Motorcycle Safety and Intelligent Transportation Systems Gap Analysis

Final Report

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16. Abstract

Intelligent Transportation Systems (ITS) present an array of promising ways to improve motorcycle safety. While ITS technologies have predominantly targeted automobiles and commercial vehicles, little has been done to specifically address motorcycles or motorcycle safety. To help rectify this, this project surveyed a wide range of ITS technologies with potential relevance to motorcycles; analyzed each technology's current relevance to motorcycles and potential to improve motorcycle safety; and then further investigated those technologies with strong potential to improve motorcycle safety. The project employed a two-pronged methodology in its survey of ITS technologies, consisting of (1) a comprehensive literature review of over 40 categories of ITS with potential relevance to motorcycles and (2) interviews with leading practitioners representing a cross section of the motorcycle industry and community. The literature review and the practitioner interviews each revealed a series of trends and gaps in the current state of research on motorcycle safety and ITS, which are documented and discussed in this report. The project then synthesized these trends and gaps to determine the overall trends and gaps, as well as the opportunities to advance ITS technology for motorcycle safety. These opportunities were translated into two types of recommendations for action: (1) recommended areas of research and (2) recommended strategies to advance both these areas of research and the overall field of ITS for motorcycle safety. The recommended areas of research include: synergizing ITS technology and implementation with the already successful technology of antilock braking systems (ABS) in motorcycles; rider-motorcycle interfaces; motorcycle safety data (including preparations to take full advantage of big data moving forward); applied research and assessments of safety benefits; and the harmonization of ITS technologies and standards (e.g., interoperable connected vehicles). The recommended strategies include: actively promote research on motorcycle ITS and explore synergies with closely related research; engage the motorcycle community and general public to improve the design and acceptance of motorcycle ITS; embrace upcoming technology (particularly connected vehicles and big data applications); and collaborate with all sectors and stakeholders to promote ITS harmonization and widespread implementation.

17. Key Words Motorcycle; safety; Intelligent Transportation Systems (ITS); adaptive front lighting; daytime running lights; advanced driver assistance systems (ADAS); antilock braking systems (ABS); collision warning and avoidance systems; curve speed warning, electronic stability programs; inter-vehicle communication systems; motorcycle detection systems; connected vehicles; rider acceptance	**18. Distribution Statement** No restrictions

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Executive Summary

Overview

Intelligent Transportation Systems (ITS) present an array of promising ways to improve motorcycle safety. ITS include a broad range of concepts, systems, and applications that apply advanced computation, information technology, and communications to vehicles and roadway infrastructure in order to improve traffic safety, mobility, and reliability. While ITS technologies have predominantly targeted automobiles and commercial vehicles, little has been done to specifically address motorcycles or motorcycle safety. To help rectify this, this project surveyed a wide range of ITS technologies with potential relevance to motorcycles; analyzed each technology's current relevance to motorcycles and potential to improve motorcycle safety; and then further investigated those technologies with strong potential to improve motorcycle safety.

The project employed a two-pronged methodology in its survey of ITS technologies. This methodology consisted of (1) a comprehensive literature review of over 40 categories of ITS with potential relevance to motorcycles and (2) interviews with leading practitioners representing a cross section of the motorcycle industry and community. The project team analyzed the literature review and practitioner interviews separately to identify the trends and gaps in each. For the literature review, only ITS technologies in categories that showed high relevance to motorcycles and the potential to improve motorcycle safety were carried forward to the in-depth analysis of trends and gaps. The findings from the literature review and practitioner interview analyses were then synthesized to uncover a set of overarching trends and gaps in the current field of ITS for motorcycle safety. These were used to inform the project's recommended next steps for advancing ITS for motorcycle safety—presented as a set of recommended focus areas and a set of strategies to advance both the focus areas and the general development of ITS for motorcycle safety.

Literature Review

The literature review analyzed over 2,400 journal articles, news items, and other documents on ITS to determine their relevance to motorcycle safety. Although over 40 categories of ITS technologies were initially defined for the literature review, the search results predominately fell into 17 categories. Of these 17 categories, seven stood out as particularly relevant to motorcycle safety improvements. These seven categories of ITS are listed below with brief descriptions of the technology included in each category.

1. Adaptive Front Lighting and Daytime Running Lights
    a. Adaptive Front Lighting—Lighting systems that provide optimized vision to the driver during night time and other poor-sight conditions by adapting headlight angle and intensity, taking into account the speed of the motor vehicle, the steering wheel angle, weather conditions, and the yaw and tilt rate of the motor vehicle.
    b. Daytime Running Lights—A lighting device on the front of a motor vehicle that is automatically switched on when the vehicle is moving forward, emitting white, yellow, or amber light to increase the conspicuity of the vehicle during daylight conditions.

