INTELLIGENT TRANSPORT SYSTEMS AND MOTORCYCLE SAFETY

Megan Bayly
Simon Hosking
Michael Regan
Monash University Accident Research Centre
Australia
Paper number 07-0301

ABSTRACT

In comparison to the widespread advancement of safety-enhancing technologies for passenger vehicles, there has been only limited development of Intelligent Transport Systems (ITS) for motorcycles. Considering the international over-representation of motorcyclists in crash statistics, in particular, the high incidence of loss of control crashes and multiple-vehicle crashes and the critical issue of motorcycle conspicuity, it would appear that the development of ITS for motorcycles should be given greater priority. The current review aimed to investigate the extent to which ITS have been applied to motorcycles (including both existing and emerging technologies) and discuss these ITS according to their likely safety benefits to motorcycle safety. A literature review and expert consultations confirmed that very few motorcycle-specific ITS currently exist, with advanced braking systems a notable exception, although a number of prototype systems have been developed. The potential to adapt emerging and existing ITS for other vehicles to motorcycles is also highlighted. Technologies that were seen to enhance the stability and braking power of motorcycles have been regarded with highest priority as these are most likely to be relevant to almost all motorcycle crash types, particularly loss of control crashes. Future motorcycle ITS developments must be safety-driven, but also consider issues such as acceptability. Evaluative studies of existing and emerging systems are a critical next step.

INTRODUCTION

This review was conducted in recognition of the lack of Intelligent Transport System (ITS) developments for motorcycles. There are numerous safety enhancing technologies for passenger and commercial vehicles, however, motorcycles to this point have been largely overlooked by both ITS and vehicle manufacturers. This is despite estimates that system-wide deployment of ITS would reduce crashes by up to 50% (e.g., [1 2 3]). The demonstrated safety advantages of ITS for passenger and commercial vehicles (e.g., [4 5 6 7 8]) suggests that ITS for motorcycles could also have important implications for reducing motorcycle crashes. The aim of this review was to provide a snapshot of the technological research and development currently being undertaken with regard to ITS and motorcycle safety. In addition, advancements in ITS for other vehicle domains have been considered for their potential to be adapted to motorcycles. This paper provides an overview of a range of in-vehicle ITS that may be implemented in the motorcycling domain, and that address those crashes that are typical for motorcycle riders.

ITS has been classified both in terms of the location of the system, and the time at which it takes effect. System location classifications of ITS are: (i) in-vehicle-based, (ii) infrastructure-based, and (iii) cooperative systems that integrate in-vehicle and infrastructure-based technologies and allow vehicle-vehicle or vehicle-environment interactions. An alternative and complementary ITS classification differentiates the time at which the system takes effect. Active systems are crash avoidance technologies that serve to prevent a crash from occurring, either through constant support to the user, or intervention in an emergency situation. Passive systems are crash mitigation systems that serve to reduce the effects of the crash once it has occurred or is occurring. Combined active and passive systems (CAPS) combine both these functions. While numerous types of ITS exist that may enhance different aspects of the road user's experience (e.g., in-vehicle information systems), only ITS which are designed to enhance the safety of vehicle occupants are reviewed in this paper. Furthermore, since infrastructure-based ITS have potential benefits for all road users and there are no infrastructure-based ITS developed specifically for motorcyclists, only emerging and existing in-vehicle and cooperative ITS will be reviewed.

In order to appreciate which ITS would be most beneficial for motorcycles, an understanding of the critical safety issues relevant to motorcycling is needed, as motorcycle crashes tend to show different characteristics to other vehicle types. The over-representation of motorcyclists in crash statistics is an international problem that is reflected in Australian crash statistics. Australian motorcyclists are three times more likely to be involved in a casualty crash than car drivers [9] and comprised 14% of the national road toll in 2005 [10]. The overrepresentation of these crashes is evident in that only 3% of registered vehicles in the Australian vehicle fleet were motorcycles [9].

