious injury. The most commonly occurring were striking an object (166) or animal (167) on the carriageway.
- Off-path, on straight crashes (170-179): 27.2% of all motorcycle crashes, 16.7% of fatal, 25.8% of serious injury. The most frequently occurring crash type, accounting for 16.7% of all motorcycle crashes, was out of control on straight carriageway crashes (174). Other common types were off carriageway to left (170) and off carriageway to left into object (171).
- Off-path, on curve (180-189): 17.3% of crashes, 22.6% of fatal, 19.9% of serious injury. Frequently occurring crash types were off carriageway on right bend (180), off right bend into object (181), off carriageway on left bend (182), off left bend into object (183) and out of control on carriageway bend (184).
- Other, i.e. passenger and miscellaneous (190-199): 1.1% of crashes, 0.4% of fatal, 0.9% of serious injury. More than half of these involved person falling from the vehicle (190).

From the above analysis, it can be seen that the most frequently occurring motorcycle crashes involve veering off-path on either straight of curved sections of the road. These crashes may, but do not necessarily, involve striking other objects or vehicles, or the motorcyclist loosing control of the vehicle. Similar proportions of serious injury and fatal crashes were observed for most crash types, with several notable exceptions which are consistent with those reported by the TAC (2006). Head-on crashes (120-129) accounted for 13% of serious injury crashes, compared with almost one third of fatal injury crashes. Conversely, a larger proportion of same direction crashes (130-139) resulted in serious injury (11.4%) than fatalities (6.2%). Similar patterns exist for on-path crashes (160-169), and off-path, on straight crashes (170-179).

Larger proportions of fatal crashes than serious injury involved collisions with other vehicles (58.2% compared with 45% for serious injury), or collisions with fixed objects (29.3% and 13.6% respectively). One quarter of serious injury crashes did not involve striking an object or vehicle (i.e., loss of control crashes), compared with only 5.9% of fatal crashes.

Analysis of motorcycle crash characteristics (all crash types, between 2000-2004) revealed that over 40% of all crashes occurred at intersections of any type, while 59.3% of crashes were not located at intersections. Also, 76.9% of crashes occurred at sections of road where no traffic control measures (e.g., stop signs, traffic lights) were in place. Crashes most frequently occurred in 50 km/hr and 60 km/hr zones (11.1% and 41.8%, respectively), and 100 km/hr zones (27.2%). Note that the above data does not account for the relative exposure of motorcyclists to each of these types of speed zones.

A pattern of crash frequency was observed over various times of day, week and year. An average of 6.6% of annual crashes occurred in the months of winter, compared with an average of 8.9% of annual crashes during all other months. While it might seem counter-intuitive that fewer crashes occur during typically wet conditions, it is likely that fewer people choose to ride during the winter months. Additionally, a far greater proportion of crashes occurred on weekends as opposed to weekdays, suggesting that more people may tend to ride recreationally on these days. In fact, 40.6% of motorcycle crashes occurred on weekends. As for time of day, the majority of crashes occur during the day (75.1%), with 58.5% of crashes occurring during the period between 9:00am and 5:00pm. Again, these figures do not account for exposure.

Road and environmental conditions were also analysed. Over 80% of motorcycle crashes occurred in dry weather, and in terms of atmospheric conditions, 88.5% of crashes occurred when visibility was 'clear'. Wind and fog were only cited as contributing factors in 0.7% and 0.5% of crashes, respectively. Crashes most frequently occurred on paved road surfaces (85.3%), and 34.9% of crashes occurred in rural locations, while 49% occurred in urban Melbourne (excluding the Central Administrative District).

In the period between January 2000 and December 2004, 95.7% of fatal motorcycle crashes, and 94.1% of serious injury crashes involved male motorcycle riders. During the same period, six pillion passengers were killed, and 213 seriously injured in motorcycle crashes. The most common age group to be involved in a crash that resulted in injury or fatality to the rider, regardless of gender, were 30-39 year olds. However, according to the TAC (2006), the group most commonly involved in fatal crashes were 21 to 29 year olds, who represented 42% of the motorcycle road toll in 2005. There was also a more than two-fold increase number of fatalities for motorcyclists over the age of forty between 1991 and 2001 (VACC, 2003). During the same period, the number of fatalities for those 26 years and under decreased by a third. The Victorian Automobile Chamber of Commerce regards this as a consequence of older riders returning to motorcycling after long absences.

Alcohol was a factor in 25% of fatal motorcycle crashes in 2005, with the majority of these involving Blood Alcohol Concentration (BAC) of over 0.05. Also, 44% of fatal crashes in 2005 occurred in 'high alcohol times', or times when alcohol is highly likely to be a factor in crashes. Unlicensed riding is also significant problem, with up to 35% of Victorian motorcycle fatalities in 2001 being unlicensed riders (TAC 2006).

Given that a considerable proportion of the developments in vehicle technology come from overseas, it is worthwhile assessing whether the pattern of motorcycle crashes in Australia differs from what has been observed internationally. This will influence the relevance of ITS advancements from other nations to Australian motorcycling. A comprehensive analysis of motorcycle crash causal factors was conducted in 1981 in the U.S. by Hurt, Ouellet and Thom. This study compiled an extensive list of observations and patterns from over 3600 motorcycle crashes, and its key findings are summarised here:

- Approximately 75% of motorcycle crashes involve colliding with another vehicle, usually a car. The remaining 25% involved colliding with the roadway or a fixed object.
- Motorcyclist error was a factor in two-thirds of single-vehicle crashes, typically a result of over-braking or speed or curve misjudgement.
- Defects in the road surface were causal factors for only 2% of crashes.
- Weather was a factor in only 2% of crashes.
- Failure on the part of the other driver to give way or recognise the motorcyclist was the leading cause of multiple vehicle crashes.
- Intersections were the most frequent site of crashes.
- Obstruction of the view of either the motorcyclist or other road user was cited as a factor in nearly 50% of crashes.
- Countermeasures to increase motorcyclist conspicuity significantly reduced crash involvement, particularly on the front of the bike and rider.
- People aged between 16 to 24 and females are over-represented in crash statistics.
- Vehicle failure was rarely a contributing factor to crashes, and was usually a result of poor maintenance.
- Fuel system leakage occurred in 62% of crashes, presenting a serious fire hazard.
- 92% of motorcyclists involved in crashes had no formal rider training, and more than half had less than 5 months experience on their vehicle.
- Alcohol was involved in nearly 50% of motorcycle fatalities.
- Inattention on the part of the motorcyclist was a common factor, as was an absence of collision avoidance skills such as counter-steering.
- Typical motorcycle crashes allow only two seconds in which to take collision avoidance actions.
- Carrying a pillion passenger does not increase crash risk.
- Unlicensed or de-licensed motorcyclists were involved in a large proportion of crashes.

- Injury severity increase with speed, alcohol consumption and motorcycle size.
- Use of helmets drastically reduced head injury severity, and caused no attenuation of sound perception or reduced peripheral vision.

The Maids report (Association des Constructeurs Européens de Motocycle; ACEM, 2004a) conducted a similar analysis of 921 motorcycle crashes in Europe between 1999 and 2000. The key findings of this study are presented below:

- 50% of crashes involved other-vehicle driver error as a primary contributing factor.
- 37% of crashes involved rider error as a primary contributing factor.
- One-third of crashes involved visual obstruction of the motorcycle or other vehicle.
- 90% of crash risks were located in front of the motorcycle.
- 60% of crashes involved collisions with a passenger car.
- Alcohol use as a factor in 5% of all crashes.
- Riders aged 18-25 were over-represented in the crash statistics, while riders aged 41-55 were under-represented.
- Traffic law violations on the part of the motorcyclist were involved in 8% of crashes, and violations on the part of other driver were involved in 18% of crashes.
- Vehicle malfunctions were associated with less than 1% of crashes.
- The motorcycle travelling at a different speed (either higher or lower) than the rest of the traffic was a factor in 18% of all crashes.
- Evasive action was taken in over 70% of crashes, and one third of these resulted in losing control of the vehicle.
- Weather-related factors were cited as a causal or contributing factor in 7.4% of crashes.
- Road defects were cited as a cause or contributing factor in 3.8% of crashes.

From this data, the ACEM (2004a) has identified the following factors as crucial to motorcycling safety: education and training, conspicuity, tampering with the vehicles performance capabilities, speed and braking. They have called for countermeasures for all these safety issues, as well as the development of passive safety countermeasures that protect the rider in the event of a crash.

Preusser, Williams and Ulmer (1995) analysed the characteristics of 2074 fatal motorcycle crashes in the United States, examining data from the Fatal Accident Reporting System (FARS). They identified 10 main types of fatal crashes, and the factors most commonly associated with them. It was found that running off-road crashes accounted for 41.3% of fatalities, followed by crashes involving failure to obey traffic laws (18.1%) and head-on crashes (10.8%). Other categories included turning across traffic, rear-ending other vehicles, and striking objects on the road way.

Several characteristics of motorcycle fatalities were also noted by Preusser, et al. (1995). The average age of fatality was 29 years, and 98% were male. Fewer fatal crashes occurred in winter months, while year-round, weekends were associated with a higher number of crashes. Alcohol was a factor in 53% of motorcycle crashes (although only approximately 80% were tested), and run off-road crashes were mostly commonly associated with intoxication (alcohol was detected in 72% of these crashes).

Haworth, et al. (1997) analysed 222 motorcycle crashes in Victoria and identified six key safety issues in motorcycling. These were: inexperience; road environment factors; alcohol and drugs; unfamiliarity with the vehicle; poor vehicle maintenance; and inappropriate speed. In fact, 23% of crashes in this study were judged to involve speeds in excess of what was appropriate for the conditions. Vehicle condition was also an important factor, with nearly 40% of motorcycles involved in crashes to be in 'poor' to 'fair' condition.

Motorcycles have unique vehicle properties that must be taken into consideration when assessing safety issues. Doğan, et al. (2004) noted that the size of motorcycles render them likely to be obscured by other vehicles and objects, and hard to detect in glary conditions. Motorcycle stopping distances are also different, where slippery conditions make emergency braking both difficult and dangerous. Other issues they identified included the additional difficulties in balancing created by carrying pillion passengers, and that motorcycle indicators are not self-cancelling, which may result in false signalling.

As already identified, violations of the motorcycle's right of way is often the cause of crashes, and this is often attributed to a failure on the part of the other driver to notice the motorcycle. Detection of a motorcycle, according to Baird and Hardy (2006), can be affected by numerous characteristics. These include the shape, luminance from the environment and headlights, shadows, sound, movement and colour of the motorcycle as well as failures in perception from the other road users, and poor judgement on the part of the other road user.

The above review provides a detailed account of the conditions and circumstances that are frequently associated with motorcycle crashes, and the situations that present the greatest risk to motorcyclists. The key issues regarding motorcycle safety, as derived from both Australian and international crash data and studies, are listed below:

- Motorcycling is associated with greater danger in terms of crash frequency and fatality than car driving.
- Running off-road crashes on either straight or curved sections of road are the most frequently reported type of motorcycle crash in Victoria.
- Crashes involving at least one other vehicle make up the majority of reported motorcycle crashes.
- Collisions with other objects are involved in around 20% of motorcycle crashes, although relatively few crashes are actually caused by other objects.
- Head-on crashes are far more likely to result in fatality than injury.
- Intersections are high-risk areas for motorcyclists.
- Motorcycle crashes are three times more likely to occur in areas where there are no traffic control measures.
- Excessive speeds are a common factor in motorcycle crashes.
- Motorcycle crashes are most likely to occur in 60 km/hr or 100 km/hr zones.
- Crashes tend to occur more on weekends than weekdays, and during the day as opposed to dawn, dusk or night time.

- Wet weather, poor visibility and unpaved road surfaces are not causal factors in the majority of crashes.
- Crashes tend to occur mostly in rural or urban areas.
- The vast majority of motorcyclists killed or seriously injured are male.
- The age group associated with the most fatalities are 20-29 year olds.
- Older riders appear to be returning to motorcycling after absences, which may result in an increase in fatalities among those over 40.
- Alcohol is a common factor in motorcycle crashes, particularly run-off road crashes.
- Unlicensed riders make up a significant proportion of the motorcycle road toll.
- The braking, stability and visibility properties of motorcycles make them more risky than other vehicles.
- Failure of other road users to see motorcyclists is a common cause of crashes.
- Motorcyclist error is a common factor in single-vehicle crashes.
- Error on the part of the other driver is a common factor in multiple vehicle crashes.
- Few motorcyclists involved in crashes have undertaken rider training.
- Obstruction of the line of sight of the motorcyclists and/or the view of the motorcyclist to the other driver is a contributing factor to many crashes.
- Carrying pillion passengers does not increase the risk of a crash.
- Vehicle failure is rarely associated with crash causation, and when this is a factor, it is usually a result of poor maintenance.

2.1 SUMMARY

A number of safety issues consistently emerged as relevant to both fatal and serious injury crashes. Single vehicle crashes were frequently cited as leading types of motorcycle crashes, followed by multiple-vehicle crashes. A number of other variables were also commonly cited as causal or contributing factors, namely speed, alcohol and motorcycle conspicuity. Failure of a car driver to see the motorcyclist was often named as a factor of multiple-vehicle crashes, while characteristics such as weather, road surface conditions and vehicle failure were not typically considered significant factors in these types of crashes. These findings are consistent with what has been observed across other large American and European motorcycle crash studies.

3 INTRODUCTION TO INTELLIGENT TRANSPORT SYSTEMS

ITS is an umbrella term for a collection of electronic, processing, communication and control technologies that can be combined and applied to the transport system (Regan et al., 2001). ITS can be used to improve traffic flow and management, provide information to transport users, track and manage commercial transport operations, enforce traffic laws, and improve road safety. These technologies can be applied to private and commercial vehicles, public transport, and infrastructure.

Whilst most ITS technologies have not been deployed for long enough to know how effective they are in enhancing safety, the safety benefits deriving from them are expected to be large (Rumar et al., 1999; Regan, et al., 2006). This has prompted many international jurisdictions around the world to support the early deployment of those technologies deemed to have the greatest safety potential.

Of those systems that have been developed to enhance road safety, three broad sub-categories can be discerned: vehicle-based systems; infrastructure-based systems; and cooperative systems (Regan, 2004).

Vehicle-based ITS technologies typically consist of sensors on the vehicle (e.g., optical systems, global positioning) that collect traffic data, on-board units (OBUs) that receive and process these data and display units that provide messages and warnings to the driver within the vehicle. Following distance warning systems, for example, utilize forward-looking radar to determine if the host vehicle is following a vehicle ahead too closely and warn the driver if this is so. These systems can be linked to vehicle controls - for example, to automatically apply the brakes if the driver fails to respond to the warnings.