2. **Advanced Driver Assistance Systems (ADAS)—**Vehicle-based systems that provide automated assistance for driving tasks such steering, braking for collision avoidance, lane departure warning, lane keeping, and adaptive cruise control.
3. **Antilock Braking Systems (ABS)—**A safety system that allows the wheels on a motor vehicle to maintain tractive contact with the road surface according to driver inputs while braking, preventing the wheels from locking up (ceasing rotation) and avoiding uncontrolled skidding.
4. **Collision Warning and Avoidance Systems**—Vehicle-based sensor system that detects objects in the roadway and alerts the driver (warning); if the driver does not respond the system will apply brakes (avoidance).
5. **Curve Speed Warning**—Infrastructure based system that uses vehicle-to-infrastructure (V2I) communications to alert drivers of the posted speed for an upcoming curve.
6. **Electronic Stability Programs**—Also known as Dynamic Stability Control, this computerized technology improves a vehicle's stability by detecting and reducing loss of traction (skidding). When the program detects loss of steering control, it automatically applies the brakes to help steer the vehicle in the direction the driver intends to go. Some programs also reduce engine power until control is regained.
7. **Inter-Vehicle Communication Systems and Motorcycle Detection Systems**
    c. Inter-Vehicle Communication Systems—Vehicle-based systems that facilitate communications between vehicles (e.g., car-to-car or motorcycle-to-car communications). It should be noted that inter-vehicle communications is commonly referred to as vehicle-to-vehicle (V2V) communications, but typically in the sense that cars or trucks would be communicating with one another. Inter-vehicle communications is also a key part of evolving connected vehicle technology (vehicles that can communicate with other vehicles (V2V), infrastructure (V2I), and pedestrians, etc. (V2X)) This report uses all terms, but the more general “Inter-Vehicle Communications Systems” was chosen as the term for the overall category in the project’s literature review, while V2V and connected vehicles were included as search terms within this category.
    d. Motorcycle Detection Systems—Vehicle-based systems that uses inter-vehicle communications to recognize other nearby vehicles and, perhaps more importantly, be recognized by other vehicles (i.e., motorcycle in a truck’s blind spot).

Each of these seven categories were first analyzed individually to understand the range of research and challenges in each category. The project team then applied this information to determine the key trends and gaps across all seven categories. Table ES-1 presents these trends while Table ES-2 presents the gaps, representing the most pressing trends and gaps in the current literature on ITS for motorcycle safety.

Table ES-1. Literature review trends.

Trends	Summary
Continuous focus on design improvements	Nearly all categories of Intelligent Transportation Systems (ITS) contained research on how to improve the technologies’ design and operation to better fit motorcycle characteristics.
Multi-instrumented vehicles	As instrumentation costs decrease, several categories of ITS (e.g., Collision Warning and Avoidance Systems and Inter-Vehicle Communications Systems) are seeking to include new instruments—such as sensors and camera-detection technology—to improve system performance.

Table ES-1. Literature review trends (continuation).

Trends	Summary
Technology analysis tools	A considerable portion of research focused on the development of models, algorithms, and simulators to test and evaluate ITS for motorcycles. Such research typically sought to improve these technology analysis tools with a better understanding of motorcycle dynamics.
Statistical analysis	Statistical analyses of ITS already operating on the market (e.g., Antilock Braking Systems (ABS) and Daytime Running Lights) have provided important insights on the real safety impacts of ITS for motorcycles. As new motorcycle ITS technologies roll out, statistical analyses will continue to play an important role in safety research.
Increase motorcycle conspicuity	Recognizing that an important factor in increasing motorcycle safety is increasing conspicuity, researchers have sought to increase motorcycle conspicuity through various ITS technologies, such as Daytime Running Lights and Inter-Vehicle Communications Systems.
Support for developing ITS for motorcycle safety	An appreciable amount of literature evaluated which areas of ITS hold the most potential for motorcycle safety, with a clear consensus that developing ITS for motorcycle safety in general is a important research concern.

Table ES-2. Literature review gaps.

Gaps	Summary
Complete prototype systems for motorcycles	There was limited research on the development or testing of complete, prototype Intelligent Transportation Systems (ITS) for motorcycles.
Assessment of safety benefits	For several categories of ITS, research into the empirical or simulated safety benefits of ITS for motorcycles is relatively lacking (e.g., Curve Speed Warning, Electronic Stability Programs, and Inter-Vehicle Communication Systems and Motorcycle Detection Systems). Notably, this is not the case for categories such as Antilock Braking Systems (ABS) and Advanced Driver Assistance Systems (ADAS).

Table ES-2. Literature review gaps (continuation).

Gaps	Summary
Acceptability of ITS to riders	In most categories, research into the acceptability of motorcycle ITS to riders was limited. (ABS and ADAS are again exceptions.) User acceptability is key for successful implementation and, therefore, it will be an important area for research as motorcycle ITS advances.
Research and regulations in the United States	Significant advances in research (the European Commission's SAFERIDER project) and regulations (mandates for ABS) have occurred in Europe. While the United States can learn from and build upon these advances, the impacts on motorcycle safety are not completely transferable to the American transportation system and traveling public—making it important to research motorcycle ITS prototypes and policies in the unique U.S. context.
Harmonization of ITS	There was virtually no research on harmonizing ITS technologies so that they are interoperable across vehicles and roadways—a concept that has recently gained traction with the launch of the Connected Motorcycle Consortium in October 2015. Given this momentum, it will be important to increase focus on research in this area.
Understudied areas of ITS	There are many types of ITS where little motorcycle-related research, or little research of any kind, has been documented. The lack of research does not mean that these understudied areas do not have the potential to improve motorcycle safety. Future research should evaluate the potential of these technologies.
Privacy	The potential privacy concerns of the motorcycle community were generally not covered in existing research. While motorcycle ITS will not collect Personally Identifiable Information (PII)—and there is no desire and no need to collect PII—it will be important for all stakeholders to voice and cooperatively address any concerns.