Multiple-vehicle crashes (head-on, side-swipe, failing to give-way) and loss of control crashes on both straight and curved sections of road are dominant types of fatal and serious injury motorcycle crashes. It has been found that up to 75% of all motorcycle crashes involve other vehicles [11]. The MAIDS study [12] reported 60% of all motorcycle crashes involved passenger cars, and that 41.3% of US motorcycle crashes are run off-road, while approximately 10% involved head-on crashes with other vehicles [13]. It has also been repeatedly shown that rider error is a significant crash factor [11 12 13], that alcohol is a factor in 25-53% of crashes, and that unlicensed riders are involved in significantly more crashes than licensed riders [11 12]. A common attribute of multiple vehicle crash causation is conspicuity, where the driver of the other vehicle claims not to have seen the motorcycle [11 12]. This may be due to driver inattention, temporary obstruction of the view of the motorcyclist, or low conspicuity of the motorcycle. Other factors, such as poor weather, poor visibility and poor road surface conditions have rarely found to be causal factors in motorcycle crashes, and collisions with pedestrians and animals comprise relatively small proportions of crashes [11 12].

While these key safety issues may show patterns unique to motorcycling, there is potential for ITS developed for other vehicles to also address these issues. ITS currently exist that may address motorcycle crashes both in terms of crash prevention and harm minimisation. The extent to which this has already occurred will be reviewed in the following sections.

THE STATE OF DEVELOPMENT OF ITS SYSTEMS FOR MOTORCYCLES

The lack of ITS-specific applications for motorcycles has not gone unnoticed in both the fields of motorcycling safety and ITS research and development. While vulnerable road users are often considered in the ITS literature (e.g.,[14]), widespread applications of ITS to motorcycling safety have not yet occurred despite the clear need and potential for such safety countermeasures [15 16 17]. Motorcycling safety bodies have also called for ITS developments and criticised the lack of consideration given to motorcycles in the ITS field [18]. The potential for inter-vehicle communication systems to address motorcycle conspicuity issues has been previously recognised [12], and stimulation of development of conspicuity enhancing technologies such as daytime running lights (DRLs), and advanced braking systems such as anti-lock braking systems (ABS) and linked braking systems, have been encouraged [19].

One of the first discussions of the potential for ITS adaptation to motorcycles postulated that while ITS have been developed for passenger vehicles, this does not preclude their modification for other vehicle types [15]. ABS, blind spot warning systems, advanced lighting systems, intersection collision monitoring, and driver (rider) monitoring, among others, were identified as existing ITS for other vehicles that could practically and usefully be adapted to motorcycles [15]. Furthermore, systems such as adaptive cruise control, traction warnings, weather warnings, vision enhancement, rider monitoring, and curve speed warnings could also be applied to the motorcycling domain[20]. The notion of ITS for collision avoidance and stability enhancement in motorcycles has also previously been highlighted [17].

The forerunners of most ITS developments of motorcycles stem from Japan's Advanced Safety Vehicle (ASV) initiative. The ASV program is concerned with the development of technologies for crash avoidance and crash minimisation. Several motorcycle manufacturers participating in this research program have developed a number of prototype in-vehicle systems. Areas of focus for these projects have included driver inattention, rear-end collisions and passive safety [21].

In summary, there is potential for ITS for motorcycles to address issues such as conspicuity and vehicle handling, and multiple vehicle collisions. As already noted, the vast majority of ITS developments to date have focused on car safety and, to a lesser extent, heavy vehicle safety. Very few motorcycle-specific ITS have been developed, although active research programs are beginning to address this. However, as seen with recent trials of ISA on motorcycles conducted in Sweden (by SWECO and IMITA) and in the United Kingdom by MIRA [22], there is potential for existing in-vehicle ITS to be adapted to motorcycles.

EXISTING AND EMERGING ITS FOR MOTORCYCLES

In this section the various ITS that may be applied to the motorcycling domain will be reviewed. The following section provides a brief description of existing and emerging ITS for all vehicle types that show potential to address the safety issues already highlighted. Each ITS has been categorised nominally according to function. A functional overview of each system is provided, with a description of the state of development of these systems, for example, whether it is commercially available, or in prototype stage. Foreseen or known issues associated these systems are also identified. It should be noted that the information provided in this review is based on an extensive search of the literature and consultation with international industry experts in motorcycling and ITS, which formed the basis of an earlier report [23]. However, it is quite possible that some emerging ITS for motorcycles have not been reviewed here if such information has not been made publicly available.