Infrastructure-based ITS technologies consist of roadside sensors that collect traffic data that are processed on site or remotely (e.g., by a service provider) and then transmitted to the driver via roadside equipment such as a variable message sign (VMS). Traffic control measures, such as signal control, and automated enforcement technologies also fall into this category. The advantage of these systems over vehicle-based systems is that traffic information and warnings derived from them are available to all drivers. Further, they are able to collect traffic data that cannot be collected by vehicle-based systems, such as the presence of ice on the road ahead (Regan, 2004).

Cooperative ITS technologies derive traffic information from the road infrastructure, other vehicles on the road network, or from both sources, and transmit this to the driver via VMS displays or via displays within the vehicle. Infrastructure-based ITS technologies can be used, for example, to detect a vehicle approaching an intersection and send a warning to other vehicles also approaching the intersection of the presence of the first vehicle. Alternatively, vehicle-based ITS technologies in one vehicle can be used to warn another vehicle equipped with ITS technologies of its presence on the approach to an intersection, without any support from infrastructure-based systems.

In vehicle safety, a distinction is often made between so-called “passive”, “active”, and combined active and passive (“CAPS”) systems. Passive systems come into effect during a crash to increase user protection or minimise crash severity. Such systems include airbags, seatbelt pre-tensioners and anti-whiplash systems. Active systems are designed to prevent a crash from occurring, by warning drivers if a crash is eminent or by taking control of elements of the driving task. Adaptive headlights and Adaptive Cruise Control (ACC) are examples of active systems. CAPS systems serve both of these roles. Such systems, for example, may use sensors (e.g., radar) to detect that a crash is eminent and pre-activate seat belt pre-tensioners and other passive systems to optimise occupant protection if it is predicted that the collision cannot be avoided. ITS technologies can be passive, active or CAPS, depending on which stage of a crash (pre, during or post) they take effect and the manner in which they are implemented.

ITS technologies can also be distinguished according to the mechanism by which they enhance safety. Some systems, for example, can reduce crash risk. An example of this is Intelligent Speed Adaptation (ISA) which, by warning drivers that they are exceeding the speed limit, lowers mean and peak travel speeds. Other systems reduce the consequences of crashes. Seatbelt reminder systems, for example increase the likelihood that occupants are belted in the event of a crash; while automatic crash notification systems provide for faster medical assistance at crash scenes. Other ITS affect the exposure of the user to crash risk. A dynamic route navigation system, for example, can be pre-programmed to avoid journeys through busy intersections or through crash sites.

The term ITS is broad, and encompasses a wide variety of technologies. This review will focus on systems that enhance safety. These include passive, active and CAPS systems and systems that may be applied to any vehicle or roadside feature, not just the motorcycle.

4 REVIEW OF THE MOTORCYCLE ITS LITERATURE

Numerous ITS technologies have been developed to improve the safety and efficiency of cars, commercial vehicles, public transport and infrastructure. While any technology that improves the safety of other road users can reasonably be assumed to also at least indirectly improve the safety of other vulnerable road users, little has been done to directly implement ITS in motorcycles (Hsu, 2000; Regan, et al., 2001). A large number of different systems have been developed to improve driver safety (see Appendix A for a full list of all ITS technologies), while there are less than ten currently commercially available ITS products for motorcycles. Even evaluations of ITS technologies for vulnerable road users fail to consider the specific safety benefits of ITS in motorcycles (e.g., Lawrence, et al., 2004).

This deficit has not gone unnoticed. Very little literature exists discussing the actual research and development of motorcycle-specific ITS applications; however, there are numerous documents which call for the urgent need for activity in this area. This recognition comes from both motorcycling and ITS groups alike, providing an encouraging platform for future developments. For example, Thirumalai (2001) noted the significant untapped market potential for ITS technologies in motorcycles, particularly those systems that address collision avoidance and stability issues.

Motorcycling associations have advocated the careful consideration of motorcycles in the development of ITS for many years. The U.S. Department of Transportation's Motorcycle Safety Foundation (MSF) released a statement in their National Agenda for Motorcycle Safety (2000) in which the lack of consideration of motorcycles in ITS development was criticised. The MSF stated that systems should be developed that enhance motorcycle conspicuity to other road users, reduce the occurrence of right of way violations on the part of other motorists, and reduce critical incidence response times to motorcycle crashes. They suggest that key areas of research should enhance the detection of motorcycles in other vehicles, and to identify and prioritise the ITS that have the potential to be applied to motorcycles. Particular emphasis was given to the need to improve advanced collision warning systems and automatic collision notification systems. Similarly, the ACEM has released a Plan for Action (ACEM, 2004b) in which it encourages the development of inter-vehicle communication ITS technologies as a means of addressing conspicuity-related crashes in Europe. Additionally, the need for more advanced braking systems to become standard in motorcycles was highlighted in this document. The British Motorcyclists Federation (BMF, 2006) has welcomed the development of on-board navigation and driver assistance ITS, and infrastructure-based traffic management technologies which give priority to motorcycles. They highlighted the potential benefits from other-vehicle collision avoidance technologies, provided that these systems are sensitive enough to detect motorcycles. The European Agenda for Motorcycle Safety (Federation of European Motorcyclists Association; FEMA, 2004) also recognised the need to shift some of the focus of ITS developments onto motorcycles. FEMA particularly encourage the use of Daytime Running Lights (DRLs), Anti-Lock Brakes (ABS) and Combined Braking Systems (CBS) among other safety countermeasures. While encouraging, these documents do not include any reference to actual existing systems. Rather, they allude to the potential for the adaptation for other systems to the motorcycle interface, without regard for the technical or implementation issues involved.

Hsu (1997) provided a discussion of the issues relating to ITS in motorcycles. According to Hsu, almost all ITS applications have been developed with car safety in mind, but the potential for developments for motorcycle is great. Specifically, ABS, vehicle diagnostic systems, rollover threshold warnings, advance lighting systems, blind spot monitoring, intersection collision warnings and driver status monitoring systems were all identified as existing car-based ITS that could be practically adapted to enhance motorcycle safety. Similarly, Bishop (2002) suggests that any driver assistance system has the potential to be applicable to motorcycles. Such systems include Adaptive Cruise Control (ACC), traction warnings, weather warnings, curve speed warnings, active headlights, night vision, emergency brake indicators, and driver fatigue monitoring. Bishop also highlighted the unique possibility for the helmet to be a platform for rider status monitoring equipment. However, he also cautioned that other vehicle-based ITS also have the potential to create new hazards to the motorcyclist. This is exemplified by inter-vehicle communication systems, where the challenge of detecting motorcycles as adequately as other large vehicles has limited many initially developed systems. This problem appears to have been overcome, with international standards now including motorcycle detection capabilities. Conversely, Bishop also suggests that workload management systems which serve to decrease driver distraction should similarly enhance motorcycle safety by allowing more of the attention capacity of other drivers to focus on motorcycle detection.

In 2000 Hsu conducted an international survey of attendees of the 4th and 5th Intelligent Transport Systems World Congress, asking participants to rank in-vehicle, infrastructure, and other-vehicle ITS applications relevant to motorcycles in terms of their priority to be researched and developed. From this input, twelve potential ITS applications for motorcycles were identified by the author. Surprisingly, only three safety-relevant ITS were included in this final list: visual enhancement of the helmet, speed warning systems, and headway sensing and collision avoidance. The other systems prioritised on this list referred to developments in vehicle efficiency and protective clothing.

A more detailed description of potential ITS applications for motorcycles was given by Regan, et al. (2001). They identified fourteen in-vehicle technologies that could improve the key motorcycle safety issues of unlicensed riding, intoxicated riding, conspicuity, balance and stability, speed and road characteristics. These systems were: speed alters/limiters, helmet-mounted displays, electronic licenses, smart-cards, alcohol interlocks, automatic crash notification systems, anti-lock braking, vehicle diagnostics, rollover threshold warnings, near-field monitoring, intersection warnings, vision enhancement systems, lane change collision warning systems, and vehicle mounted airbags (see Chapter 3 for system descriptions). Regan and colleagues proposed that many systems that are relevant to young novice drivers may also be relevant to motorcycle safety, as a high proportion of motorcycle crashes involve novice riders. At the time of publication of this report, none of these systems, nor any other-vehicle system, had yet been designed and evaluated specifically with motorcycle safety in mind. Similarly, no existing collision warning systems were yet sensitive enough to reliably detect motorcycles. It was also suggested by Regan, et al. that there exists a potential to adapt what has been learnt from the aviation industry regarding helmet-mounted displays.

In recent years, a number of ITS have emerged as being most suitable or easily adapted to motorcycling. In a discussion of ITS in relation to motorcycle safety, Ulleberg (2003), named three specific active and passive systems that should be safety-enhancing if adapted to motorcycles. These were ABS, daytime running lights and airbags. Anti-lock brakes are an ITS that has a high potential to enhance motorcycle safety, although the direct benefits of these systems have not yet been evaluated. More advanced braking technologies have obvious safety-enhancing benefits, in terms of reducing both the likelihood and the fear of the brakes locking in an emergency situation. Losing control of the path of the motorcycle is a real risk should the brakes lock, and the fear of this occurring means few riders use the maximum braking potential of their vehicle. It is thought that ABS will result in a positive change in rider behaviour, as well as an actual reduction in motorcycle crashes. Lu and Shih (2005) assessed the applicability of an ABS system to light motorcycles. They found ABS performed well in both wet and dry conditions, and considered the application of ABS to light motorcycles to be acceptable. This was not, however, an evaluation of a commercially available system, and it seems that no other independent studies of the applicability of braking assistance systems to motorcycles have been conducted, although advanced braking systems have been developed by Honda, including ABS and linked braking systems (see Chapter 3).

Ulleberg (2003) suggested that daytime running lights (DRLs) will reduce the occurrence of multiple-vehicle collisions during the day, and that this effect will be further enhanced by other conspicuity related countermeasures, such as reflective clothing. Indeed, Elfvik and Olsen (2003; cited in HUMANIST, 2006) reviewed 16 studies of DRLs in motorcycles, and found that laws or campaigns advocating their use were associated with a 7% reduction in multiple vehicle crashes. Daytime running lights are one of the most technically mature safety countermeasures, having actually been implemented in several countries, and have been shown to have significant effects in reducing conspicuity-related crashes. They have been mandatory in Malaysia since 1992, and in the years immediately following this legislation, crashes in which conspicuity was cited as a factor decreased by 29%, with a compliance rate of 82% (Umar, Mackay & Hills, 1996). Given that approximately 60% of Malaysia's vehicles are motorcycles, the benefits of this system were high. DRLs have also been implemented in Singapore in 1995, resulting in a reduction in fatal and serious injury crashes (Yuan, 2000). A review of daytime headlight laws in the United States found a 13% reduction in the number of fatal motorcycle crashes associated the use implementation of a compulsory daytime headlight law, and estimated that 140 fatal motorcycle crashes between 1975 to 1983 could have been avoided if this intervention was implemented nationally (Zador, 1985). Paine, et al. (2005) suggested dedicated DRLs have the potential to reduce fatal motorcycle crashes in Australia by 13%. However, DRLs for new motorcycles were mandated in Australia in 1992, but this was revoked in 1997 due to a lack of evidence of their effectiveness. In a review of the effectiveness of DRLs in Australia, Cairney and Styles (2003) noted that while small reductions in motorcycle crashes (2%) had been observed since the implementation of this law, there were no statistically significant reports of improved safety linked to DRLs. They also concluded that more research is needed into which circumstances (e.g., location, time of day) DRLs are most effective, and which crash types are reduced by this ITS.

The introduction of daytime running lights for other vehicles has been heavily criticised by FEMA (2001). They have argued that DRLs are have not been proven to enhance road safety, through both research and implementation in various countries, and that DRLs actually reduce the safety of vulnerable road users such as motorcyclists, bicyclists and pedestrians. According to this group, DRLs reduce the conspicuity of other road-users by increasing visual glare and visual clutter, distorting distance perception and obscuring the view of other road users. They create visual strain, and the attention of the motorist is occupied by the DRLs, rather than looking out for vulnerable road users.

As a caveat, it should be noted that DRLs are not traditionally considered an ITS technology. DRLs are not intelligent, strictly speaking, as they do not involve information processing or communication functions. However this distinction is not universally accepted, and given the variety of literature available regarding DRLs as a motorcycle safety enhancing technology, they were included in this review.

Another more technically mature ITS in motorcycles is vehicle-mounted airbags, although the safety benefits of this ITS in motorcycles are somewhat contentious. There have been concerns about the potential for these to increase head and neck injury upon deployment (Ulleberg, 2003), although they have also been shown to be effective in reducing the incidence of being thrown from the motorcycle in multiple vehicle collisions. Honda has developed, evaluated and improved an airbag system for a large touring motorcycle, which was demonstrated to be effective in minimising fatalities and serious injuries associated with frontal impact crashes (Kuroe, Namiki, & Iijima, 2005; Yamazaki, Iijima & Yamamoto, 2001). They developed a 157 litre airbag that could be deployed in 45 msec, which did not inappropriately deploy under normal riding conditions or present an additional injury risk when the rider was in a forward leaning position or when a pillion passenger was present. Another passive system that has been trialled in motorcycles is an automatic crash notification (ACN) system. This combined ACN and anti-theft mechanism has been developed and tested in both simulated and test-track conditions. However on-road testing of this system has not yet been reported (Findlay & Morphett, 2003). ACN systems are relatively new, even in cars.

Intelligent speed adaptation (ISA) is a technology that has recently attracted a lot of research, although this has again focused on passenger vehicles. ISA has not yet been formally trialled in motorcycles, although the possibility of this adaptation has been recognised. In a presentation to the International Working Group on Speed Control, Fowkes (2004) discussed the potential application of ISA to motorcycles. It was stated that a prototype vehicle would be developed and tested in 2005 in the United Kingdom, with user ratings of the system to be gathered. No data from this trial has been released yet. However, Fowkes alluded to some of the issues pertinent to ISA in motorcycles, namely: that motorcycles have different speed and acceleration patterns to other vehicles; making the operations of the system different to cars; that sufficiently installing the system on a motorcycle will be difficult given the size and power needs; and there is potential for interference from vibration from the vehicle. The display of information must also be modified, either through visual or auditory information provided to the helmet. Similarly, the actively supporting components must be altered. Here Fowkes suggested that vibration in the throttle, seat or headrest were viable options over pedal resistance. It was also stated that an intervening ISA system should interfere with power supply to the engine or throttle rather than the braking system.

The forerunners of motorcycle ITS developments come from the Japanese Advanced Safety Vehicle (ASV) initiative, jointly set up in 1991 by the Japanese Ministry of Land, Infrastructure and Transport, academics and vehicle manufacturers. This is a program aimed at encouraging the development of vehicle technologies specifically aimed at crash prevention and minimisation. The first five years of this project focused on passenger vehicle safety, while more recently the program has been extended to technologies for commercial vehicles and motorcycles. Honda, Suzuki and Yamaha have been heavily involved in this project, developing prototype ASV's (both passenger vehicles and motorcycles) and numerous ITS technologies specifically for the motorcycles interface.