Practitioner Interviews

The literature review findings were supplemented with interviews with leading practitioners from an international cross section of manufacturers, researchers, public agencies, and industry associations. These interviews provided a diversity of perspectives and a more nuanced understanding of the current state-of-the-practice. Together, the interviews revealed that the themes described in Table ES-3 hold particular importance for the development of ITS for motorcycle safety going forward.

Table ES-3. Practitioner interview themes.

Themes	Summary
Strong motorcycle community	There is a strong sense of community among motorcycle riders in the United States. While the number of riders is relatively small, the voice of the motorcycle community is strong.
Connectivity	Practitioners identified connectivity as an important Intelligent Transportations Systems (ITS) application for the near-term, recognizing current momentum behind connected vehicle technology for automobiles (i.e., vehicle-to-vehicle (V2V) and vehicle to infrastructure (V2I) connectivity). Practitioners want to ensure that motorcycles are considered and included in the development of such technologies.
System-wide approach	Practitioners highlighted that new ITS technologies will benefit from interacting with each other. While they consider most new technologies potentially beneficial, bundling and rolling out new technologies as part of an interoperable system will increase safety benefits.
Riding experience	Practitioners emphasized the importance of designing ITS technologies specifically for the motorcycle riding experience, which differs greatly from the automobile driving experience.
Bottlenecks: Funding and robust data	Practitioners noted two primary obstacles facing the advancement of research on ITS for motorcycle safety: (1) funding and (2) robust data on motorcycle safety and usage. Practitioners believed there should be more funding opportunities for research and development across the entire spectrum of motorcycle safety research activities. Practitioners also highlighted how more detailed and comprehensive data on motorcycle crashes and usage could enhance understanding of the U.S. rider experience and help develop ITS technologies specifically for motorcycle safety.

Overall Trends and Gaps in Intelligent Transportation Systems for Motorcycle Safety

The project team then synthesized the literature review trends and gaps and the practitioner interview themes to distill the overall trends and gaps in the field of ITS for motorcycle safety, as shown in Table ES-4 and ES-5, respectively.

Table ES-4. Overall trends in Intelligent Transportation Systems for motorcycle safety.

Trends	Summary
Consensus that Intelligent Transportation Systems (ITS) can improve motorcycle safety	There is an overarching sense that ITS technologies can have a significant, positive impact on motorcycle safety. A clear example is the success of Antilock Braking Systems (ABS), which the literature and practitioners highlighted for its demonstrated safety benefits.
Need for tailored solutions	There was a clear consensus in the literature and among practitioner that tailoring ITS technologies specifically to motorcycle will be critical to realizing the full benefits of ITS for motorcycle safety. However, while this need is widely acknowledged, research has just begun to address it.
Increase in connectivity	Many practitioners see Connected Vehicle technology as having great potential to improve motorcycle safety and encourage the research community to take advantage of this area's current momentum. Again, while this trend is widely acknowledged, research has just begun to address it.
Bundling technologies	Practitioners highlighted the added benefits of developing ITS technologies as interoperable systems. This was reflected in research efforts such as the SAFERIDER project, which developed several ITS applications under a single human-machine interface in order to avoid past complications with technologies developed separately.
Not just improve safety, improve riding experience	The acceptability of ITS to riders is key to the successful implementation of this technology. This issue is closely related to the need to develop ITS tailored to motorcycles, but focuses more on the human-machine interface and extends to perceptions of what riders want and need from new technology. Again, the importance of this issue is widely acknowledged, but much work remains to be done.

Table ES-5. Overall gaps in Intelligent Transportation Systems for motorcycle safety.

Gaps	Summary
Motorcycle safety data	Practitioners identified the lack of robust data sets as a primary gap, indicating that they seek data beyond the purview of existing databases such as the Fatality Analysis Reporting System (FARS). A dialogue among diverse practitioners may be needed to consider the benefits and costs of expanding current databases.
Multi-sector collaboration and the harmonization of Intelligent Transportation System (ITS)	Expanding collaboration among all sectors of the motorcycle industry will help make the most of limited resources for the development of ITS for motorcycle safety. Such actions will help efforts to harmonize ITS and to develop interoperable technologies.
Acceptability and customization of motorcycle ITS	Going forward it will be critical to move beyond recognizing the importance of acceptability and customization (tailored solutions) of motorcycle ITS, to actually actively researching, testing, and implementing ways to improve acceptability and customization.

Table ES-5. Overall gaps in Intelligent Transportation Systems for motorcycle safety (continuation).