Active Safety ITS

Crash Avoidance ITS

Crash avoidance ITS are active systems that alert the rider to potential hazards in the road environment and/or dangerous riding behaviours. *Collision warning systems* are designed to detect potential hazards on the road using radar, laser, or infrared to monitor the frontal, rear and/or lateral roadway. Feedback is provided to the user when a hazard is detected. Some systems may also activate an automated collision avoidance function. The latter typically involve system intervention of steering and/or braking functions, and therefore adaptation of this function to motorcycles could be problematic. *Following distance warning systems* combine the information from forward-facing infrared cameras or radars with acceleration sensors to determine the time or distance headway to the leading vehicle, and alert the driver if some minimum headway threshold is reached. *Inter-vehicle communication* is a cooperative ITS that utilises GPS technology to communicate between vehicles. Information regarding location, direction and vehicle speed is transmitted between vehicles, allowing advanced warning of other approaching vehicles. Infrastructure-based versions of inter-vehicle communications systems, termed *intersection collision avoidance*, are also emerging. *Lane departure warning systems* monitor the lateral position of the vehicle in relation to the lane edges with radar, infrared cameras, or similar detection hardware. If the vehicle is about to depart the lane, the departure warning system provides visual, auditory or tactile feedback to the user. *Lane keeping systems* utilise similar functions, and additionally apply steering force that prevents the vehicle from drifting further, which again may not be suitable for motorcycles. *Pre-crash systems* combine the active and passive collision avoidance technologies described above (CAPS systems). For example, potential collisions activate the pre-crash system that in turn primes other vehicle systems, such as advanced braking systems or passive ITS in order to minimise the effects of the crash.

Crash avoidance ITS have not been widely developed for motorcycles. However, some of these systems have clear potential for improving motorcycle safety and can be implemented without affecting the rider's control over the motorcycle. While collision warning systems are not commercially available for motorcycles, Yamaha's ASV-2 prototype vehicle includes such a system. Similar technologies that detect animals and pedestrians are currently being developed for passenger vehicles that may also apply to the motorcycling domain. The benefits of these latter systems for motorcycle use may be limited given that pedestrian and animal crashes comprise relatively small proportions of motorcycle crashes [11 12]. Inter-vehicle communication systems may prove very important for preventing the larger proportion of motorcycle-related multiple vehicle crashes occurring in urban areas [12], in particular crashes occurring at intersections where the visual conspicuity of motorcycle riders and driver's inattention to approaching motorcycles are often factors [24]. It should be noted, however, that these systems require a large proportion of the vehicle fleet to have adapted this technology in order for it to have notable impact on crashes.

Following distance warning systems, lane keeping/departure warning systems, and pre-crash systems that link ABS with forward collision sensors, while commercially available on four-wheeled vehicles, have not yet been developed for motorcycles. Implementation of systems that include automation or intervention of vehicle functions would be problematic unless reliable steering and braking control systems were developed, and even then there may be low acceptability by motorcycle riders, who have been shown to ride motorcycles for reasons other than just transportation [25]. Furthermore, the potential positive effects of lane keeping and lane departure warning systems on reducing run-off-road crashes may attenuate if such systems do not take into account purposeful changes in lane position such as when the motorcycle splits lanes.

Stability and Braking Enhancing ITS

Numerous ITS exist that serve to increase the braking potential of vehicles. One common such system is *anti-lock brakes,* which controls and optimises the braking performance of the vehicle and prevents wheels from locking under forceful braking events. ABS monitors the rotation of the wheels, and regulates braking pressure should they begin to lock. Contact between the wheels and the road is maximised, and the stability and path of the vehicle is maintained. Another system which similarly maximises the braking potential of the vehicle in emergency situations is *brake assist.* Brake assist serves to reduce the stopping distances of the vehicle. Forceful braking pressure is detected, and the system applies additional hydraulic pressure to the brakes. Brake assist has been developed in recognition that maximum braking pressure is rarely achieved in emergency situations. This may be especially true of motorcycles, where the independent nature of the front and rear brakes means they are not always optimally applied. *Linked braking systems* aim to counteract the potential of non-optimum motorcycle braking behaviour by applying dual braking pressure (i.e. from both brakes) even when only one brake is applied.