Phase 2 of Honda's ASV Project aimed to address four safety issues: driver attention and rear-end collisions; vulnerable road user safety; motorcycle active safety; and motorcycle passive safety (Asanuma, et al., 2000). Motorcycle active safety was addressed through inter-vehicle communication systems and enhanced headlights, and a vehicle diagnostic system which monitors the air pressure of the motorcycle's tyres. Passive safety was enhanced with a motorcycle airbag system (described above). In addition to these motorcycle-mounted technologies, Honda's second prototype passenger vehicle (ASV-2) included several systems aimed at improving vulnerable road user safety. The poor conspicuity of motorcyclists and pedestrians was addressed with a Night Vision System, an Active Headlight System, and inter-vehicle communication system for cars. These technologies are discussed in greater detail in Chapter 3. The safety-enhancing possibilities of these systems are encouraging; however, as noted by Asanuma, et al. of Honda's Research and Development department, the exploration of their actual benefits is ongoing.

Similarly, Suzuki has developed an ASV motorcycle equipped with a helmet mounted display (HMD), a visibility improving helmet and adaptive front lighting (Gotoh, et al. 2001). They have also equipped passenger vehicles with motorcycle detection systems, which operate via a weak radio signal emitted from the motorcycle, detected by sensors located on vehicles. The development of this inter-vehicle communication ITS is of high priority to Suzuki's ASV program. On-road testing of the passenger ASV with this motorcycle detection system has begun but neither preliminary nor final reports from this are available yet. Yamaha's ASV-3 has recently been developed, incorporating a front-mounted airbag system, however, no literature describing or evaluating these systems could be found.

While the reports of the developments of motorcycle specific ITS applications are promising, there are significant issues associated with the introduction of technology to the motorcycle interface. Hsu (1997) identified several factors that must be considered for any motorcycle ITS development: the principles that apply for ITS in cars do not automatically apply to motorcycles; motorcycles generally travel at a lower speed than cars; acceleration noise is greater in motorcycles; motorcycles often ride side-by-side and have different overtaking behaviours than cars (although this may be specific to riding behaviours in Asia, where a greater proportion of vehicles are motorcycles). Another significant problem is the lack of mounting space. Adaptation of the system within the vehicle is inherently more difficult in motorcycles than cars. This was highlighted by Mitterrieter, Schlagmann and Stocker (2005), who identified the difficulties in the integration of the human-machine interface of navigation systems in motorcycles. Providing a safe yet usable interface is a huge challenge for any vehicle-mounted ITS.

There are also acceptability issues that must be noted. The British Motorcycling Federation has expressed concern over the potential for ITS to turn the motorcycle into a 'puppet'. By this, they refer to automation of the riding task, either through technologies that reduce the workload of the rider, or by technologies which externally take control of the vehicle, where there is potential for the stability of the vehicle to be disturbed. The BMF is also cautious to welcome any ITS that involves surveillance. The European Agenda for Motorcycle Safety (FEMA, 2004) discussed similar issues. They stressed that any ITS that influences the behaviour of the motorcycle (i.e. has an intervening function) should only ever be voluntary and carefully developed to ensure the stability of the motorcycle is not compromised in any environmental condition. FEMA also expressed concern that because motorcycles may be inherently unsuitable for some ITS traffic management applications, they should not be excluded from road use because of this incompatibility. Similarly, they strongly discourage the development of any ITS that, while enhancing the safety of the user, places other road users at risk. They have concern that the development of ITS for other vehicles places motorcyclists in a possible position of compromised safety. This sentiment was shared by the U.S. Motorcycle Safety Foundation, which in its National Agenda for Motorcycle Safety (2000) stated that developments in ITS, if not safety enhancing, should at least not compromise the safety of motorcyclists.

4.1 SUMMARY

Very little literature regarding motorcycle-specific ITS currently exists. What is available largely concerns airbag and daytime running light systems, which have been developed and tested with encouraging results. Furthermore, a considerable amount of the available literature has come from the Japanese Advanced Safety Vehicle program, where prototype systems have been developed by Honda, Suzuki and Yamaha. However, no objective evaluations of the effectiveness of these systems were found, and few of these systems have yet been made commercially available. Numerous motorcycling and ITS groups have called for the development and improvement of ITS in motorcycles, although many also express concern for the automation of the riding process or potentially compromised safety resulting from ITS. What is clear from this literature review is the world-wide lack of research and development of safety enhancing ITS technologies for motorcycles.

CHAPTER 2 – EXPERT CONSULTATIONS

1 OBJECTIVES

The purpose of undertaking informant interviews was to supplement the literature review with contemporary information from expert sources. In order to obtain knowledge of all emerging ITS applications for motorcycles, consultation with industry experts was thought to be an effective method of gaining up to the most recent and relevant information. While Chapter 1 established what ITS already exists through the literature review, these communications were aimed at discovering what ITS are currently being developed, and discussing the issues associated with ITS in motorcycles.

2 PROCEDURE

Contact with industry experts was sought in a variety of ways. Industry leaders and academics in Australia were consulted in both face to face and telephone meetings, while international contacts engaged in electronic correspondence. MUARC’s network of contacts within the ITS and vehicle manufacturing industries, as well as academics, independent consultants and road safety groups was utilised in this process. Emails to individuals and mailing lists were sent out seeking information and further contacts regarding ITS in motorcycles. In all, several hundred industry experts from Australia, Japan, Europe and America were contacted during this process. Ethical restrictions within Monash University prevent these individuals from be named for confidentially reasons. However, these limits do not prevent the organisation and position of participants from being identified. A complete list of the mailing lists and organisations or groups contacted and their nationality is presented in Appendix B.

3 STRUCTURE OF THIS CHAPTER

This section presents the key findings from the numerous consultations with these individuals. The general scope of the discussion will be given, and this will be related to what was identified in the literature review, in terms of what new information was presented, what confirmed or contradicted the findings of the literature review, and what new issues were raised.

4 FINDINGS

In total, over 700 individuals were contacted in the expert consultation process. While not every individual replied to the request for information, those that did respond were from a wide variety of government, academic and industry institutions from around the world. Within Australia, information was provided by individuals from ITS Australia, the South Australian Department of Transport, Energy and Infrastructure, the National Transport Commission, the Queensland Centre for Accident Research and Road Safety, Australian Arrow Pty Ltd, Xenon Technologies Pty Ltd, Licensys and NRMA.

Groups within Europe included SWECO, IMITA, TNO Netherlands, Belgacom, MIRA, Association des Constructeurs Européens de Motorcycle (The Motorcycle Industry in Europe), the British Motorcycling Association, BMW, Volvo, Traffic Technology International, the University of Gent, Arsenal Research and INRETS.

Numerous individuals from European government transportation departments also conferred with MUARC during this process. Representatives from Austria, Sweden and the UK all shared information regarding ongoing ITS projects within Europe. Within Japan, contact was made with Honda's Research and Development department, and the National Institute of Advanced Industrial Science and Technology. A leading America ITS academic was also involved in these consultations.

The vast majority of experts contacted knew of very few, if any, ITS developments specific to motorcycles. A large number regretfully expressed their lack of knowledge of any directly relevant information or resources, but were often able to refer the authors to other contacts or websites that may yield useful information. One topic that was frequently alluded to was the testing of ISA in motorcycles. It was revealed that several preliminary studies have been conducted in Europe. However these are either ongoing or have been abandoned, and no published data has been made available from these tests. It seems that the application of cooperative speed limiting devices to motorcycles is fraught with technical difficulties, and adequate funding for such trials is difficult to obtain.

An Australian expert in road safety mentioned that the British Department of Transportation has been involved in an ISA trial with MIRA, a UK-based vehicle engineering and evaluation company. This is the same trial alluded to by Fowkes (2004; see Chapter 1), but was described in greater detail by this contact. This project began in 2001 with the main focus on passenger vehicle driver behaviour, and is to be completed in March 2006. Part of the scope of the project was to extend the application of ISA to trucks and motorcycles, with field trials scheduled for 2003. Deliverables from this project will not be available until the end of 2006. A preliminary report from this trial (Wilkie & Tate, 2003) briefly stated that ISA was incompatible with motorcycles at that stage of the project, as the mechanisms of the operation of such a system were still unknown. An ISA-equipped motorcycle was scheduled for development as part of this project, but whether or not this was carried out or evaluated has not yet been reported.

Another motorcycle ISA trial was conducted in Sweden by SWECO. According to a senior member of this organisation, four motorcycles were fitted with an informative ISA system (one which alerts the user to excess speeds with physical feedback but does not intervene with the control of the vehicle). This was exactly the same system as what was fitted to passenger vehicles. There was no budget for the adaptation of the system to a motorcycle interface, resulting in the test-riders being involved in the installation and manual operation of the system. The project was abandoned due to these technical difficulties, and a report was produced in Swedish only. The conclusions of this report were summarised in English by this contact. Essentially, it was concluded that installation of the system on motorcycles is inherently difficult because of the vehicle's size; successful installation is further complicated by the need to make the components weather and theft resistant; GPS delays (the delay in communication between the vehicle and the infrastructure) are more pronounced and dangerous on motorcycles; and that auditory messages delivered by the system require integration with the helmet.

An even smaller trial was conducted by IMITA, a Swedish vehicle safety company, where a single employee of SWECO installed and trialled an IMITA-developed ISA system on his personal motorcycle. This individual was contacted, and he provided a detailed account of this process. He stated that as there was no funding from the Swedish Road Administration no deliverables were produced that described this test. Similar to the trial described above, the system was a GPS-based passenger vehicle system that was fitted to the frame of the motorcycle. This presented the same issues regarding where to position the system onto the vehicle. Unlike the aforementioned trial, though, this was a limiting system, where the system applied resistance in the throttle if the user tried to exceed the speed limit.

The individual reported that the device was only infrequently effective. For reasons unknown, components of the system worked at a higher frequency than they normally would on a car, resulting in the CPU becoming overloaded and the ISA system unable to recognise the vehicle's current speed. However, this was admittedly decade-old technology. When the system was operating at lower speeds it was more consistent, and the resistance in the throttle was reported to be an effective means of slowing the vehicle. The contact concluded the overview of the trial by stressing the need for further on-road trials and development of the human-machine interface of the ISA system.

Another contact within the Austrian Department of Transport and Mobility did not know of any specific motorcycle ITS developments, however he raised three issues regarding motorcycle safety in Europe. Firstly, anti-lock brake systems have been widely accepted as a useful technology in motorcycles that need to be more widely available. Secondly, there is "strong pressure" to improve infrastructure specifically to enhance the safety of motorcyclists. Thirdly, there has been a call from the 6th Framework Programme of the European Union for motorcycle-specific ITS research. Investigation into this revealed that a project, Advanced Protection Systems (APROSYS), has already begun although it will not be complete until 2009. No preliminary findings from this project are available yet.

Several contacts mentioned the Advanced Safety Vehicle project. One contact from the Japanese National Institute of Advanced Industrial Science and Technology pointed out that although this project is ongoing, the results from these ITS developments are already being implemented. Examples of this include integrated braking assistance systems that are currently on the market, with more than 30,000 devices distributed, and motorcycle navigation systems that have been commercially available for over a year. A leading academic in ITS research also highlighted another project which included an inter-vehicle communication system that was tested and demonstrated in 2005, and also advancements by Honda in creating a motorcycle airbag system. These developments were reviewed in Chapter 1.

A member of the ITS Australia mailing list recalled a display of motorcycle ITS by BMW at the 8th ITS World Congress in 2001. This system was a GPS-based navigational device with a blue-tooth equipped helmet. This technology was unique in that it allowed the GPS to still function in remote locations where a satellite connection may fail. The member who shared this information highlighted the potential for such as system to be integrated with various other types of relevant information, such as weather reports and warnings of upcoming hazards.

It was also bought to the authors' attention by an Australian vehicle technology manufacturer that a world-first product has been developed in Australia. This product, Xtreme Beam, is an emergency hazard light and early warning crash detection system. The system incorporates a continuous flashing light to enhance vehicle conspicuity, tilt sensors and an emergency lighting system that illuminates the vehicle in the event of a crash. This is one of few ITS devices that has been specifically designed for motorcycles, and was launched in 2002. Also, the emergence of electronic licence plates for motorcycles was mentioned by another contact. As yet, the only country to implement electronic vehicle identification (EVI) has been Singapore, although it has been proposed in the UK as a means of reducing the high incidence of motorcycle tax evasion. These systems will be described further in Chapter 3.

A meeting with a national ITS industry expert was held. The specific purpose of this meeting was to establish what recent advancements in ITS technology were occurring within Australia, and what ITS for motorcycles were currently available in Australia. None of the ITS technologies identified in this meeting were not already mentioned in the literature review. In particular, airbags, ABS, ISA, inter-vehicle communication and adaptive headlights were the main ITS technologies that were discussed. Concerns were raised by the expert about current commercially available helmet-mounted displays, which were thought to be not yet up to Australian standards, and that their high cost and likelihood of compromising the safety of the helmet meant that, in their current form, HMDs are not yet ready to be adopted in Australia.

Additionally, some interesting points regarding the development of ITS for motorcycles were raised in this meeting. The ITS expert expressed concern that current safety-oriented ITS technologies are not being developed with specific safety issues in mind. That is, the development of ITS has not been driven by accurate crash data. According to this expert, crash classifications need to be nationally standardised and better developed to provide a greater account of crash causation, in particular, human error factors. Improvement of crash classification systems should accordingly lead to better road safety countermeasures. It was also suggested that gaining a better understanding of near-miss crashes was as important as understanding serious injury and fatal crashes, and that this could be gathered from existing 'crash-cam's' at intersections, and from on-road naturalistic motorcycle riding studies.

A phone conference was also conducted with a leading Australian academic in motorcycle safety research. The purpose of this conference was to discuss which potential ITS applications would be most beneficial to motorcyclists. Firstly, the key safety issues relevant to motorcycling were discussed, and both the authors and this expert were in agreement that failure to see crashes, speed, and multiple vehicle crashes were of highest relevance to motorcycling safety. This expert considers there to be six key contributing factors to motorcycle crashes. These are: the vulnerability of the motorcyclist to injury; inexperience or inconsistent riding experience; driver failure to see the motorcycle; instability of the motorcycle; road surface and environmental hazards; and risk taking behaviour. The second part of the consultation involved reviewing a list of all known emerging and available ITS for all vehicles and infrastructure (see Appendix A for this list) that may have the potential to improve motorcycling safety. This expert identified the following systems as having the greatest potential to enhance motorcycle safety: adaptive front lighting; airbags (both vehicle and jacket based); alcohol detection and interlock; anti-lock brakes; curve-speed warnings; daytime running lights; electronic licensing; forward collision warning; helmet-mounted display; impact cut-off systems; inter-vehicle communication; linked brake systems; rear-view helmet; road surface condition monitoring; roll stability control; and vehicle diagnostic systems. Each of these systems was deemed to address at least one key safety issue. Systems which served to reduce unlicensed and intoxicated riding were very positively regarded by this expert. However, this expert was very reluctant to accept any system that did not address the issues of acceptability and usability. Concern was also expressed that some systems may actually encourage unsafe riding behaviour, where, for example, motorcyclists may try to exceed the recommended speed provided by curve-speed warning systems, seeing reaching the thresholds of such systems as a type of ‘challenge’.