Gaps	Summary
Assessment and definition of safety benefits	As the development of ITS prototypes advances, it will be important to rigorously assess and quantify the real-world safety benefits of the new technologies. Given the complex interactions between technology, roadway conditions, and rider behavior it cannot be assumed that technical advancements automatically improve safety.
Research in the United States	Applying and studying ITS prototypes in the unique United States context will ensure that new technologies are designed for maximum effectiveness and safety in the U.S. Accounting for contextual and cultural difference in this way will also help improve the acceptability and customization of ITS for motorcycles.
Privacy	The potential privacy concerns of the motorcycle community will be important to address going forward. While motorcycle ITS will not collect Personally Identifiable Information (PII)—and there is no desire and no need to collect PII—giving all stakeholders the opportunity to voice concerns and reach a common consensus on this issue will help realize the full benefits of motorcycle ITS.

Recommendations

Lastly, the project team used the overall gaps and trends to identify several opportunities to advance research on ITS for motorcycle safety. These opportunities were translated into two types of recommendations for action: (1) recommended areas of research for practitioners throughout the industry to focus on, and (2) recommended strategies to advance research in these areas—as well as research on ITS for motorcycle safety in general. These recommendations are followed by a discussion on how the United States Department of Transportation (U.S. DOT) can lead the industry to act upon these recommendations.

1. **Recommended areas of research:** The following research areas have been identified as having strong potential to improve motorcycle safety and rider experience.
    - **Technology synergy with Antilock Braking Systems (ABS)**. ABS stood out as one of the most promising and mature areas of motorcycle ITS. This momentum should be sustained and built upon with further research. Researchers should explore synergies between ABS and other areas of ITS to help promote and implement less mature ITS technologies.
    - **Rider-motorcycle interface**. The acceptability and customization of ITS for motorcycles was a major theme in almost all resources consulted for this report. The embodiment of this theme moving forward will be through the rider-motorcycle interface (also known as the human-machine interface, or HMI) of ITS devices for motorcycles. The rider-motorcycle interface, therefore, will become increasingly critical in both the effectiveness and acceptance of motorcycle ITS.
    - **Motorcycle safety data**. Improving the availability of robust, comprehensive data sets will help efforts to develop ITS for motorcycle safety across the board. The National Highway Traffic Safety Administration (NHTSA) may consider enhancing the Fatality Analysis Reporting System (FARS) by working with practitioners to ensure that FARS includes the type of data needed to advance ITS for motorcycle safety. Regardless of the

method, a collaborative effort between public agencies, research institutions, manufacturers, and riders to improve data on motorcycle usage and safety will offer huge benefits to future research.

- **Applied research and assessment of safety benefits**. Pushing research towards more applied real-world work is an important next step in the development of ITS for motorcycle safety. Both the literature review and the practitioner interviews pointed to the limited amount of research on the real-world safety impacts of various ITS technologies. Building off existing research and turning towards more applied topics will help accelerate the implementation of ITS for motorcycles.
- **Harmonization of ITS**. The harmonization of ITS—meaning the development of ITS technologies that are interoperable across vehicles and roadways—will become a critical research focus moving forward. The recent launch of the Connected Motorcycle Consortium called attention to the dearth of research on this topic. It is clear that connectivity and interoperable ITS are trending topics that will be essential to the next stage of motorcycle ITS.

2. **Recommended strategies to address gaps and needs:** To help take action on the recommended areas of research—and generally to address the identified gaps and challenges in research on ITS for motorcycle safety—the following four strategies are recommended as a way to comprehensively promote the development of ITS applications for motorcycle safety:
    - **Actively promote research**. Limited funding for research is a chronic problem in many fields and is not easy to solve. In addition to making the case for research exclusively focused on ITS for motorcycle safety, researchers and other champions should explore opportunities to include motorcycle ITS research in other closely related, funded research initiatives.
    - **Engage the motorcycle community and the general public**. Although the motorcycle community is strong, it is also small and relatively uninvolved in research activities. It is important to increase opportunities for riders to provide feedback to research institutions, manufacturers, and public agencies on the issue of ITS and motorcycle safety. Engaging the motorcycle community more on this topic will ensure that the unique safety needs of motorcyclists are met as ITS technologies continue to develop. It will also be especially important in addressing any privacy concerns and increasing the acceptability of ITS to riders
    - **Embrace upcoming technology**. With the upcoming deployment of Connected Vehicles and big data, practitioners need to be prepared to take advantage of these opportunities to increase safety, enhance mobility, and collect more robust data on motorcycle usage (speeds, volumes, etc.) and safety. Conducting foundational research on these topics will help all practitioners make better use of these upcoming technologies once they have matured.
    - **Collaborate**. Collaboration between all sectors and stakeholders will be key to the fast and successful development and implementation of ITS for motorcycle safety. Widespread implementation will greatly improve the benefits of all categories of ITS for motorcycle safety. Promoting and supporting this collaboration from a federal level has the potential to be especially impactful, particularly when it comes to the involvement of State DOTs and other public transportation agencies.

All of these strategies and recommended areas of research hinge to some degree on increased communication between stakeholders and a clear commitment to pursuing the safety benefits of motorcycle ITS. As immediate next steps, stakeholders—public agencies, manufacturers, research

organizations, and riders—should explore ways to expand communications (steering groups, public meetings, and conferences) and voice their commitment to advancing ITS for motorcycle safety.