Other systems address the stability characteristics of the vehicle. *Roll stability systems* monitor the yaw rate and speed of the vehicle, and the rider is warned if a critical threshold of tilt has been breached. Up to one-third of crashes have been found to occur on curves [12], and roll stability systems for motorcycles may at least partially address this. *Electronic stability control* (ESC) detects wheel traction, lateral acceleration, yaw rate, steering wheel position and speed and determines whether the actual course of the vehicle is the same as the driver's intended course. If there is a discrepancy, ESC applies individual braking pressure to the wheels to correct the vehicles trajectory.

Although ESC is commercially available for passenger vehicles under numerous product names, stability enhancing ITS are less advanced in terms of development for motorcycles. In fact, whether such as system would be feasibly adapted to a two-wheeled vehicle is questionable due to the unique stability and braking characteristics of two wheel vehicles. However, given that this review has attempted to encompass all ITS that may potentially address motorcycles safety issues, of which stability (in loss of control crashes) is a key factor, ESC can justifiably be included here. Furthermore, ESC in other vehicles has been associated with single-vehicle crash reductions of up to 67% (e.g., [26 27 28]). Roll-stability systems for motorcycles are more advanced. While this technology has largely been developed for commercial vehicles and SUV's, tilt sensors are commercially available for motorcycles.

Advanced braking systems are a leading area of ITS developments for motorcycles, and much of the braking technology reviewed here already exists for motorcycles. Loss-of-control crashes may be significantly reduced with ABS for motorcycles. Until recently, however, surprisingly little implementation of ABS in motorcycles had occurred [29] despite ABS for cars and light trucks being available for many years, and numerous discussions in the literature of the potential benefits of ABS for motorcycles (e.g., [12 15]). A notable exception is developments in ABS and other advanced braking systems from Honda. The only application as yet of brake assist to motorcycles has been to Yamaha's ASV-2 Model 1. Linked braking systems are a better-established ITS. These systems may be combined with brake assist or ABS (as in Honda's advanced braking systems). Evaluative studies of implemented advanced braking systems for motorcycles are not publicly available.

Visibility-enhancing Systems

Advanced lighting systems should serve two benefits to motorcyclists. First, they may address the unique safety issue of conspicuity of motorcycles to other road users. Second, they may provide better illumination of the road environment for motorcycle riders. Serving the former function, *daytime running lights* provide a constant frontal light whenever the vehicle is in operation, typically employing an existing headlight at around 80% of its normal luminance. Traditional fixed headlights tend to illuminate the shoulder of the road when cornering rather than the intended path of the vehicle. Motorcycle DRLs have been associated with considerable reductions in daytime crashes in several Asian countries (e.g., [30 31 32]). *Adaptive front lighting,* or *active headlights,* use input from vehicle speed and angular velocity sensors to adjust the angle of the headlight when cornering. A rotating mechanism in the headlight maintains a parallel angle with the road at all times, maximising illumination of the road at night [33]. There is potential for this system to both enhance the conspicuity of the motorcycle to other vehicles while cornering, as well as the primary aim of improving the visibility of the riding environment. Therefore, adaptive front lighting may address the significant safety issues of conspicuity and crashes occurring on curves, at least at night-time. *Vision enhancement systems* provide an augmented view of the road environment. These may employ radar, laser or infrared imaging to detect objects on the road, and overlay this enhanced image on the windshield of the vehicle, and potentially the visor of the rider (see helmet mounted displays in the next section). These systems enhance the riders' functional viewing distance and increases the contrast of objects in poor visibility conditions such as at night-time or in fog.

DRLs are a technically mature ITS, are a standard feature on many motorcycles, and have been made mandatory in a number of jurisdictions. DRLs are widely considered an effective and economical vehicle safety technology [34]. There is debate whether daytime DRLs should be classified as ITS. However, given that DRLs are conspicuity-enhancing in-vehicle technologies with well-demonstrated safety enhancing effects, they have been included in this review. Adaptive front lighting is a less technically mature ITS, although such as system was implemented on Yamaha's ASV-2 Model 1. Vision enhancement systems are an emerging technology for all vehicle types.