4.1 SUMMARY

Consultations with industry experts did not yield any information about currently existing systems that the authors were not yet aware of, with the exception of the Xtreme Beam system. However, this process was invaluable in a number of ways. Firstly, it confirmed the worldwide lack of ITS developments for motorcycles. Secondly, information about preliminary motorcycle ISA trials in Europe was gathered. As reports from these small trials have not, and most likely will not, be published, this knowledge could not have been gained without these consultations. Thirdly, this process allowed external input regarding the issues of ITS in motorcycles in the absence of peer-reviewed literature. Conferring with a motorcycle safety expert and other ITS experts has confirmed which ITS appear to be most relevant to motorcycles.

CHAPTER 3 – REVIEW OF ITS TECHNOLOGIES

1 OBJECTIVES

This section describes the ITS technologies that are relevant to motorcycle safety. Included are all categories of ITS – active, passive and CAPS, in-vehicle, infrastructure-based and cooperative. This section aims to provide a comprehensive review of all the proposed and existing ITS technologies that have the potential to enhance motorcycle safety. In determining what ITS are, or could be, available for motorcycles, any ITS identified in the literature review presented in Chapter 1, as well as the systems mentioned during the expert consultations presented in Chapter 2 have been included here. Also, in reviewing what ITS are available and emerging in passenger and commercial vehicles, any systems that could reasonably adapted for motorcycles are covered in this section. The inclusion of the various systems in this section has also been driven by the safety issues described in Chapter 1, where systems most relevant to the key safety issues of motorcycling, or those that have already been adapted for motorcycles, have been explored in greater detail. Systems that are obviously incompatible with motorcycles, such as seat-belt pre-tensioners and anti-whiplash seats have not been included here, although a complete list of ITS for all vehicle types is provided in Appendix A.

2 STRUCTURE OF THIS CHAPTER

This section will firstly list and describe all in-vehicle ITS for motorcycles in alphabetical order, followed by systems which may be applied to other vehicle types (i.e., passenger and commercial), and finally, infrastructure-based and cooperative ITS. The purpose of each ITS will be identified, including the manner in which the system is designed to enhance safety, and a functional and technical description will be provided. Where possible, any commercially available systems will be identified and any information evaluating the safety benefits of the system will be named. Also, when available, pictures and descriptions of motorcycle-specific systems have been included here.

3 REVIEW OF ITS TECHNOLOGIES

3.1 ACTIVE IN-VEHICLE ITS

3.1.1 Adaptive Front Lighting; Active Head Lights

Adaptive headlights improve the illumination of the path of the motorcycles on curves. When cornering the change in the optical axis of the headlight reduces visibility of the road, because the beam illuminates the shoulder rather than the road. Adaptive headlight systems incorporate vehicle speed and angular velocity sensors with a rotating mechanism behind the headlight. The position of the headlight is adjusted in accordance with the speed and position of the bike, so that it maintains a horizontal axis that is parallel with the road surface. Adaptive headlights ensure that the illumination from the headlight is projected on the intended path of the motorcycle when cornering. The Yamaha ASV-2 Model 1 has been equipped with adaptive headlights, but at this stage this is still an emerging active ITS in motorcycles.

While it has been noted that more crashes tend to occur during the day than at dusk or at night, any system that improves the safety of the motorcyclists of curves will be highly beneficial given the high proportion of run-off-road-on-curve crashes reported in Victoria. Adaptive headlights may also serve to increase the conspicuity of the motorcycle to other vehicles on corners. However, this effect needs to be investigated.

Figures 1 and 2 Examples of adaptive front-lighting system compared with traditional headlights. (Source: Nakai, 2000).

Note: In figure on right, the top caption reads "without system" and bottom caption reads "with system".

3.1.2 Advanced Driver Assistance Systems

Advanced Driver Assistance Systems (ADAS) combine various sources of information and present this to the rider in both visual and auditory form. The purpose of these systems is to reduce human error in the riding task and the workload of the user. This allows more rapid detection of potentially hazardous situations and leads to faster decision making and responding. These systems may integrate information from navigation systems, other ITS devices and information from the instrumentation panel, and present them to the rider in an unobtrusive way.

The Yamaha ASV-2 contains rider support system (termed the Multi-Information System) which incorporates the information from a range of ITS technologies (curve speed warning, forward collision warning). It presents the rider with visual cues, such as flashing warnings on the instrument panel, and auditory warnings in the form of "Beware of…". The system also combines information from the vehicle itself, such as speed and position, and the surrounding environment. Similarly, BMW has implemented a SmartWeb system on a motorcycle, which features internet access, off-board navigation, address book and an MP3 player function.

Advanced driver assistance systems do not address specific safety issue or crash type. However, provided that they are designed and implemented in ways which maximise the amount of information available to the user while minimising distraction, these systems should improve motorcycling performance and may complement other ITS with which they are integrated.

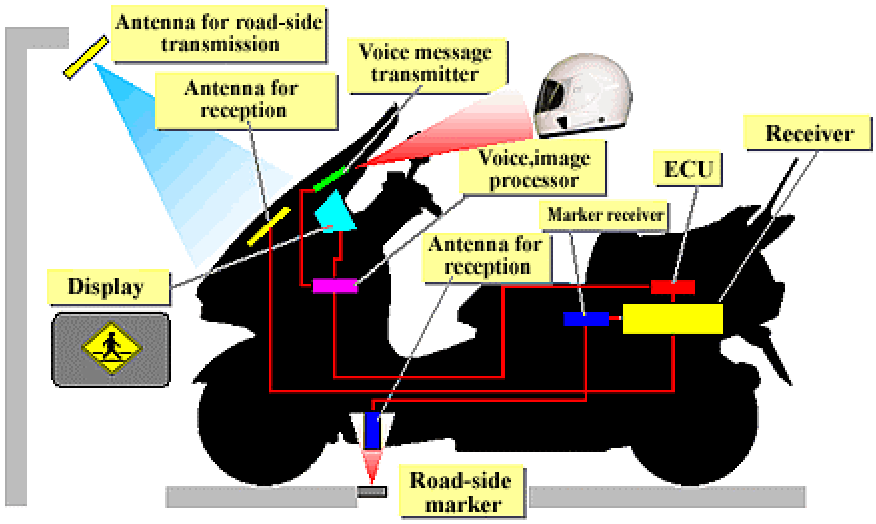


Figure 3 Yamaha's Rider Support System. (Source: www.yamaha-motor.co.jp)

3.1.3 Alcohol Detection and Interlock

Alcohol detectors typically analyse the breath alcohol content of the user, and determine whether the individual is fit to ride. Users blow into a tube which contains alcohol sensors, similar to that used in roadside breath testing. The system is connected to the ignition system of the vehicle, and the ignition is disabled if an excessive BAC is detected. Another form of alcohol detector in passenger vehicles monitors the level of ambient alcohol in the vehicle cabin and, if alcohol is detected, a breath test is required from the driver. If this is failed, the system disconnects the electrical system of the vehicle within a certain time period. However, as noted by Regan, et al. (2001), the latter system would be difficult to integrate in motorcycles.

Alcohol interlock systems are now established technologies implemented in several jurisdictions around the world. In Victoria, alcohol interlocks are fitted to vehicles as a condition of licence for drivers/riders who have been convicted of serious drink drinking offences. A small number of motorcycles in Victoria have been fitted with alcohol interlocks. Alcohol detection and interlock systems are emerging technologies, which have not yet been introduced in motorcycles. According to the TAC, alcohol was associated with almost 25% of Victorian motorcycle fatalities in 2005. Alcohol detection and interlock systems have been shown to be effective in cars with repeated drink-drivers in various international trials (Kullgren, et al., 2005) although they have not yet been tested in the general population or in motorcycles. Also, given the recent successful roadside saliva testing for illicit substances in drivers (marijuana and ecstasy) in Victoria, there appears to be the potential for the adaptation of this technology to include an in-vehicle illicit drug detector. This is merely a proposition – there have been no systems such as this developed or tested either in motorcycles or other vehicles.

3.1.4 Animal Detection System

These systems aim to alert users to animals ahead on the roadway. Animal detection systems rely on radars, lasers or other visual systems such as infrared sensors to detect the presence of animals. These systems need to be sensitive enough to detect small moving objects, but still have a low rate of false alarm. The different characteristics of animals as opposed to pedestrians, in terms of height, shape and speed, means these systems have different technical specifications from other object-detection systems, such as forward collision warning and pedestrian detection. Alternatively, wildlife dispersal systems emit a high frequency ultrasound from the vehicle, with the intent of deterring animals from entering the roadway.

These systems are emerging for all vehicle types. Only 2.5% of motorcycle crashes between 2000 and 2004 in Victoria involved striking an animal, and only 3 of these crashes resulted in fatality to the motorcyclist. However, run off-road crashes resulting from avoiding animals may be reduced with these systems.

3.1.5 Anti-lock Braking System

Anti-locking brakes (ABS) are designed to optimise the braking performance of the vehicle, by maximising the contact between the vehicle's tyres and the road surface. By preventing the wheels from locking and skidding during emergency braking situations, the rider retains better control of the stability and path of the vehicle. However, this does not necessarily reduce the stopping distance of the vehicle. ABS monitors the rotational speed of the wheels and releases the braking force if the wheels begin to lock. It is especially important for motorcycles to maintain rotation of the wheels even when braking, as this gives control over the direction of the vehicle.

The consequences of brakes locking are far worse for motorcycles than cars, yet little has been done to implement this technology in motorcycles (Ulleberg, 2003), although Honda has developed ABS as one of its advanced braking systems. ABS reduces the risk of motorcyclists being thrown from the vehicle, or losing control of the vehicle. ABS may lead to a reduction in forward collision and run off-road crashes, two of the most commonly reported crash types in Victoria.

Diagrams of this system are available at http://www.world.honda.com/motorcycle-technology/brake/p6.html#02.

3.1.6 Brake Assist

Brake assist systems maximise the braking potential of the vehicle, reducing stopping distances in emergency situations. The ability to independently control the front and rear brakes of the motorcycle is important for maintaining control in a dynamic riding environment. However, as a consequence, maximum braking force is rarely achieved in emergency stopping situations. When rapid and forceful braking pressure is applied (as in an emergency brake), the brake assist system applies additional hydraulic pressure to the front and rear brakes. Brake assist works in conjunction with ABS, where the braking pressure from both the front and rear brakes are assessed, and an acceleration sensing unit automatically intervenes and applies maximum braking pressure while preventing the brakes from locking.

Reduction in stopping distances should lead to a reduction in the severity, if not the incidence, of forward collisions and collision involving striking objects on the roadway. To the authors' knowledge, this system has only been introduced in motorcycles on the Yamaha ASV-2 Model 1.

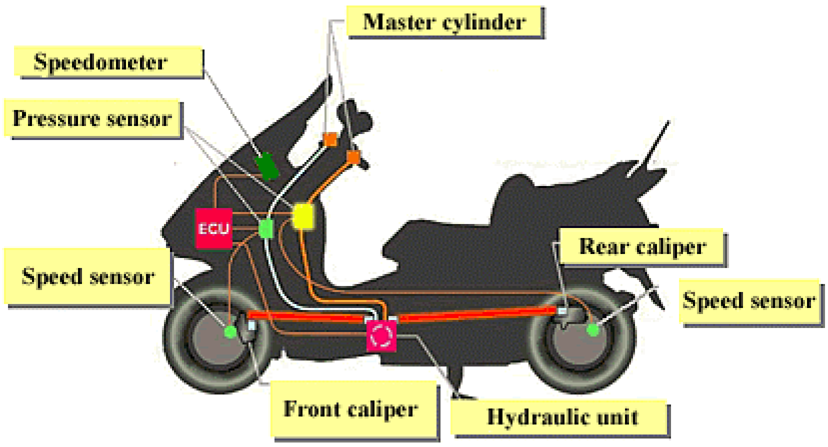


Figure 4 Features of Yamaha's Brake Assist System of the ASV-2 Model 1 (Source: www.yamaha-motor.co.jp)

3.1.7 Collision Warning and Avoidance Systems

Collision warning and avoidance systems monitor the area immediately surrounding the vehicle and when a vehicle is deemed to be too close to the hazard, the system either alerts the user (warning systems), or provides both an alert and intervention via the brakes of the vehicle (avoidance systems). Different forms of these systems exist (lateral, frontal and rear), although they generally employ the same principles to monitor the roadway. Laser or radar sensors positioned laterally, frontally or at the rear of the vehicle detect the presence of other vehicles within the same or adjacent lanes to the vehicle. The system continuously monitors the position of the motorcycle and other vehicles, and provides an alert if a vehicle is within a potentially hazardous proximity.

Frontal collision warning systems employ laser or radar sensors located on the front of the vehicle which monitor the distance from other vehicles within the same lane. Lateral collision warning systems alert riders to vehicles that may appear in the blind spot of the vehicle. Rear facing collision systems have been devised to protect the vehicle from being rear-ended by following vehicles. These have been applied to buses, where vehicles following too closely behind are provided with a visual warning to attract the attention of the driver of the following vehicle.

These systems have not yet been implemented in motorcycles, and are in fact only emerging in other vehicles. Forward collision warning systems, however, have been applied to the Yamaha ASV-2. Other applications of these systems are unknown to the authors. The avoidance of forward collisions should serve to reduce the severity and occurrence of frontal impact collisions with other vehicles and objects on the roadway.

They have the potential to reduce the incidence of multiple vehicle crashes, particularly vehicles travelling in the same direction crashes (e.g., side-swipe and rear-end crashes).

3.1.8 Curve Speed Warnings

Curve speed warnings may be either infrastructure or vehicle-based. Essentially, speed warnings or advice based on upcoming changes in the road geometry are communicated to the driver, either through an on-board display or via fixed or variable message signs on the roadside. This advice may be in the form of a recommended speed, a warning that the vehicles current speed is too fast, or information regarding the angle and camber of the road ahead.

These systems have not yet been introduced or evaluated in motorcycles. However, the Yamaha ASV-2 has curve-speed warning as part of its rider support system. Speed limit advice is not provided by this system, only the shape of upcoming curves. As already noted, any system that reduces the incidence of curve-related crashes, which account for over 17% of all motorcycle crashes in Victoria, will have a significant effect on motorcycle safety.