In the implementation of these strategies, the U.S. DOT is in the position to set the tone for the rest of the industry. By establishing a national commitment to finding innovative ways to advance motorcycle ITS research, the U.S. DOT can help incentivize researchers to explore synergistic ways to include motorcycle ITS in existing research programs, as well as prompt the industry to start making plans for connected vehicles and big data. By initiating and encouraging additional channels of communication between industry stakeholders and the motorcycle community, the U.S. DOT can help promote a culture of collaboration and engagement that supports the development of harmonized, widely accepted motorcycle ITS technologies.

The U.S. DOT should also consider the costs and benefits of promoting the project's recommended areas of research through federally funded research or other sponsored development activities. Some of these areas have been selected due to their potential to widely benefit motorcycle ITS devices and, therefore, represent high-impact research investments. For example, developing an effective and acceptable rider-motorcycle interface will be critical to the successful implementation of many promising motorcycle ITS devices. Likewise, improved data for research will benefit virtually any future effort to improve motorcycle safety.

Introduction

Project Overview

Over the past 20 years (1995 to 2015) motorcycle fatalities in the United States have increased in both total number and as a percentage of total motor vehicle fatalities—from 2,138 in 1995 (five percent of total motor vehicle fatalities) to 4,693 in 2015 (13 percent of total motor vehicle fatalities). This trend has occurred despite a significant decrease in the total number of motor vehicle fatalities during this same time period—from 41,817 in 1995 to 35,092 in 2015. (Insurance Institute for Highway Safety, Highway Loss Data Institute, Motorcycle statistics based on analysis of U.S. DOT Fatality Analysis Reporting System (FARS) data, November 2016, http://www.iihs.org/iihs/topics/t/motorcycles/fatalityfacts/motorcycles.) While motorcycles make up only three percent of all registered vehicles in the United States, motorcyclists account for 13 to 14 percent of all traffic fatalities on the roads today. Unlike automobiles, the design of motorcycles does not include basic structural elements that inherently increase safety; as a result, the consequences of a motorcycle crash are often quite serious for the motorcyclists. These statistics underline the importance of improving motorcycle safety in the U.S. as well as highlight key safety concerns that new safety technologies should target.

Intelligent Transportation Systems (ITS) technologies present an array of promising ways to improve motorcycle safety. ITS technologies include a broad range of concepts, systems, and applications that apply advanced computation, information technology, and communications to roadway infrastructure and vehicles in order to improve and enhance traffic safety, efficiency, and save money. While ITS technologies have been and continue to be developed and tested primarily for passenger motor vehicles and commercial vehicles, little has been done to specifically address motorcyclist safety. Towards this end, this project broadly surveyed ITS technologies with the potential to advance motorcycle safety and then further investigated those technologies with strong potential to enhancing motorcycle safety.

In total the project analyzed over 2,400 journal articles, news items, and other documents as part of a comprehensive literature review. Although over 40 categories of ITS technologies were initially defined for the literature review, the search results predominately fell into 17 categories. Seven categories of ITS stood out as particularly relevant to motorcycle safety improvements: (1) Adaptive Front Lighting and Daytime Running Lights, (2) Advanced Driver Assistance Systems (ADAS), (3) Antilock Braking Systems (ABS), (4) Collision Warning and Avoidance Systems, (5) Curve Speed Warning, (6) Electronic Stability Programs, and (7) Inter-Vehicle Communication Systems and Motorcycle Detection Systems. These categories were analyzed in-depth to determine the key trends and gaps in current research on ITS for motorcycle safety.

Additionally, interviews with leading practitioners from an international cross section of manufacturers, researchers, public agencies, and industry associations supplemented the literature review. These interviews provided a diversity of perspectives and a more nuanced understanding of trends and gaps in the current state-of-the-practice. The project team synthesized the themes from these interviews and the literature review to distill the overall trends and gaps in the field of ITS and motorcycles, as well as opportunities for moving forward.

Review of Safety Issues related to Motorcycles

According to the National Highway Traffic Safety Administration (NHTSA) Traffic Safety Facts Report, there were close to 8.5 million registered motorcycles in 2013, representing three percent of all of the registered vehicles in the United States. (National Highway Traffic Safety Administration (NHTSA) Traffic Safety Facts Report, http://www-nrd.nhtsa.dot.gov/Pubs/812148.pdf.) The usage of these vehicles was also a very small portion of the total vehicle miles traveled in the U.S., with only 20,000 million miles traveled, 0.7 percent of the total Vehicle Miles Traveled (VMT) in the U.S. Figures 1 and 2 show a comparison of fatal and injury crashes per the registered number of vehicles and miles traveled.