Advanced Driver Assistance Systems

Advanced driver assistance systems (ADAS) serve to provide additional information available to the user, and/or present integrated information from various warning ITS and the vehicle instrumentation panel. Additionally, numerous systems exist that address specific elements of the driving task. For example, *curve speed warnings* indicate to the rider that the current speed is inappropriate for upcoming changes in the road geometry. Such information is discerned cooperatively, through roadside beacons or GPS systems. *Road surface monitoring systems continuously* uses laser, radar, and/or video imaging to screen the road surface for abnormalities, such as debris, ice or potholes. The system may be used to either provide additional information to the rider, or integrate with advanced braking or collision avoidance systems to increase stopping distances and headways to suit the road conditions [35]. *Helmet-mounted* displays project vehicle information onto the rider onto an area of the helmet visor. These systems serve to eliminate the need for the rider to take their eyes of the road to view vehicle information, such as speed and RPM. The display is projected at a similar focal distance as the roadway, so that the rider does not need to re-focus while viewing the information. However, the extent to which driver inattention or distraction resulting from looking at the vehicle's instrumentation panels is a crash factor is largely unknown at this stage. *Rear-view displays* provide the user a view of the roadway behind the vehicle. Rear-facing cameras continuously capture the road environment, and display this information either on visual interfaces within the vehicle, or on the upper area of the helmet visor. Such systems may help prevent multiple-vehicle crashes, such as rear-end or side-swipe crashes, although it is worth noting these have not been identified as leading motorcycle crash types. *Intelligent speed adaptation (ISA)* provides speed control to the user. Speed zones are transmitted cooperatively to the vehicle, and the system either passively alerts the user when excessive speeding occurs, or in intervening systems, prevents the driver from exceeding the speed limit. In passenger vehicles, this may be in the form of upward pressure on the accelerator pedal.

An ADAS 'rider support system' introduced on the Yamaha ASV-2 incorporates information from the forward collision warning system, curve speed warning system, speedometer, and navigation system, and conveys this information on a visual display on the console and via an earpiece worn by the rider. Integrated systems such as this are not specific to particular crash types, but serve to reduce rider workload and enhance the information available to the rider and are therefore expected to indirectly enhance motorcycle safety. Curve speed warnings are in an initial stage of development. Similar infrastructure-based systems for commercial vehicles currently exist, however, the only in-vehicle application of such technology to motorcycles known to date has been in Yamaha's ASV-2. Several types of commercially available visual display systems for motorcycles currently exist and are relatively advanced. Existing helmet-mounted display systems project information such as speed, fuel levels, RPM, and gear position to the rider's visor. Road surface monitoring technology is emerging in all vehicle types, and may serve to reduce loss of control crashes, although road surface conditions are rarely cited as key factors in motorcycle crashes [11 12]. While ISA for motorcycles has been tested in a number of European trials, no formal reports of these investigations are currently available. However, it was communicated to the authors that the different acceleration and deceleration patterns of motorcycles compared to other vehicles, as well as technical considerations such as throttle resistance as feedback and vibration from the motorcycle must be addressed.

Therefore, adaptation of ISA is at a formative stage. Notably, it has been shown that motorcycle accidents are not often characterised by excessive speed [12].

Driver Management/Monitoring Systems

Driver management/monitoring systems restrict or monitor the vehicle operator and may prevent an individual from turning on the vehicles ignition, and/or continuously assess the ability of the operator to safely operate the vehicle. For example, *alcohol interlocks* analyse the breath alcohol content (BAC) of the user. The system typically disables the ignition of the vehicle, which is only enabled if the breath content of the vehicle is below a predetermined BAC level. The breath testing device may be mounted on the vehicle, or a device on the key fob. *Driver vigilance systems* monitor the status of the driver and/or driving performance and determine whether the driver is fatigued or inattentive. These systems monitor factors such as eye movement, steering wheel grip, lateral lane movement, or may involve devices that require regular input from the driver. While issues such as fatigue and intoxication are significant safety issues for car and heavy vehicle domains, where systems that monitor driving performance have been estimated to reduce fatal and injury-related crashes by 10-15% [2], less is known about their potential impact on motorcycle crash rates.

Electronic licenses are mechanisms that prevent unauthorised individuals from operating a given vehicle. The engine is immobilised until an authorised card is present. The role of unlicensed vehicle operation in crash rates is largely unknown, although it has been shown that unlicensed riding is a factor in a significant proportion of crashes [11]. However, it is a common feature of motorcycle graduated licensing schemes to include power restrictions for learner riders, and this ITS may provide a mechanism for enforcement of these restrictions.