3.1.9 Daytime Running Lights

Daytime running lights (DRLs) aim to address the key safety issue of motorcycle conspicuity. Using the existing headlight, DRLs provide a constant beam, typically 80% of the headlight's normal illuminance, whenever the motorcycle ignition is activated. Illumination of the frontal view of the motorcycle serves to increase the visibility of the vehicle to other road uses. DRLs are an existing technology in motorcycles. It should be noted that many motorcycles in Australia are currently hardwired for the headlight to operate at full illuminance every time the motorcycle is started.

Motorcycle conspicuity is a serious concern for traffic safety as evidenced by the high proportion of crashes involving the other driver's failure to see a motorcycle. While the actual effectiveness of DRLs requires further investigation, any ITS which has the potential to enhance the visibility of the motorcycle to other road users is relevant to motorcycle safety. Dedicated DRLs should be more effective than mandated headlight use laws, as they eliminate motorcyclists' forgetting to, or deliberately choosing not to, turn on their headlights. The lower luminance of DRLs compared to that of headlights also has economic and environmental advantages.

3.1.10 Driver status monitoring

These systems monitor the performance of the driver, and provide alerts or stimulation if the driver is determined to be impaired (e.g., drowsy), and in some instances, take control of the vehicle from the driver. The systems may monitor driver inattention and/or fatigue in a number of ways, such as eye movement cameras, grip sensors, lane position monitors and devices that require regular input from the user. Some systems may use a combination of these.

Driver monitoring systems are currently emerging in passenger and commercial vehicles. There are obvious difficulties in applying these systems, particularly eye tracking devices, to the motorcycle, and the extent to which motorcyclist fatigue, inattention, distraction and other driver states are factors in motorcycle crashes is unknown.

Another emerging technology which works in conjunction with drowsiness detection systems is drowsiness relieving systems. When drowsiness is detected in the user, the system emits a tone, vibration and/or fragrance (which would likely not be applicable to motorcycles) to increase alertness.

3.1.11 Electronic Licences; Smart Cards

Electronic licences aim to prevent unlicensed riding. The licence, or smart card, must be inserted into the vehicle to unlock the ignition system. Only valid licences, or cards which have been registered to that particular vehicle will activate the vehicles ignition.

Electronic licenses also have the potential to be used to monitor and record the activity of learner riders or at-risk (e.g., inexperienced) riders (Regan, et al., 2001). Logs of riding conditions, distances and durations could be electronically recorded and collated as a means of ensuring riders either gain experience in a variety of situations, or do not ride outside their limitations. Electronic licenses can also be combined with a smart card ignition system. A wide variety of information can be stored on these systems, including traffic law violations and medical details.

Honda has developed a smart card key system aimed at improving motorcycle security. Replacing a traditional key-based lock, the ignition is replaced by a dial that can only be activated once the vehicle is unlocked with the smart card. This system immobilises the ignition of the motorcycle, and prevents tampering with the key cylinder. Given the high rate of theft of motorcycles, and the relatively low rate of vehicle recovery (Findlay & Morphett, 2003), motorcycle security improvements have obvious benefits to the motorcycling community. The safety benefits from these systems will be seen through a reduction in the occurrence of unlicensed riding. Across all vehicle types, unlicensed driving tends to also be associated with higher levels of intoxication and speeding.

A diagram of the system configuration of this technology is available at http://www.world.honda.com/motorcycle-technology/Smartcardkey/p2.html#01.

3.1.12 Electronic Stability Program

Electronic Stability Program (ESP) is a system which aims to maintain control of the vehicle's trajectory when the vehicle looses optimum contact with the road surface. This may occur when cornering too fast, over- and under- steering, riding on poor road surfaces, or in emergency stopping situations. ESP detects loss of traction, the lateral acceleration of the vehicle, yaw data, steering wheel position and vehicle speed to determine whether the vehicle has, or is about to, lose control. Differential braking pressure is applied to each wheel, depending on the trajectory of the vehicle.

ESP has been developed specifically for four-wheeled vehicles. To the authors' knowledge, no applications of ESP for motorcycles currently exist, and whether ESP can even be applied to two-wheeled vehicles is unknown. However, a successful motorcycle ESP system should reduce the incidence of loss of control crashes, particularly those occurring on curves.

3.1.13 Following distance warning

Following distance warnings serve to assist the driver in maintaining a safe following distance between the motorcycle and the leading vehicle. Using acceleration sensors and radar or lasers mounted on the front of the vehicle, the system monitors the speed of the motorcycle and the distance from the leading vehicle, and determines an appropriate headway from this information. If this distance is breached, the system comes into effect. Warnings are typically auditory and/or visual. This ITS is specifically aimed at reducing the occurrence of rear-end crashes. This technology has not yet been introduced in motorcycles.

3.1.14 Helmet-Mounted Displays

In order to enhance the delivery of information to motorcyclists, visual displays can be presented to the rider through their helmet. These systems eliminate the need for the rider to take their eyes off the road. Information that is typically provided on the instrument panel, such as speed, fuel levels, and engine RPM can be displayed with these systems, as well as information form other ITS applications. Mini-projectors within the helmet superimpose visual displays over the riders viewing field so that the user does not have to adjust the focus of their viewing distance to see the display. The visual information can also be enhanced by auditory information

Current commercially available systems include Veypor's Sportvue HUD (Heads-Up Display), and MS2. While the Veypor system has been developed for motorcycle racing, it also provides information relevant to everyday riding, such as speed, RPM and gear position. The position of the display in the visor is adaptable to suit the rider's preference.

The actual safety benefits of HMDs have not yet been evaluated to the authors' knowledge, and their direct effects may be difficult to assess, as they may also be incorporated into another ITS system, such as curve speed warnings. The potentially distracting or obscuring effects of these systems also need to be investigated.

Figures 5 and 6 Veypor's Sportvue display system (Source: www.veypor.com)

3.1.15 Inter-Vehicle Communication System

Inter-vehicle communication systems can potentially address a wide range of crash types, including intersection crashes, where driver inattention or visual obstruction is often a factor (Satomura, 2000). These systems enable automatic communication between multiple vehicles about their relative speed, position, course, and vehicle type. Information about other vehicles is detected and displayed on a heads-up display, navigation console or via auditory guidance, and provides alerts when crashes are deemed to be eminent.

In the Honda ASV-2 the system consists of two displays within cars: the navigation unit display which shows the vehicles location in relation to others, and a heads-up display which shows the alerts. In motorcycles, the same information is provided to the rider through a heads-up indicator, located near the vehicle controls, and a receiver and speaker in the rider's helmet. In a similar configuration, the Yamaha ASV-2 Model 1 sends an infrared signal from the motorcycle to vehicles equipped with IVCS. Model 2 of this ASV also contains a stopping distance warning system, notifying the rider how far the vehicle is from the stop line of the intersection.

The effectiveness of such systems, however, depends on the saturation of them within the population. Obviously, the system will be most effective if it is implemented in every vehicle. There is also concern that users of these systems will become over-reliant on them, leading to risk homeostasis; users may begin to assume the system will make safe judgements for them. However, the potential for this ITS to reduce one of the leading motorcycle crash types, multiple vehicle crashes at intersections, is great.

A pictorial representation of this system is available at http://www.its-australia.com.au/itslibrary/CONFERENCES/ITS_WORLD_CONGRESS_7th_Turin_ITALY/4243.pdf.

3.1.16 Lane Keeping and Departure Warning Systems

Systems that monitor the vehicle's position within the lane have already been developed for cars and commercial vehicles. The position of the vehicle in the lane is monitored with laser, radar or video monitoring of the lane edge markings ahead and to the side of the vehicle. The system either provides warnings or actively supports the driver by altering the course of the vehicle if its position deviates from the lane. Feedback is provided to the driver through visual and/or auditory signals, such as a 'rumble strip' noise on the side appropriate to the lane deviation.

The relevance of these systems to motorcycles is debatable; certainly no systems for motorcycles are emerging as far as the authors are aware, aside from those of the ASV programs. However, there may be potential for this system to be effective on curves, where maintaining lane position may reduce run off-road on curve crashes.

3.1.17 Linked Braking Systems/Combined Braking Systems

As already noted, the independent nature of the front and rear brakes of motorcycles can result in a failure to achieve optimum deceleration. Linked braking systems apply braking pressure from both wheels in order to reduce stopping distances even though only one brake may have been applied by the rider. Honda's combined braking system, for example, applies pressure to both the front and rear brakes when only the rear brake is activated. These systems can also be combined with ABS, allowing greater control over the motorcycle as well as greater braking force.

Linked braking systems have been available on some Honda models since 1993, and Honda intends to introduce advanced braking systems to many more models in the future. As of 2003, 1.5 million advanced braking systems, also including ABS, were distributed by Honda worldwide.

As with ABS and brake assist, linked braking systems can enhance motorcycle safety by reducing forward collision crashes and loss of control crashes.

Diagrams of Honda's Combi Brake System for large sports touring motorcycles are available at http://www.world.honda.com/motorcycle-technology/brake/p5.html#01.

3.1.18 Pedestrian Detection System

These systems may employ video, laser and/or radar sensors to detect the presence of foreign objects in the path or periphery of the vehicle. Since pedestrians may vary in height and width (depending on their physical size or orientation to the vehicle), as well as speed, detection of moving pedestrians (especially in a cluttered visual field) is a challenge for any such system, and the sensors must be powerful enough to detect the object with enough time for evasive action to be taken, with a minimal risk of false alarms.

The Yamaha ASV-2 Model 2 contains a pedestrian crossing support system, which detects and alerts the motorcyclist to pedestrians at designated crossings. Similar systems have not yet been introduced in other motorcycles.

Crashes involving pedestrians accounted for only 1.5% of all motorcycle crashes in Victoria in 2000-2004, with only one of these crashes being fatal to the motorcyclist, although more loss of control crashes caused by avoiding pedestrians may also be reduced.

3.1.19 Rear-view Displays

Rear-view displays provide greater visibility of the road environment directly behind the motorcycles. A rear-facing camera projects a view of the road and traffic behind the motorcycle to a display system, providing an additional rear-view to that provided by rear-view mirrors. This technology may be helmet- or vehicle-based. Helmet-based systems incorporate both the camera and the display into the helmet itself. The camera is built into the helmet structure to avoid compromising the integrity of the helmet, and the visual display is projected to the top of the visor, above the frontward view of the road. This system does reduce some of the visual field, although it also removes the need to look away from the road ahead.

The manufacturers of Reevu, the only commercially helmet-mounted rear-view system that the authors are aware of, assert that after becoming familiar with the system, no conscious effort is needed to monitor the rear-view. Vehicle-based systems, such as that developed for Honda's ASV-3 motorcycle, mount the camera on the vehicle and have a video display on the instrumentation panel. Three cameras, including a rear-facing one, are mounted on the Yamaha ASV-2 Model 1 as part of their advanced driver assistance system. These systems are relevant to crashes from the same direction, particularly overtaking crashes.

Figures 7 and 8 Examples of views from Reevu's helmet-mounted rear-view system (Source: www.reevu.com)

3.1.20 Road Surface Condition Monitoring

Road surface condition monitors serve to alert the motorcyclist to abnormalities in the road surface ahead. Systems that monitor the road surface using video or laser scanning techniques can also be combined with ABS, collision avoidance and speed limiting systems to adjust vehicle speed to suit these conditions (Bishop, 2005). These systems may also employ a cooperative approach, where information from roadside beacons or other data collection points are transmitted to the vehicle, providing prior warning of changed road conditions. This information allows the rider and other ITS applications to adjust riding and vehicle behaviours appropriately.

As yet, surface monitoring is only an emerging technology in all vehicle types. While the conditions of the road surface are not often cited as causal factors in motorcycle crashes, slippery or uneven conditions may contribute to the severity of crashes.

3.1.21 Roll Stability

Such systems monitor the speed and vertical position of the motorcycle, and warn the rider if loss of control may occur. Rollover countermeasures have primarily been implemented in commercial vehicles, where the danger of rolling over on steep curves or exit ramps is high. The only stability warning system for motorcycles known at this point is the component of the Xtreme Beam system. As part of the detectors which sense whether the motorcycle has over-turned, the tilt sensors of this system provide warnings to the rider when the tilt of the motorcycle is too great when cornering.

There is a high instance of running-off road crashes on curves in motorcycles. Any system that addresses the balance of the motorcycle may have great potential safety benefits for this type of crash.

3.1.22 Speed Alerting/Limiting Systems

Speed alerting and limiting systems typically use the same principles to determine the actual speed of the vehicle compared to the appropriate or desired speed. The maximum speed may be absolute, manually or variably determined. Absolute measures are typically used in commercial vehicles, where the top speed of the vehicle is fixed at a certain point which cannot be over-ridden by the driver. Manually set systems can be changed or modified by the user, while variable systems adapt to the speed limit of a given area (as in ISA).

These systems take effect in one of two ways. Alerting systems simply warn the rider of that the speed currently being travelled is excessive. These warnings may be auditory or visual, and these warnings may increase in frequency or intensity if they are ignored. Speed limiting, or governing, systems take an active role in speeding prevention. When an excessive speed is reached, mechanisms within the vehicle prevent further acceleration. This can occur either through haptic feedback through the accelerator pedal with increased resistance, or via mechanical control of the fuel and electrical systems of the vehicle.

Speed alerters and limiters are emerging technologies, and have not yet been introduced to motorcycles. However, their potential to reduce speed related crashes may have an impact on almost all motorcycle crash types.

3.1.23 Vehicle Diagnostics

Vehicle diagnostic systems monitor the status and performance of various vehicle components and systems, and alert the user to potential malfunctions. While vehicle failure is rarely cited as a causal factor of motorcycle crashes, mechanisms that detect and alert the rider of potential problems will contribute to motorcycle safety. As suggested by one of the experts in the consultation process, these systems will be especially relevant to infrequent riders who may not regularly maintain their vehicle.

The Honda ASV-2 motorcycle contains one vehicle diagnostic system which utilises air pressure and temperature sensors integrated in the valve of the front and rear tyres. Information from these sensors is sent via radio waves to a vehicle-mounted display. The rider is informed when air pressure in either tyre changes, or if temperatures within the tyres become extreme. As far as the authors are aware, no other similar systems for motorcycles exist.

3.1.24 Vision Enhancement

Two types of vision enhancement systems exist. Passive systems detect the radiated energy from objects naturally in the environment. Active systems use illumination or scanning techniques for detection. The enhanced image of the environment is presented to the user via a heads-up display overlayed on the windscreen, or in the case of motorcycles, this may be a display on the console or a helmet-mounted display.

Poor visibility, due to either environmental factors or factors related to the rider, such as age, can greatly increase the risk or severity of crashes. The ability to detect changes in the road surface and geometry, as well as obstacles and other vehicles is essential to safe motorcycling. The system projects an improved or higher contrast view of the visual field during poor visibility conditions. Vision enhancement systems provide the rider with an improved view of the vehicles path.