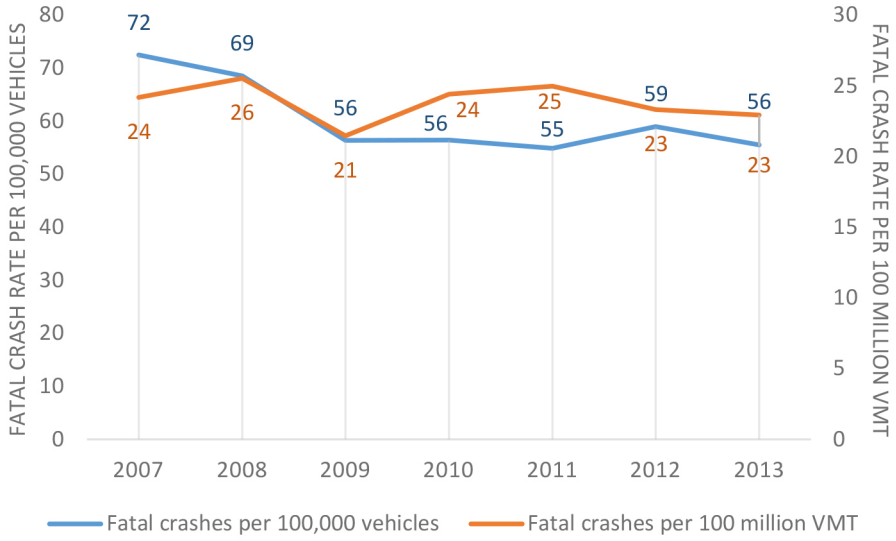


Figure 1. Graph. Fatal motorcycle crash rates.
(Source: 2013 Traffic Safety Factsheet, National Highway Traffic Safety Administration.)

Figure 1 shows the number of fatal crashes declined from 2007 to 2009, as registered vehicles increased through the years. A similar reduction occurs when VMT is used to normalize the number of motorcycle crashes. However, the rate of fatal crashes has remained fairly constant from 2009 to 2013, as crash rates per registered number of vehicles varied from 55 to 59 crashes per 100,000 vehicles, and from 21 to 25 crashes per 100 million of miles traveled. This shows that in recent years, there has not been a significant reduction in fatal crashes.

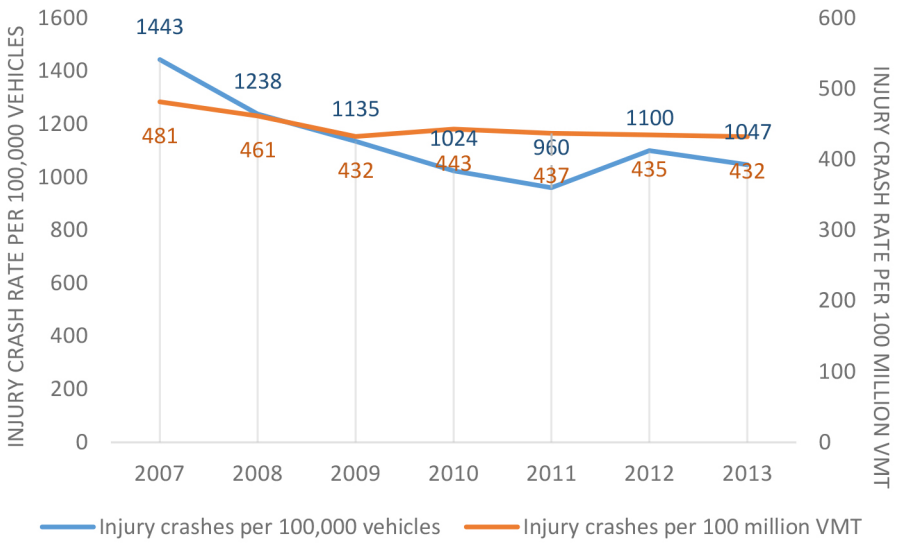


Figure 2. Graph. Injury motorcycle crash rates.
(Source: 2013 Traffic Safety Factsheet, National Highway Traffic Safety Administration.)

Figure 2 shows a reduction in injury crash rates from 1,443 in 2007 to 1,047 in 2013, as injury related crash rates decreased with the passing of years, except for 2012 when the crash rate increased. However, the crash rate per 100 million of miles traveled did not decrease significantly, especially from 2009 to 2013, when the crash rate remained fairly stable at 432 injury crashes per 100 million miles traveled. This last indicator is important because it shows that although crash rates have decreased in relation to the number of registered vehicles they have remained stable in relation to usage, or VMT. The fact that the crash rates in relation to usage remained stable from 2009 to 2013 suggests that riders' safety has not increased significantly in the most recent years, such as increased ownership of ABS-equipped motorcycles and state laws mandating rider education for all new riders.

To understand the magnitude of safety issues in motorcycles, we compared the data shown in Figure 1 and 2 to general vehicle's statistics. In 2013, the fatality rate for motorcyclists was six times the fatality rate for passenger car occupants. Per VMT, motorcyclist fatalities were 26 times more frequent than passenger car occupant fatalities, and motorcyclists were five times more likely to be injured in a crash. In 2013, motorcyclists accounted for 14 percent of all traffic fatalities and four percent of all people injured while driver and passenger occupants represented 18 percent of fatalities, and four percent of injuries.

According to 2013 data, the most harmful event in over half of the fatal motorcycle crashes was a collision with another motor vehicle. In two-vehicle crashes, 74 percent were frontal collisions and six percent were struck in the rear. In 2013 there were 2,182 fatal motorcycle crashes involving other types of vehicles. Of these crashes, 42 percent were with another vehicle turning left while the motorcycle was traveling straight; in 21 percent of these crashes both vehicles were driving straight. Furthermore, motorcycle crashes are more frequently involved with fixed objects than other vehicles, 22 percent of fatal crashes involved a collision with fixed objects (compared with 18 percent for passenger vehicles, 14 percent for light trucks, and four percent for large trucks). Given that collisions with other vehicles are identified as a common threat to riders, there is a need to determine how motorcycles can communicate better with other vehicles and use technology to ease the inter-modal interactions.