Alcohol interlocks on motorcycles for riders who have been convicted with riding over a legal BAC have been trialled in Australia, but as yet their effectiveness has not been evaluated. Driver vigilance monitoring systems are emerging technologies in other vehicle domains, but have not yet been applied to motorcycles and there are technical challenges in adapting such systems to inside the motorcycle helmet. Electronic licences are an emerging technology, with heavy vehicle fleet management leading the development of such systems. A similar technology, referred to as *smart cards,* has been developed for motorcycles by Honda to reduce motorcycle theft, where the ignition can only be activated by one of these cards.

Passive Safety ITS

Passive safety systems are those that take effect during or immediately after a crash in order to minimise harm to the vehicle occupant. For example *airbags* absorb the kinetic energy of the vehicle occupant during a crash, reducing injury severity. Airbags installed below the airbags inflate when triggered by impact sensors in the front wheels, and are relevant to all frontal impact crashes. However, unique issues concern motorcycle airbags since they must be designed to take into account that the position of the rider is not always upright such that there may be smaller distances between the rider's face and the airbag than that typical for car drivers, and that the presence of pillion passengers will affect the forward force of the rider [36]. A motorcycle-specific innovation is inflatable *airbag jackets* that deploy when a cable connecting the jacket to the vehicle is severed when the rider is propelled from the vehicle, cushioning the rider from impact with the ground. *Automatic crash notification (ACN) systems* detect the occurrence of a crash through vehicle speed, tilt, and deceleration sensors, and automatically notify emergency services. GPS units inform emergency services of the vehicles location. ACN should perform several important functions [37], such as informing the user that emergency services have been contacted and when they are due to arrive through auditory and/or visual displays, providing information to the user from the emergency services operators, and updating this information in real-time. *Emergency lighting systems* illuminate the vehicle in the event of a crash (a passive system) and serves to enhance the visibility of the vehicle to other road users and emergency services. Emergency lighting systems for motorcycles are commercially available.

Relatively fewer passive than active ITS applications exist that are relevant to motorcycling. However, of those systems identified here, it is important to note that these systems are in considerably advanced development for motorcycles, particularly with regard to airbags. In-vehicle airbag systems have been developed by Honda through the Advanced Safety Vehicle program. These systems are currently commercially available, although no evaluative literature regarding their effectiveness could be identified. ACN systems for motorcycles are in a preliminary stage of development, and initial tests of their adaptability to motorcycles have been conducted [38]. No formal evaluations of their effectiveness were available. Airbags, airbag jackets and automatic crash notification systems are applicable to all crash types that may result in serious injury or fatality. Systems that minimise occupant injury or improve the response times of emergency services have previously been predicted to improve crash outcomes. For example, it has been estimated that of crashes in which a motorcycle airbag could have been triggered, 44% would have resulted in less serious injury outcomes for the motorcyclists [39]. Numerous studies have predicted that automatic crash notification systems may be effective (for at least passenger vehicles) in reducing serious injury and fatal crashes by between 5-15% [40 41 42]. At least one Australian emergency lighting exists that product incorporates with a roll stability warning device currently.

CONCLUSION

The present review, has identified nine existing safety enhancing ITS systems for motorcycles. In addition, eight emerging technologies currently in prototype form, and several additional ‘potential’ systems have been described. These have been discussed in terms of the critical motorcycling safety issues, namely loss of control crashes, multiple vehicle crashes, and additional factors such as conspicuity, alcohol and unlicensed riding. While some of these systems serve to address specific safety issues, such as interlocks and alcohol-related crashes, other systems will show comprehensive benefits across a number of crash types. For example, advanced braking systems are relevant to any event where forceful braking is applied. Importantly, this is one area of ITS development that has shown a significant amount of development. However to date there are no available studies on the effectiveness of the existing systems identified, with the exception of DRLs. In addition to technical development, future research should address issues such as acceptability, usability, negative behavioural adaptation, and further in-depth analysis of crash causal factors such as distraction.

ACKNOWLEDGEMENTS

The authors would like to thank VicRoads, and in particular Chris Brennan, for assistance in funding and reviewing this research. The authors also wish to thank Brent Stafford, of ITS Australia, and Professor Narelle Haworth, from the Centre for Accident Research & Road Safety - Queensland, for their input to the research.