Vision enhancement systems are an emerging ITS for both passenger vehicles and motorcycles. Poor visibility is rarely cited as a causal factor in motorcycle crashes. However, in Victoria between 2000 and 2004, 7.2% of crashes occurred in rainy conditions, and approximately one quarter of crashes occurred at night. Vision enhancement systems may reduce these figures.

3.1.25 Visibility Improving Helmet

Visibility improving helmets serve to prevent visual impairment due to fogging of the helmet shield, which may occur in cold and rainy conditions. Two kinds of visibility improving helmet exist. The first acts as a dehumidifier, streaming dehumidified air from a small cooling unit to the helmet. The second involves a double-layered shield with a hydrophilic property to create heated insulation within the shield.

Visibility improving helmets are an existing motorcycle-specific technology. However, their effectiveness, and the exact proportion of motorcycle crashes that are affected by the helmet visor fogging is unknown.

Diagrams of the dehumidifying and heating systems are available at http://www.its-australia.com.au/itslibrary/CONFERENCES/ITS_WORLD_CONGRESS_8th_SYDNEY_2001/ITS00226FUL.pdf.

3.2 PASSIVE IN VEHICLE ITS

3.2.1 Airbags

Airbags serve to reduce injury severity by absorbing the kinetic energy of the occupant when they are propelled forward in a crash. This is a passive system, in that it takes effect after a crash has occurred with the aim of minimising injury to the user. In the event of a motorcycle crash, the airbag is deployed, and acts to cushion the forward propulsion of the rider and prevent them from being thrown from the vehicle. The system comprises the airbag mounted on the front of the vehicle below the handlebars, and acceleration sensors and bump-sensors located on either side the front wheel system. Impact is detected by sensors in the front wheel, and the airbag is deployed. The sensors of the system are calibrated to deploy the airbag in collision situations only, not in other situations such as riding over potholes or curbs. To increase its stability, straps hold the airbag in place.

Traditionally, vehicle-mounted airbags have been implemented in cars and commercial vehicles. However Honda and Yamaha have recently developed and evaluated motorcycle airbags, initially at least for their Advanced Safety Vehicles. Honda has scheduled the release of vehicle-mounted airbags on one model in the US in mid-2006.

An issue that must be addressed in the design and evaluation of these airbag systems is that the position of the rider is not always upright (Takeshi, 2000). The rapid deployment of the airbag should not injure the rider if they are in a forward-leaning position. Also, the presence of a pillion passenger must be considered. The additional force from the passenger behind the rider may injure the rider, or, the passenger may be offered no protection from the airbag. Similarly, the development and evaluation of the system should consider that not all front impact crashes occur at 90 degrees to the other object.

Frontal-impact crashes with both other vehicles and objects on the roadway are a significant safety issue for motorcycles. Motorcycle airbags would serve to address the high prevalence of upper body injuries that occur as a result of front impacted crashes. In these crashes, the motorcyclist is usually thrown from the vehicle, and the injuries most often stem from impact with other objects or the ground. Airbag systems could reduce the likelihood of being thrown from the vehicle.

A diagram of this system components are available at http://www.world.honda.com/MotorcycleAirbag/operation/. Pictures of the system deploying in crash tests are available at http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv19/05-0316-O.pdf.

3.2.2 Airbag Jackets

A recent development in motorcycle safety is airbags built into a rider's jacket. These systems involve the same principles as vehicle-mounted airbags, where upon detection of a crash situation the airbag is automatically deployed to minimise injury to the rider. However, the mechanisms of airbag jackets are different to those of traditional airbags. Jacket airbags come into effect once the motorcyclist has been thrown from the vehicle, rather than trying to prevent this from occurring. The jacket is connected to the vehicle through a cable, and when this connection is severed (the force of the rider being thrown from the motorcycle uncouples a pin or key in the jacket) the airbag inflates. The rider will still hit the ground with the same force, but they will be protected with a cushion of air surrounding their upper body. Airbag jackets are inflated by a carbon dioxide cylinder built into the jacket, which is less flammable than the gases used to inflate vehicle-mounted airbags.

There are a number of commercially available airbag jackets. However, there is no existing independent evaluation of their effectiveness. Hit-Air conducted a shock-absorbing test on their airbag jacket, showing that this system was more effective than both a regular riding jacket and a jacket with additional padding.

Airbags jackets, like vehicle-mounted airbags, are passive systems which serve to reduce injury severity. In addition to front-impact crashes, airbag jackets could be effective in a range of loss of control or multiple vehicle crash where the rider is thrown from the vehicle.

Diagrams of the jacket at full inflation are available at http://www.airbagco.com/penetration.htm.

3.2.3 Automated Crash Notification System

Automatic crash notification (ACN) systems aim to reduce critical incident response times to crashes by automatically informing emergency services when and where the crash has occurred. Automatic crash notification uses input from the vehicle's ignition, acceleration, tilt and shock sensors to determine if the vehicle has crashed. Often ACN is linked to the vehicle’s airbag system, so that any crash severe enough to result in the airbag being deployed will also activate the ACN. Emergency services are automatically contacted and the location of the vehicle is provided by a GPS systems. If required, the system can be overridden by simply pressing a button. More advanced systems are able to inform the emergency services of the severity and nature of the crash, and speakers are provided so that the rider can communicate with the emergency services operator.

ACN systems are an emerging technology in both passenger vehicles and motorcycles. Preliminary testing of these systems in motorcycles has been carried out by the NRMA (Findlay & Morphett, 2003), although further tests of effectiveness in accurately detecting crashes and reducing response times are yet to be conducted.

Automated crash notification addresses three critical issues to motorcycling safety. First, as in all crashes, the more rapid the response of emergency services, the better the outcome for those involved. Second, motorcycle crashes frequently result in the motorcyclist being thrown from the vehicle, possibly rendering them unable to manually call for help. Third, a high proportion of motorcycle crashes are single vehicle, and around one third occur in rural regions of Victoria, such that if the motorcyclist is unable to call for aid themselves, there may be no-one else around to do so.

3.2.4 Crash Data Recorder; Black-Box Recorder; Event Data Recorders

Crash data recorders consist of a variety of vehicle system sensors and detectors to measures factors such as acceleration, location, pre-crash activity, time of crash, rollover and yaw data, braking activity and airbag deployment. While these serve only to provide post-crash information to investigators, they can improve safety by providing a better understanding of the factors contributing to motorcycle crashes, leading to better road and vehicle design, and improved motorcycle training. These devices have not yet been implemented in motorcycles.

3.2.5 Emergency Hazard Light; Continuous Strobe Light

Vehicle lighting systems that are activated in the event of a crash are a recent ITS development, and have only been implemented as part of a multi-faceted system that was developed for motorcycles in Australia and launched in 2002. This system, Xtreme Beam, consists of an emergency hazard light, a continuous strobe light to enhance rider conspicuity and an early crash warning system, which detects when the tilt of the motorcycle is greater than what is deemed to be safe. The sensors in the system activate emergency hazard light when a crash is deemed to have occurred, vastly improving the visibility of the injured motorcyclist to other road users and emergency services. The continuous illuminator in this system emits a constant flashing light that draws the attention to the motorcycle. It projects downward onto the road, so as to illuminate the outline of the vehicle, rather than distracting other road users.

The conspicuity enhancing effects of this system both pre and post crash could have significant effects in reducing crash occurrence, specifically failure to see crashes, and in reducing the severity of crashes by decreasing critical response time, particularly in rural and night time crashes where the vehicle may be difficult to locate.

Figure 9 Xtreme Beam mounted to rear (Source: Xtreme Beam, 2006).

3.2.6 Impact Sensing Cut-off Systems

These systems disable fuel and electrical systems to prevent the vehicle igniting after a crash has occurred. The system may involve crash sensors and fuel leakage detectors (i.e. vapour sensors). This is an emerging ITS in motorcycles, although fuel system cut-offs have been applied to some models of passenger vehicles. The incidence of motorcycles igniting post-crash is relatively low, although according to Hurt et al. (1981), fuel system leakage occurred in over half of motorcycle crashes in the US, presenting a potential fire hazard.

3.3 COMBINED ACTIVE AND PASSIVE SYSTEMS

3.3.1 Pre-crash System

Pre-crash systems come into effect when an inevitable crash has been detected. Sensors detect an eminent crash and prepare the vehicle and rider in order to either prevent or minimise the crash. For example, braking assistance systems may be pre-charged to minimise delays in braking, and the airbag system may be deployed.

Pre-crash systems have been introduced in some passenger vehicles, however, they have not yet been adapted to motorcycles, even in prototype form. They have the potential to decrease the severity of all types of motorcycle crashes by protecting the motorcyclist in the event of a crash.

3.4 ACTIVE OTHER VEHICLE ITS

3.4.1 Lane-Change Warnings

Failure to adequately check the roadway before merging or changing lanes is a common cause of motor vehicle crashes. The development of lane-change warnings for cars, buses and trucks has not been specifically aimed at improving the safety of motorcycles. However, they have potential to reduce failure to see crashes with motorcycles.

Lane change warning systems employ laser or radar sensors to monitor the space directly surrounding the vehicle, such as the blind spot. If another vehicle moves into this space, the driver is warned through either a visual or auditory warning. Some systems may also actively take control of the vehicle and steer away from the other object.

3.4.2 Motorcycle Detection System

Motorcycle detection systems can be seen as a simplified version of inter-vehicle communication systems. They serve to alert other drivers of the presence of the motorcycle, but do not provide the speed information that inter-vehicle communication does, nor do they necessarily transmit information about other vehicles to the motorcycle. The presence of the motorcycle is also transmitted and detected by a different method. The motorcycle emits a weak radio signal from a transmitter mounted on the vehicle. This signal is detected via receivers on the front and rear of the other vehicles, and the driver is informed of the motorcycle's presence and location through auditory and visual displays. Such systems may also be called vehicle proximity warning, and can be applied to emergency vehicles.

These systems are emerging technologies, where the concept has been adapted from advanced warning devices for emergency vehicles. Motorcycle detection systems specifically address other driver failure to see crashes. They may be less effective than inter-vehicle communication at improving motorcycle safety at intersections, However, head-on, rear-end, and side-swipe, crashes with other vehicles may be avoided with these systems.

3.5 PASSIVE OTHER VEHICLE ITS

3.5.1 External airbags

Airbags fitted externally to the front bumper and bonnet of passenger vehicles have been developed in order to increase pedestrian safety (Holding, Chinn, & Happain-Smith, 2001). If an impact with a pedestrian is determined to be likely by sensors located on the front of the vehicle, these airbags are deployed in order to absorb the kinetic energy of the pedestrian during the impact, minimising injury.

While this is an emerging technology designed for pedestrian safety, there may be potential motorcycle safety to be improved by external airbag systems in multiple-vehicle crashes. Whether these systems are robust enough to protect motorcyclists needs to be investigated.

3.5.2 Pop-up Bonnet

Pop-up bonnet systems increase the ‘crush’ space between the pedestrian or motorcyclists head and torso in the event of a pedestrian-vehicle crash. Upon deployment, the system pushes the bonnet upward creating a larger gap between the bonnet and engine beneath. This cushions some of the vulnerable road user’s kinetic energy, minimising injury. Alternatively, if the impact is with another vehicle, the system makes the bonnet more rigid.

These systems may involve bumper sensors, which detect a collision as contact is made with the front of the vehicle. Alternatively (and ideally), the system may involve sensors that detect the vulnerable road user before a collision has occurred. This allows more rapid activation of the system, ensuring the pop-up mechanisms have deployed and the bonnet has been stabilised before the pedestrian makes contact with the vehicle.

These systems are an emerging technology created to protect pedestrians rather than motorcyclists. Pop-up bonnets may be relevant to multiple vehicle crashes where the motorcycle is struck from the front of the passenger vehicle. However, it is essential that the system is sensitive enough to differentiate a motorcycle from other vehicles, as locking the bonnet in a motorcycle crash may actually increase the severity of injury to the motorcyclist.

3.5.3 Additional Other-vehicle ITS Systems

As already noted, any safety countermeasure introduced in another vehicle should reasonably be expected to enhance the safety of other road users. Therefore, many systems already described in this chapter in relation to motorcycles also show safety benefits to all road users, including motorcycles, when applied to other vehicles. Technologies that may be most relevance to the key safety issues of motorcycling when applied to other vehicles include collision warning and avoidance systems, adaptive headlights, inter-vehicle communication and vision enhancement systems, which all serve to increase the conspicuity of vulnerable road users to the driver. Implementing these technologies in other vehicles would reduce the occurrence of other-driver failure to see crashes.

3.6 INFRASTRUCTURE-BASED ITS

3.6.1 Animal Detection Systems

Two forms of infrastructure-based animal detection systems exist. The first relies on a beam between two sensors parallel to the road. An animal passing through this beam will interrupt this signal, and a visual warning is provided to drivers via beacons on the roadway. However, a limitation of this system is that the direction of movement of the animal cannot be determined. This may result in a high incidence of false alarms from animals exiting the roadway. A more advanced system monitors a given area with an infrared camera, and if a large animal is detected a visual warning is presented in the same manner as the previous system.

Animal detection systems are emerging technologies that are relevant to crashes involving animals, including both collisions with animals, and crashes that result from avoiding animals on the roadway.

3.6.2 Automated Enforcement

Enforcement technologies that are currently employed throughout Victoria include laser speed detectors, red light cameras and alcohol breath tests. Random roadside saliva tests for illicit drugs have recently been trialed, and there has been some movement toward the introduction of electronic licence plates on motorcycles as a means of detecting speeding and failures to stop at red lights.

3.6.3 Pedestrian Detection Systems

Pedestrian detection systems at signalised intersections involve sensors which detect the presence and speed of pedestrians at crosswalks. The duration of the 'walk' signal may be adjusted to accommodate slow-moving pedestrians. Pedestrian-vehicle crashes in urban areas could be reduced by pedestrian detection systems, which account for a small proportion of motorcycle crashes.

3.6.4 Variable Message Signs

Variable message signs can be used to convey a variety of information to road users, such as indications of traffic congestion, crashes ahead, upcoming road works, and weather conditions, and to vary and display the speed limit appropriate to these conditions. VMS are used to present information to all road users rather than one specific vehicle type. They may also be used in variable speed limit systems and weather information systems.

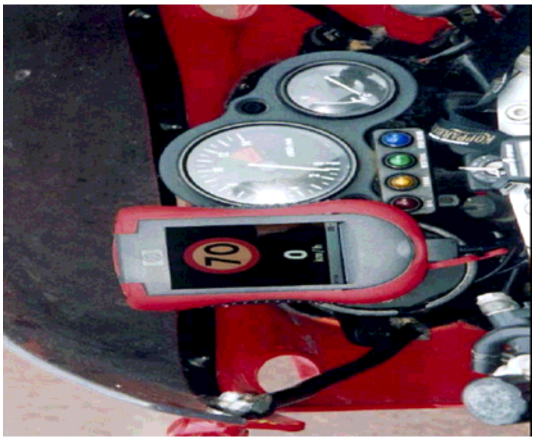
Given the stability issues associated with motorcycling, the potential benefits of VMS for motorcycles are high. The ability to convey information about upcoming hazards, such as poor weather, abnormalities in the road surface, traffic congestion, changes in speed limits and material on the road surface may reduce the incidence of loss of control crashes.