Motorcyclists are a vulnerable population in today's transportation network; although the number of motorcyclists is small, the number of crashes is significantly larger than for other vehicles. To address safety concerns for motorcyclists it is important to identify the causes of these crashes.

According to NHTSA, and supported by analysis prepared by the Insurance Information Institute (III), five main factors influence the outcome of fatal motorcycle crashes (http://www.iii.org/issue-update/motorcycle-crashes.):

- Age—According to NHTSA 2013 data, 55 percent of all motorcyclists killed in a crash were over 40 years old, compared to 46 percent in 2004. It is important to state that age is not identified as a crash cause, but it is a determining factor in the crash severity, as injury outcomes from similar crashes can result in different injuries in a young rider compared to an older rider.

- Alcohol Use—In 2013, 28 percent of all motorcycle fatal crashes had a Blood Alcohol Concentration (BAC) of 0.08 or over, while another seven percent had levels between 0.01 and 0.07.

- Speeding—Thirty-four percent of all fatal motorcycle crashes reported speeding as a factor, which was higher than for passenger cars (21 percent), light trucks (18 percent), and heavy trucks (8 percent) related fatal crashes.

- Licensing—One out of four motorcyclists involved in fatal crashes were riding without a valid license, compared to 13 percent for passenger car drivers.

- Helmet use—NHTSA estimates helmet use saved 1,630 motorcyclists' lives in 2013. In total, 41 percent of the motorcyclists killed in crashes were not helmeted.

In addition to identifying the crash causes, it is also important to understand how the crashes occurred. While policy changes and increased enforcement efforts can impact these crash factors, technology could help incentivize changes by improving safety conditions for motorcyclists across the set of factors identified above. Technology could enhance the riding experience across all ages, making it easier to have control over the vehicle by considering riding characteristics across different ages. Technology could also reduce the number of alcohol-related crashes, as new technologies seek to disable a vehicle if the operator is under the influence of alcohol or other substances. Speed regulation is also an area where technology can help improve safety conditions, as technologies such as Speed Limiting Systems seek to limit riders to ride over unsafe speed limits. Finally, improving helmet design and incorporating new technologies into helmets could offer substantial safety benefits and possibly help promote greater helmet use.

Transportation systems are currently experiencing a major breakthrough as technology applications continue to interact with people's mobility alternatives. Motorcyclists are not an exception. Considering that data in the most recent years shows that motorcyclists are amongst the most vulnerable users of current transportation services, technology improvements should be promoted and embraced. As crash causes for motorcycle safety issues are more precisely defined, Intelligent Transportation System solutions can be designed to address them, and improve safety issues across all users.

Review of Intelligent Transportation Systems

ITS technologies include a broad range of concepts, systems and applications that apply advanced computation, information technology and communications to roadway infrastructure and vehicles in order to improve and enhance traffic safety, efficiency and save money.

The initial concept for ITS applications can be traced back to the General Motors Futurama showcase at the 1939 World's Fair in New York. In the "City of Tomorrow" exhibit a concept of vehicles moving by electronic controls along freeways and surface streets was shown. This concept was later named the Automated Highway System and remained the focus of advanced highway programs through the 1960s and 1970s.

The concept of integrating highway and vehicle systems was called for in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). ISTEA provided funds for intelligent vehicle highway system research and set up an advisory body called the Intelligent Vehicle Highway Systems of America (IVHS America). IVHS America was a public/private partnership, established to promote and coordinate the development and deployment of Intelligent Vehicle Highway Systems across different cities in the United States. IVHS America was changed to ITS America in 1991. ITS America was reconceived as a non-profit industry association, having a greater flexibility to involve different stakeholders in technology systems, such as the academic and private sector, and functioned as a federal advisory committee to the United States Department of Transportation (U.S. DOT) through the ISTEA timeline.

ITS has achieved explosive growth in the past 10 years due to the numerous advances in communications and information technology along with documented benefits provided to traffic safety and efficiency. In order to track new technologies and identify ITS implementation paths, the U.S. DOT created the National ITS Architecture. The National ITS Architecture is "a common framework for planning, defining, and integrating intelligent transportation systems. It is a mature product that reflects the contributions of a broad cross-section of the ITS community". (http://www.iteris.com/itsarch/.) Through the National ITS Architecture, eight fields are defined:

1. Travel and Traffic Management
2. Public Transportation Management
3. Electronic Payment
4. Commercial Vehicle Operations
5. Emergency Management
6. Advanced Vehicle Safety Operations
7. Information Management
8. Maintenance and Construction Management

This study focuses on Advanced Vehicle Safety Operations. Advanced Vehicle Safety Operations is the ITS field that bundles in-vehicle and infrastructure technology, seeking to improve safety conditions and enhance transportation operations efficiency, while reducing environmental impacts. With this general objective in mind, Advanced Vehicle Safety Systems defines seven particular services (Definitions from the National ITS Architecture: http://www.iteris.com/itsarch/html/user/userserv.htm.):

1. **Longitudinal Collision Avoidance.** These systems assist the driver by: sensing potential and/or impending collisions or dangers to the front or rear of the vehicle; eliciting proper collision avoidance actions from the driver; and/or providing temporary automatic control of the vehicle to assist the driver in avoiding the potential collision situation. This service provides rear-end collision warning and control, Adaptive Cruise Control (ACC), head-on collision warning and control, and backing collision warning, among other technologies.
2. **Lateral Collision Avoidance.** This service is specifically aimed at augmenting the vehicle operator's ability to avoid collisions by first providing information, and second, if a crash situation is imminent, providing warnings and/or assuming temporary control of the vehicle.