REFERENCES

[1] McKeever, B.B. 1998. “Working paper: Estimating the potential safety benefits of intelligent transport systems.” Washington DC: Mitretek Systems.

[2] Rumar, K. Fleury, D. Kildebogaard, J. Lind, G. Mauro, V. Berry, J. Carsten, O. Heijer, T. Kulmala, R. Machata, K. and Zackor, I. 1999. “Intelligent Transportation Systems and Road Safety.” Report prepared for the European Transport Council, Brussels.

[3] OECD. 2003. “Road safety: Impact of new technologies.” Paris, France: Organisation for Economic Cooperation and Development.

[4] Lee, J.D. McGehee, D.V. Brown, T.L. and Reyes, M.L. 2002. “Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator”. Human Factors, 44, 314-335.

[5] Farmer, C.M. Wells, J.K. and Lund, A.K. 2003. “Effects of head restraint and seat redesign on neck injury risk in rear-end crashes.” Traffic Injury Prevention, 4, 83-90.

[6] Kulmala, R. 1997. “The potential of ITS to improve safety on rural roads.” Proceedings of the 4th World Congress on Intelligent Transport Systems (Berlin, Germany Oct. 21-24).

[7] Maccubbin, R.P. Staples, B.L. Mercer, M.R. Kabir, F. Abedon, D.R. and Bunch, J.A. 2005. “Intelligent Transport Systems benefits, costs, and lessons learned: 2005 update.” FHWA-OP-05-002. Washington DC: Mitretek Systems.

[8] NHTSA. 1996. “Effectiveness of occupant protection systems and their use.” Washington DC: National Highway Traffic Safety Administration.

[9] Australian Bureau of Statistics. 1996. “Australian Social Trends.” Available at: www.abs.gov.au/ausstats/, accessed 24/05/06.

[10] Traffic Accident Commission. 2006. “Motorcycle Crash Data.” Available at: www.tacsafety.com.au, accessed 23/05/06

[11] Hurt, H.H. Oullet, J.V. and Thom, D.R. 1981. “Motorcycle Accident Cause Factors and Identification of Countermeasures. Volume 1: Technical Report.” Traffic Safety Centre, University

of Southern California.

[12] Association des Constructeurs Européens de Motocycle. 2004. “The motorcycle industry in Europe: A plan for action.” Available at: http://www.acembike.org/html/start.htm, accessed 05/02/2007.

[13] Preusser, D.F. Williams, A.F. and Ulmer, R.G. 1995. Analysis of fatal motorcycle crashes: Crash typing. Accident Analysis and Prevention, 27, 845-851.

[14] Lawrence, G.J.L. Hardy, B.J. Carroll, J.A. Donaldson, W.M.S. Visviskis C. and Peel, D.A. 2004. “A study on the feasibility of measures relating to the protection of pedestrians and other vulnerable road users.” Transportation Research Library.

[15] Hsu, T.P. 1997. “Proposed ITS issues on motorcycle traffic.” Proceedings of the 4th World Congress on Intelligent Transport Systems, (Berlin, Germany, June 6-7).

[16] Regan, M.A. Oxley, J.A. Godley, S.T. and Tingvall, C. 2001. “Intelligent Transport Systems: Safety and Human Factors Issues.” Royal Automobile Club of Victoria Research Report 01/01. RACV: Melbourne, Australia.

[17] Thirumalai, K. 2001. “ITS innovation challenges for 21st century transportation safety and services market.” 8th ITS World Congress (Sydney, Australia, Sept. 30- Oct. 4).

[18] Motorcycle Safety Foundation. 2000. “National Agenda for Motorcycle Safety.” U.S. Department of Transportation. Available at: www.nhtsa.dot.gov, accessed 3/07/06.

[19] Federation of European Motorcyclists Associations. 2004. “European Agenda for Motorcycle Safety. Outline.” Available at: http://www.fema.ridersrights.org/safety/EAMS_febr04.pd, accessed 05/02/07.

[20] Bishop, R. 2002. “The road ahead for intelligent vehicle systems: What’s in store for riders?” Presented at the 8th Annual Minnesota Motorcycle Safety Conference (March).

[21] Asanuma, N. Kawai, M. Takahashi, A. Shigenari, R. and Ochi, K. 2000. “Intelligent technologies of ASV: The research and development of ASV-2 in Honda.” Proceedings of the 7th Annual Intelligent Transport Systems World Congress (Turin, Italy, Nov. 6-9).