3.7 COOPERATIVE ITS

3.7.1 Intelligent Speed Adaptation; External Vehicle Speed Control

Intelligent speed adaptation (ISA) provides speed control assistance to the user. It is a co-operative technology, in that it involves, for perfect operation, both infrastructure and in-vehicle devices to maintain a legal speed limit within the vehicle. The appropriate speed limit for the area is transmitted to the vehicle either through beacons on the roadside or on-board digital maps. ISA may be limiting or alerting. Alerting, or passive, systems provide a visual or auditory warning to the user when the speed limit is exceeded. Limiting, or active, systems intervene to limit the vehicle speed to the speed limit or some other threshold, usually by increasing resistance in the accelerator or throttle control. This system can be overridden in emergencies. ISA can also be adapted to automatically adjust speed limits to suit high-congestion situations or poor weather conditions where lower speeds are safer. See Young, Regan and Haworth (2004) for a review.

As noted in the literature review and expert consultations, ISA in motorcycles is only an emerging technology in need of further development. However, ISA has the potential to reduce speed related crashes, which should be relevant to all types of singe and multiple vehicle crashes.



Figures 10 and 11 Examples of ISA on motorcycles (Source: SWECO).

3.7.2 Navigations Systems; Route Guidance Systems

Navigation systems provide dynamic and personalised travel information to the user, as well as the ability to plan and share travel routes. However, in motorcycles there are safety issues associated with the integration of the display into the vehicle. These systems may be either in-vehicle or employ a mobile device such as a PDA. On-board systems tend to be better integrated into the HMI. However, they are limited by the inflexibility of the data stored within the unit. That is, the information is not regularly updated as in mobile devices. Mobile device systems allow access to a wider range of information but do not have the same usability benefits as on-board systems (Mitterreiter, et al. 2005). Hybrid systems, which are integrated into the vehicle in a similar way to on-board systems and allow regular updating of information may serve to improve the safety of these units considerably. Information must be presented clearly without distracting the user or obscuring the view of the instrumentation panel of the motorcycle.

Navigation systems have been developed that can be fitted in any vehicle, and may include features such as helmet-mounted Bluetooth-enabled headsets. These systems often combine mobile phones, MP3 players, radios, traffic flow information and 'point-of interest' features. As additional safety features, these systems can notify the driver of school zones and traffic cameras.

As with advanced driver assistance systems, the effects on motorcycle safety of these units may not be direct. However, if the system is able to reduce the demands of the riding task, then improved user safety is a logical consequence. Navigation systems are especially useful to motorcycling, as riders often plan scenic leisure rides and are highly dependent on reliable weather information (Mitterreiter, et al., 2005).

CHAPTER 4 – PRIORITISED LIST OF ITS

1 INTRODUCTION

The purpose of this review was to estimate which Intelligent Transport Systems might be most beneficial in enhancing motorcycling safety. All ITS technologies known to the authors that have been, will be, or could reasonably be, adapted to the motorcycle have been reviewed in the previous chapters, and the relevance of each ITS to the various key safety issues has been discussed. In this chapter, an attempt is made to prioritise candidate systems considered to have the greatest potential to enhance motorcycle rider safety.

2 PRIORITISATION CRITERIA

In prioritising candidate ITS, there are many criteria that should be considered. These include the following:

Safety relevance: This refers to the extent to which the system addresses priority rider safety problems.

Effectiveness: This refers to the extent to which the system performs as intended by the designer of the system. This necessarily includes consideration of such issues as penetration rate, reliability, acceptability to riders, and rider adaptation to the system.

Availability: In determining which systems are most viable for motorcycles, the availability of the system should be considered. Systems which already exist, or at least exist in other vehicles, are able to be better assessed than emerging systems.

Cost: The cost of the ITS is an important factor in determining how easily it will be accepted and how quickly it will saturate the market.

Acceptability: Systems which are positively regarded by consumers will be more widely adopted by the population. Factors which contribute to acceptability include usefulness, ease of use, effectiveness, affordability and social acceptability (Regan, et al., 2002).

Reliability: The ability of a system to perform consistently over time and in a variety of conditions is essential to its overall effectiveness.

Technical maturity: Similar to availability, systems which have been in development for a greater period of time should be more robust and better evaluated than more recent ITS.

Adaptability to the motorcycle: Given the size and usability limitations of the motorcycle interface, any ITS must successfully address issues regarding ergonomics, physical size of the system, and interference with the riding process. Furthermore, the system must be robust to vibration and exposure to the weather.

Security: Consideration should also be given to the potential for theft from these systems. Retro-fit devices in particular may present a greater security risk.

Saturation within the market: Some systems depend on a high level of saturation within the market in order to be effective. For example, inter-vehicle communication will only be useful part of the time unless all vehicles use the system.

Table 2 contains a prioritised list of ITS, with those systems deemed to have the greatest safety relevance positioned higher on the list. This list has been constructed using safety as the sole evaluative criteria. The technologies above the first bold line are considered to be those that most directly address the key safety issues of motorcycling, namely multiple vehicle crashes, loss of control crashes (both on straight and curved roads), conspicuity, speed, and intoxicated and unlicensed riding. The remaining systems either address less immediate safety issues, or address these key safety issues in a less direct manner. The final two systems are passive ITS for other vehicles that show significant potential to enhance motorcycle safety. As the decision of what ITS to include on this list involved an element of professional judgement, an independent opinion from an Australian motorcycle safety research expert was also obtained. The systems deemed most safety relevant by this expert largely concurred with the crash data.

Table 2 Prioritised list of ITS for motorcycles.

System	Purpose	Safety benefits	Characteristics
Systems that are regarded to show direct safety benefits			
Electronic stability program	Maintain traction of the vehicle	Loss of control crashes, and off-path on curve crashes	Active In-vehicle
Linked braking systems **	Maximise braking force	Prevent frontal collisions and running off-road crashes	Active In-vehicle
Anti-lock brakes **	Prevent brakes locking	Most relevant to frontal and object collision crashes	Active In-vehicle
Brake assist *	Reduce stopping distances in emergency brakes	Most relevant to frontal and object collision crashes	Active In-vehicle
Intelligent speed adaptation *	Prevent the vehicle exceeding the speed limit	Prevent speed related crashes	Active Cooperative
Inter-vehicle communication *	Prevent other driver failure-to-see crashes	Multiple vehicle crashes, particularly at intersections	Active In-vehicle
Curve speed warnings *	Prevent excessive speeds on curves	Off-path, on curve crashes, which account for 17% of all motorcycle crashes	Active In-vehicle or infrastructure

System	Purpose	Safety benefits	Characteristics
Road surface monitoring	Warn riders of abnormalities in road surface	Reduce running off-road crashes	Active In-vehicle
Roll stability **[1]	Warn riders if tilt of motorcycle is too great	Off-path, on curve crashes, which account for 17% of all motorcycle crashes	Active In-vehicle
Daytime running lights **	Increase motorcycle conspicuity	All multiple vehicle crashes during daytime	Active In-vehicle
Automatic crash notification *	Automatically inform emergency services of vehicle's location in the event of a crash	Reduce emergency response times	Passive In-vehicle
Electronic licensing/ Smart cards **	Prevent unlicensed riding	Should reduce alcohol and speed related crashes	Active In-vehicle
Alcohol detection and interlock **	Prevent intoxicated riding	Any type of crash involving alcohol. 25% of fatal motorcycle crashes involve BAC over .05	Active In-vehicle
Airbag jackets **	Minimise injury to the rider when thrown from the vehicle	Relevant to any single or multiple vehicle crash where the rider is thrown from the vehicle	Passive In-vehicle
Airbags **	Prevent the rider being thrown from the vehicle in front-impact crashes	Frontal impact crashes with other vehicles and objects	Passive In-vehicle
Systems that are regarded to show indirect safety benefits			
Forward collision warning	Prevent motorcycle striking objects/ vehicles in path	Reduction of frontal impact crashes	Active In-vehicle
Adaptive front lighting *	Improve visibility of the road when cornering	Crashes occurring on curves at night or in poor visibility conditions.	Active In-vehicle
Object detection systems (animal, pedestrian etc.)	Warn driver of objects in path	Prevent collisions with objects on roadway	Active Infrastructure

System	Purpose	Safety benefits	Characteristics
Vehicle diagnostics *	Warn driver of vehicle system problems	Prevent loss of control crashes	Active In-vehicle
Advanced driver assistance *	Reduce rider workload	Prevent loss of control crashes	Active In-vehicle
Navigation systems **	Reduce rider workload	Prevent loss of control crashes	Active In-vehicle
Driver vigilance monitoring	Monitor alertness and fatigue in rider	Prevent loss of control crashes	Active In-vehicle
Emergency lighting systems *[1]	Illuminate vehicle after a crash has occurred	Reduce emergency response times	Passive In-vehicle
Helmet mounted display **	Minimise need for riders to take eyes off road	Loss of control crashes and potentially speed-related crashes	Active In-vehicle
Rear-view helmet **	Increase riders field of view	Prevent side-swipe and rear-end crashes	Active In-vehicle
Impact sensing cut-off systems	Prevent electrical and fuel systems igniting in a crash	Prevent minor injury crashes becoming serious or fatal	Passive In-vehicle
	Passive, other-vehicle ITS systems		
Pop-up bonnet systems	Cushion impact of upper body with car bonnet	Minimise injury in vulnerable road user collisions	Passive Other vehicle
External airbag	Cushion impact of rider with other vehicle	Minimise injury in vulnerable road user collisions	Passive Other vehicle

* Have been trialed in motorcycles
** Commercially available for motorcycles
[1] Commercially available as part of Xtreme Beam system only

The criterion used to rank the systems was safety relevance. In doing so it was assumed that the chosen systems would be effective in addressing the most important crash types and contributing factors. However, in the absence of actual data on the effectiveness of these systems it is not known how effective they will actually be in enhancing rider safety.

It was beyond the scope of this study to include consideration of the other criteria mentioned above. To do so would have required considerable additional research and consultation. The orders of priority are, therefore, speculative and tentative.

Based on the available data and the intended safety benefits of these ITS, a general picture of which systems may be most effective can be drawn. For example, the current list regards any system that enhances the stability, traction or braking properties of the motorcycle (ABS, ESP and linked braking systems) as the most promising. Any system which improves the performance of the motorcycle on curves or in emergency braking situations should show significant safety enhancing effects. These have been ranked higher than systems that specifically address one safety issue, such as speed (ISA) or on-curve crashes (curve speed warnings and roll stability), or motorcycle conspicuity (inter-vehicle communication, DRLs).

Active systems have generally been given higher priority than passive systems, as preventative technologies generally have a greater safety-enhancing effect. That being said, however, passive systems such as ACN and airbags remain important, as these are systems that will come into effect in any crash type. Systems which reduce risk exposure by reducing the incidence of intoxicated or unlicensed riding have also been regarded as priority ITS for motorcycle safety. As with passive ITS, these systems have the potential to reduce almost all crash types.

Technologies such as advanced driver assistance, navigation systems and helmet mounted displays were not designated as high priority systems as there is no available literature describing the effects of rider distraction on motorcycle safety. These systems serve to reduce the workload of the user – whether or not this will result in significant safety benefits for motorcyclists cannot be predicted.

Object detection and collision warning systems were not included in the top half of the list. This is because the extent to which crashes are a result of the motorcyclist failing to see the object, vehicle, animal or pedestrian ahead is unknown. Advanced braking systems, which are relevant to all types of collision crashes, were regarded as more beneficial to these types of crashes.

CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

1 INTRODUCTION

The current report was undertaken to inform VicRoads of Intelligent Transport Systems (ITS) that could reduce the incidence and/or severity of motorcycle casualty crashes. In order to do so, a number of activities were undertaken.

A comprehensive review of motorcycling safety issues was conducted. This encompassed crash statistics and research from both Australia and other developed nations, and considered the different crash patterns of serious injury and fatal crashes. Overall, it was found that running off-road crashes on both straight and curved sections of road were the most commonly occurring types of single-vehicle crashes; crashes involving vehicles travelling in opposing directions or intersection crashes were the most commonly occurring type of multiple vehicle crashes. Alcohol, speed and motorcycle conspicuity were consistently cited as either causal or contributing factors in motorcycle crashes.

Following this, a review of all known literature regarding ITS in motorcycles was undertaken. This review included any literature that reported the development or testing of an ITS technology in motorcycles, as well as any discussion of potential future applications and implementation issues of ITS in motorcycles. Very little literature was available for this review, highlighting the relatively small effort that appears to have gone into the research and development of ITS to enhance motorcycle safety.

Expert consultations were then conducted with ITS and motorcycling experts. Academics, manufacturers and industry leaders from both national and international organisations, were contacted via telephone and email, and in person. The purpose of these communications was to discuss and identify emerging ITS technologies for motorcycles that may not yet have been published. While few additional technologies were identified, this process proved invaluable in that the information provided by several of these contacts has not been, and most likely will not, be published. For example, several contacts within Europe have been involved in small trials of Intelligent Speed Adaptation (ISA) in motorcycles that had either been abandoned or undocumented. The expert consultations also highlighted that compared to the extensive research involving ITS for cars and commercial vehicles, research and development specific to ITS in motorcycles is relatively scarce.

The information gathered from the review of motorcycle safety, the review of ITS literature, and the additional information yielded from the expert consultations were then combined. All ITS technologies that had been identified as having the potential to enhance motorcycle safety were briefly described in terms of their functional and technical aspects, and their relevance to motorcycle safety.

The final step of this review was to create a list of all technologies identified, prioritised according to the potential for each to address critical crash problems. This chapter also included a discussion of other criteria that should be considered in the evaluation of the viability of ITS technologies in motorcycles.

2 CONCLUSIONS

On the basis of the material reviewed, there are 15 ITS that, in the opinion of the authors, have the greatest potential to address critical motorcycle crash problems. There are, in addition, other conclusions that can be drawn from this study.

- Very few ITS have been developed specifically for motorcycles, and all of those that do exist are in-vehicle systems.
- Some motorcycling groups have expressed concern about the potential for ITS technologies to automate aspects of the riding task or to compromise motorcycle rider safety. It is critical that the views of the motorcycling fraternity be properly researched and understood, and that this knowledge be used to inform the design and deployment of technologies which are acceptable to them. There have been no formal studies of the acceptance to riders of ITS in motorcycles.
- Of those systems that have been developed, very little evaluative data exists. Hence, the effectiveness of these systems in improving safety and user performance is as yet largely unknown.
- Many ITS exist or are emerging for other classes of vehicle that have potential to enhance motorcycle safety directly or indirectly.
- Whilst the types of fatal and injury crashes that motorcycles have are known, the causal factors which underlie these crashes are less well known, especially the role of human error.
- There is no known national strategy for the design, development, deployment and evaluation of ITS in motorcycles. Indeed, it is pertinent to note that Victoria's Vehicle Safety Strategy and Action Plan 2004-2007 makes no reference to motorcycles.
- Motorcycles pose particular problems when it comes to the technical adaptation of certain ITS systems, particularly those that have not been custom-designed for motorcycles.
- The bulk of research and development of ITS systems for motorcycles has been undertaken in Japan, largely as part of the national ASV program in that country.

The present work should be regarded as preliminary given the paucity of information currently available about the estimated and actual safety benefits of ITS technologies for motorcycles.

3 THE FUTURE

3.1 RESEARCH NEEDS

The following are regarded as immediate research needs deriving from this project.

- The views of the motorcycling fraternity must be properly researched and understood in order to inform the design and deployment of technologies which enhance safety and are acceptable to them.
- No attempt has been made to estimate the relative harm reductions associated with deployment of ITS in motorcycles. This is an important research priority.
- In-depth identification and prioritisation of motorcycle safety problems that are amenable to ITS intervention, which would serve to stimulate industry to develop ITS that address those problems is desirable (in addition to, as at present, identifying

existing and emerging technologies and searching for crash problems that they might solve). To do so requires a far better understanding of the causal factors that underlie motorcycle crashes and incidents, including human error.

- Establish the effectiveness of ITS technologies through the collection and evaluation of crash data, field operational testing and analytical modelling of estimated risk.
- Fundamental research on the effects on rider performance and behaviour of human-machine interaction with new technologies that deals with issues such as distraction, cognitive workload, over-reliance on technology, training requirements, situational awareness, and so on.
- Further research, development, and evaluation, of emerging systems which appear to have great potential to enhance safety, such as ISA, inter-vehicle communication etc.
- Research to determine the cost-benefits of deploying ITS relative to other countermeasures in addressing intractable rider safety problems. For example, research could be undertaken to determine whether rear-view displays are more effective than the optimal use of side mirrors.

3.2 GENERAL ISSUES

Conspicuous by its absence in the literature is any reference to the roles that key stakeholders, including governments, can play in facilitating the early deployment of ITS technologies for motorcycles which are capable of enhancing safety. The following are general recommendations that, if implemented, will optimise the potential for ITS to enhance motorcycle rider safety.

- There should be an Australian New Car Assessment Program (ANCAP) -equivalent system to encourage manufacturers to equip motorcycles with safety critical ITS.
- Like ITS technologies for other vehicles, there is a need to stimulate rider demand for systems that provide the greatest safety benefits.
- There is a need for the development of standards for the design of ITS technologies for motorcycles, as there is for the design of ITS technologies for other vehicles.
- Targeted research on specific safety technologies, particularly those with high estimated benefit-cost ratios requires funding and support.
- The effectiveness of ITS technologies, through the collection and evaluation of crash data, field operational testing and analytical modelling of estimated risk needs to be established.
- Demonstrate to riders that systems with high safety potential work and that there are no unintended or adverse consequences associated with their use.
- Leverage previous research and development, here and overseas, in facilitating the deployment of candidate systems.
- Facilitate the development and dissemination of system architectures and standards for the design, deployment and evaluation of future technologies.
- Provide infrastructure support for emerging cooperative and infrastructure-based systems.
- Introduce and support fiscal incentives to stimulate system demand, such as tax incentives, reductions in insurance premiums, reduced road user charges and access to parts of the road network at reduced cost.
- Provide an effective legal and regulatory framework to support system deployment and remove regulatory barriers

- Initiate and support cross-industry activities, such as the European "e-Safety" forum and its working groups, to harmonise system development and deployment.
- Ensure that new systems entering the market, both OEM (Original Equipment Manufacturers) and aftermarket products, do not distract or otherwise compromise rider safety in unintended ways.
- Promote an industry-wide approach to the development of standard tests and methods for evaluating new ITS safety technologies.

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APPENDIX A – LIST OF ALL ITS

System	Description	Emerging/ existing	Vehicle Type
In-vehicle - Active			
Adaptive cruise control	Monitors and maintains a safe time or distance headway with leading vehicles	Existing	Passenger & commercial
Adaptive front lighting	Improve the illumination of the vehicles path on curves by altering the direction of light beam	Existing	All
Advanced driver assistance	Employ a range of telematics and vehicle control systems to reduce driver workload and error	Emerging	All
Alcohol detection and interlock	Disable vehicle's ignition if alcohol is detected in the breath of the user	Existing	Passenger & commercial
Animal detection systems	Detect and alert the user to animals on the roadway	Emerging	All
Anti-lock braking systems	Provide smooth and even braking pressure to all wheels, and prevent the wheels from locking	Existing	All
Automated headlights	Headlights are automatically turned on in low ambient lighting	Existing	Passenger & commercial
Automated windscreen wipers	Windscreen wipers are automatically turned on when rain is detected on windshield	Existing	Passenger & commercial
Brake assist	Applies maximum braking pressure in emergence stops	Existing	Passenger & commercial
Continuous strobe lighting	Provide a continuous flashing light which illuminates the vehicle to other road users	Existing	Motorcycle
Daytime running lights	Low-luminance front-mounted lights, automatically activated when headlights are not turned on	Existing	All

System	Description	Emerging/ existing	Vehicle Type
Driver vigilance monitoring	Monitor vehicle/user behaviour and/or physiology provide alerts or intervene if the user is fatigued or inattentive	Emerging	Passenger & commercial
Drowsiness relieving system	Provide alerts such as tones, haptic feedback or fragrance if users is fatigued or inattentive	Emerging	Passenger & commercial
Electronic licensing	Disable ignition unless licensed user is identified	Emerging	All
Electronic stability program	Detects loss of control of vehicle and intervenes on each wheel to maintain trajectory	Existing	Passenger & commercial
Emergency brake advisory systems	Activate rear brake lights when the accelerator is rapidly released	Emerging	Passenger & commercial
Fleet management systems			
Automatic vehicle location	Continuous tracking of fleet	Existing	Commercial
Cargo monitoring systems	Monitor the position of cargo and alert the driver to problems	Existing	Commercial
Digital tachographs	Record vehicle speed, distance and time of journey	Emerging	Commercial
Electronic towbar	Automated following vehicles in a convey, where only first vehicle has a driver	Emerging	Commercial
Following distance warning	Alerts user when headway with leading vehicle is too short	Existing	Passenger & commercial
Forward collision warning	Alert user when an object has been detected ahead on the roadway that is slower than the user's vehicle	Existing	Passenger & commercial
Heads-up display	Projects a display of vehicle information onto the windshield	Emerging	Passenger & commercial
Helmet-mounted display	Projects a display of vehicle information onto the visor of the helmet	Existing	Motorcycle

System	Description	Emerging/ existing	Vehicle Type
Inter-vehicle communication systems	Vehicles communicate their speed, direction, location and vehicle type and this information is displayed to the user	Emerging	All
In-vehicle tutoring systems	Provide feedback to the user regarding vehicle performance	Emerging	All
Lane keeping assistance	Monitor the vehicle's lateral position, and either alert or intervene when the vehicle deviates from the lane	Existing	Passenger & commercial
Lane changing collision avoidance	Monitor the vehicle's blind spot and provide alerts when vehicles are located in this area	Existing	Passenger & commercial
Linked braking systems	Apply braking pressure to both wheels even when only one brake is engaged by the user	Existing	Motorcycles
Motorcycle detection system	Motorcycles transmit the speed and location to other vehicles, alerting other drivers when motorcycles are in close proximity	Emerging	Passenger & commercial
Pedestrian detection systems	Detect and alert the user to pedestrians on the roadway	Emerging	All
Rear-view display	Displays real-time images of the road environment direction behind	Existing	Motorcycles
Reverse collision warning system	Detect and alert the user to the proximity of objects directly behind the vehicle when reversing	Existing	Passenger & commercial
Road surface condition monitoring	Monitor the road surface ahead and alert the user of abnormalities, material or fluids on the road surface	Emerging	All
Seatbelt reminder and interlock	Detects the presence of occupants and disables the ignition if seatbelts are not in use	Existing	Passenger & commercial
Speed alerting and limiting systems	Alert the user or inhibit further acceleration when a pre-set limit is exceeded	Existing	Passenger & commercial

System	Description	Emerging/ existing	Vehicle Type
Traction control	Provides greater control when accelerating by applying braking pressure or altering the fuel or power supply	Existing	All
Vehicle diagnostic systems			
Tyre pressure monitoring	Monitor the temperature and pressure of the tyres and alert user to potential problems	Existing	All
Visibility improving helmet	Prevent fogging of the motorcycle helmet visor through heating or dehumidifying systems	Existing	Motorcycles
Vision enhancement	Provide a high contrast image of the road and road environment during low luminance or poor visibility conditions	Emerging	Passenger & commercial
In-vehicle - Passive			
Active head restraints	Adjusts the headrest into a more upright and forward position in the event of a crash in order to prevent/minimise whiplash injury	Existing	Passenger & commercial
Airbag jackets	Airbags within the jacket inflate when the rider is thrown from the vehicle	Existing	Motorcycles
Airbag systems			
Airbags	Deploy upon detection of crash that exceeds a predetermined intensity level	Existing	All
Inflatable carpet	Airbag system located in the floor of the vehicle, under the pedals	Emerging	Passenger & commercial
Inflatable curtain	Airbag system located on the upper side of the vehicle to protect the head	Existing	Passenger & commercial
Knee airbags	Airbag system located in front of the knees	Existing	Passenger & commercial

System	Description	Emerging/ existing	Vehicle Type
Seat positioning sensor	Detect the position of the seat and accordingly adjust the inflation of the airbag	Emerging	Passenger & commercial
Weight/pattern recognition sensors	Determine whether an occupant is an adult or child, and accordingly adjust the inflation of the airbag	Emerging	Passenger & commercial
Anti-submarining seat	Airbags within the seat inflate during impact to prevent the occupant slipping forward	Emerging	Passenger & commercial
Anti-whip lash seats	Rearward motion of the backrest during a crash to absorb energy	Existing	Passenger & commercial
Automatic rollbars for convertibles	Retractable roll bars are activated in the event of a roll-over, protecting rear-seat occupants	Existing	Convertibles only
Emergency lighting systems	Illuminate the vehicle post-crash	Existing	All
External airbags	Airbags mounted externally to the front bumper and bonnet inflate upon collision with a pedestrian	Emerging	Passenger & commercial
Impact sensing cut-off systems	Disable electrical and/or fuel systems post-crash	Emerging	All
Impact-sensing door unlock	Unlock vehicle's doors upon detection of a crash	Emerging	Passenger & commercial
Pop-up bonnet systems	Rear of vehicle's bonnet is pushed upward upon collision with pedestrian to create a cushioning space between the bonnet and engine block	Emerging	Passenger
Seatbelt pre-tensioners	Reduce slack in the seatbelt upon detection of a crash	Existing	Passenger & commercial
Seatbelt load limiters	Gradually loosens seatbelt (after pre-tensioned) when the seatbelt is loaded during a crash	Existing	Passenger & commercial

System	Description	Emerging/ existing	Vehicle Type
In-vehicle – Combined Active and Passive Systems			
Pre-crash systems	Determine when a crash is eminent and prime passive safety systems	Emerging	All
Infrastructure - Active			
Animal detection systems	Detect animals on the roadway and alert road users to their presence via signs on the roadway	Emerging	
Pedestrian detection systems	Detect slow moving pedestrians on crossings and adjust signal timing to accommodate walking speed	Emerging	
Speed feedback indicators	Measure vehicles speed and display this next to the actual speed limit via roadside signs	Existing	
Traffic control systems	Systems that improve the flow of traffic, including automated tolling, ramp control, signal control and probe vehicles	Emerging	
Vehicle warning systems	Warn road user if vehicle speed or height/width is too great for the conditions via roadside signs	Emerging	
Variable message signs	Display dynamic information to road users via roadside signs	Existing	
Variable speed limits	Changes in speed limits to suit traffic or environmental conditions are delivered via roadside signs	Existing	
Weather information systems	Deliver weather-related information to road users, via roadside signs, dedicated radio channels or in-vehicle information systems	Existing	
Infrastructure - Passive			
Incident management systems	Systems that aid in the detection, management and clearing of incidents	Emerging	

System	Description	Emerging/ existing	Vehicle Type
Infrastructure – Combined Active and Passive Systems			
Cooperative - Active			
Curve speed warning	Information or warnings regarding the speed or geometry of a curve ahead is delivered by a on-board unit and GPS system	Emerging	
Navigation systems	Deliver information regarding vehicles position and intended path via a GPS or satellite system and on-board unit	Existing	
Intelligent speed adaptation	Alert or limit the speed of the vehicle according to the posted speed limit, using roadside beacons or GPS systems to determine this speed	Emerging	
Intersection collision avoidance	Vehicles approaching an intersection communicate their speed and direction with roadside beacons, which alert other vehicles of their position	Emerging	
Vehicle pre-emption systems	Sensors within traffic signals detect approaching emergency vehicles or public transport and alter the signal pattern to give these vehicles priority	Emerging	

APPENDIX B – ORGANISATIONS/GROUPS CONTACTED DURING EXPERT CONSULATIONS

Country	Organisation	Other
America	Bishop Consulting	
Australia	Australian Transport Bureau	
Australia	ITS Australia	
Australia	Department for Transport, Energy & Infrastructure	Government 2 individuals contacted
Australia	National Transport Commission	
Australia	Australian Arrow Pty Ltd	
Australia	Xenon Technologies Ltd	
Australia	NRMA	2 individuals contacted
Austria	KfV - Austrian Road Safety Board	Government
Australia	Centre for Accident Research & Road Safety	Research
Belgium	University of Gent	2 individuals contacted
Belgium	Belgacom	Telecommunications company
Denmark	BMW	
Europe	ACEM – Association des Constructeurs Européens de Motocycle	“The Motorcycle Industry in Europe”
France	INRETS – Institut National de Recherche sur les Transports et Leur Sécurité	“French National Institute for Transport Safety & Research”
Holland	TNO	Research 3 individuals contacted
Japan	National Institute of Advanced Industrial Science & Technology	Government
Japan	Honda Research & Development	

Country	Organisation	Other
Sweden	Swedish Road Administration	Government
		2 individuals contacted
Sweden	SWECO	Research
		4 individuals contacted
Sweden	Volvo	
Sweden	IMITA	
United Kingdom	British Motorcycling Association	
United Kingdom	Traffic Technology International	Publication
United Kingdom	Reevu	Manufacturer

Also:

- ITS Australia members mailing list (approximately 70 members)
- SCI3 mailing list (approximately 400 members)
- Surface Transportation Technical Group Human Factors and Ergonomics Society Mailing List (approximately 320 members)