[22] Fowkes, M. 2004. “News on ISA PTW.” Presented at the International Working Group on Speed Control (Barcelona, Spain).

[23] Bayly, M. Regan, M. Hosking, S. 2006. Intelligent Transport Systems and Motorcycle Safety. Monash University Accident Research Centre Report 260. MUARC: Clayton, Australia.

[24] Satomura, M. 2000. “Motorcycle detection system.” Smart Cruise 21-Demo (Tsukuba, Japan, Nov. 28 - Dec. 1).

[25] Tham, K.Y. Seow, E. and Lau, G. 2004. “Pattern of injuries in helmeted motorcyclists in Singapore.” Emergency Medical Journal, 21, 478-482.

[26] Bahouth, G. 2005. “Real world crash evaluation of vehicle stability control (VSC) technology.” Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles (Washington DC, June 6-9).

[27] Dang, J. 2004. “Preliminary results analyzing the effectiveness of Electronic Stability Control (ESC) systems.” DOT HS 809 790. Washington DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

[28] Farmer, C. 2004. “Effect of Electronic Stability Control on automobile crash risk.” Traffic Injury Prevention, 5, 317-325.

[29] Ulleberg, P. 2003. “Motorcycle safety – A literature review and meta-analysis.” Institute of Transport Economics, Norway.

[30] Umar, R.S.R. Mackay, M.G. and Hills, B.L. 1996. “Modelling of conspicuity-related motorcycle accidents in Seremban and Shah Alam, Malaysia.” Accident Analysis and Prevention, 28, 325-332.

[31] Elfvik R. and Olsen S. 2003. “Daytime running lights. A systematic review of effects on road safety.” TØI report 688/2003. Oslo. Available at: http://www.toi.no/attach/a456292r623287/688_2003_sum.pdf, accessed 05/06/07.

[32] Yuan, W. 2000. “The effectiveness of the ‘ride-bright’ legislation for motorcycles in Singapore.” Accident Analysis and Prevention, 32, 559-563.

[33] Nakai, N. 2000. “Adaptive front lighting system

(for motorcycle).” Smart Cruise 21-Demo (Tsukuba, Japan, Nov. 28 - Dec. 1).

[34] Olssen, T. Truedsson, N. Xafis, V. Tomasevic, N. Logan, D. Fildes, B. and Kullgren, A. 2006. “Safecar II: A review and evaluation of vehicle safety features and systems.” Clayton, Australia: Monash University Accident Research Centre.

[35] Bishop, R. 2005. “Intelligent Vehicle Technology and Trends.” Norwood: Artech House.

[36] Takeshi, Y. 2000. “Airbag system for motorcycle.” Smart Cruise 21-Demo, (Tsukuba, Japan, Nov. 28 - Dec. 1).

[37] Campbell, J. Carney, C. and Kantowitz, B. 1998. “Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations.” FHWA-RD-98-057. Washington, Federal Highway Administration.

[38] Finlay, A. and Morphett, A. 2003. “ITS enabled motorcycle safety and security.” Proceedings of the 10th World Congress and Exhibition on Intelligent Transport Systems and Services (Madrid, Spain, Nov. 16-19).

[39] Berg, F.A. and Rücker, P. 2003. “Analysis of the benefit potential of a motorcycle airbag to improve rider safety – results from accident research and crash tests.” In 9th EAEC International Congress: European Automotive Industry Driving Global Changes (Paris, France, June 16-18).

[40] Abele, J. Kerlen, C. Krueger, S. Baum, H. Geißler, T. Grawenhoff, S. Schneider, J. and Schulz, W.H. 2005. “Exploratory study on the potential socio-economic impact of the introduction of intelligent safety systems in road vehicles.” Tetlow, Germany: VDI/VDE Innovation.

[41] eSafety Forum. 2005. “Final report and recommendations of the implementation road map working group.” (Brussels, Belgium, Oct. 18) http://www.esafetysupport.org/en/esafety_activities/esafety_working_groups/implementation_road_map.htm

[42] Apogee/Haggler Baillie. 1998. “The effects of urban form on travel and emission: Synthesis of the literature.” Washington DC: US Environmental Protection Urban and Economics Division.