The service includes lane change/blind spot situation display collision warning and control, as well as lane/road departure warning and control.

3. **Intersection Collision Avoidance.** This service is specifically aimed at providing vehicle operators with assistance in avoiding collisions at intersections. The situations addressed include those that arise when vehicles improperly violate the right-of-way of another vehicle, or when the right-of-way is not clear. The service will provide warnings of imminent collisions with crossing traffic, as well as warnings of stop control—either a stop sign or a traffic signal—in the intersection ahead.
4. **Vision Enhancement for Crash Avoidance.** This service can reduce the number of vehicle crashes that occur during periods of poor visibility. The focus of this effort is on systems that can improve the ability of the driver to perceive the roadway itself and objects on and along the roadway. This improved visibility would allow the driver to avoid potential collisions with other vehicles, fences and railings, pedestrians, wildlife and livestock, or obstacles in the line of travel; and would assist the driver in complying with traffic signals and signs.
5. **Safety Readiness.** This service implements systems that provide drivers with warnings regarding their own driving performance, the condition of the vehicle, and the condition of the roadway as sensed from the vehicle. At the more complex level, Safety Readiness systems will also include the ability to assume temporary, partial control of the vehicle in situations deemed to be highly hazardous. The service includes Impaired Driver Warning and Control Override systems that monitor driver performance features and either warn of impaired driver condition or take temporary control of the vehicle to prevent or discourage continued driving under such circumstances. The service also includes Vehicle Condition Warning systems that monitor the performance of components, such as tires and brakes, whose degradation could have a significant impact on the safe operation of the vehicle, and warn of their imminent failure. The service includes In-Vehicle Infrastructure Condition Warning systems that detect and warn the driver of unsafe conditions on the roadway or bridge infrastructure, such as the presence of ice or water.
6. **Pre-crash Restraint Deployment.** This service reduces the number and severity of injuries caused by vehicle collisions. This is accomplished by developing means both to anticipate an imminent collision and to activate passenger safety systems prior to the actual impact, or earlier after crash onset than is currently feasible.
7. **Automated Vehicle Operation (AVO).** This service provides a fully automated vehicle-highway system in which instrumented vehicles operate on instrumented roadways without operator intervention. Drivers will enter an AVO lane through a check-in area where the AVO system will check the worthiness of the vehicle and driver. The AVO system assumes control of an approved vehicle and moves it onto an AVO lane, merging it with the other automated vehicle traffic.

To compliment these services, and to include upcoming Connected Vehicle technology, the U.S. DOT is currently developing a new area that closely relates to Advanced Vehicle Safety Operations, the Connected Vehicle Reference Implementation Architecture (CVRIA). CVRIA is a framework that would facilitate the development and deployment of services and technologies from Connected Vehicle technologies.

Potential ITS Applications for Motorcycles

The ITS services defined above have been extremely useful in identifying gaps and needs for different modes of transportation. Commercial vehicles, transit management, and a wide spectrum of challenges facing private vehicles are identified and thoroughly described in the ITS Architecture framework. However, the private vehicle needs are highly skewed toward automobiles. In many cases, ITS technologies designed primarily for automobiles will also provide benefits to motorcycles.

For example, advanced traffic signal systems, ramp metering, variable speed limits, incident management, road weather management, and traveler information are ITS applications that benefit all motor vehicle users. In other cases, ITS technologies need to be tailored to motorcycles—and doing so has the potential to greatly improve motorcycle safety. These areas of ITS are the focus of this study.

As a starting point, the U.S. DOT provided the project with a list of 40 categories of investigation, or areas of ITS with potential applications and benefits to motorcycles, shown in Table 1 below. These categories cover a wide range of ITS technologies with potential applications to motorcycles.

Table 1. Categories of investigation.

Intelligent Transportation Systems Topics	
Adaptive Front Lighting	Speed Limiting Systems
Advanced Driver Assistance Systems	Vehicle Diagnostics
Alcohol Detection and Interlock	Vision Enhancement
Animal Detection Systems	Visibility Improving Helmet
Antilock Braking Systems	Airbags
Brake Assist	Airbag Jackets
Collision Warning and Avoidance Systems	Automated Crash Notification Systems
Curve Speed Warnings	Crash Data Recorder
Daytime Running Lights	Emergency Hazard Light
Driver Status Monitoring	Impact Sensing Cut-Off Systems
Electronic Licenses, Smart Cards	Pre-Crash Systems
Electronic Stability Programs	Lane-Change Warnings
Following Distance Warning	Motorcycle Detection Systems
Helmet-Mounted Displays	External Airbags
Inter-Vehicle Communication Systems	Pop-Up Bonnet
Lane Keeping and Departure Warning Systems	Automated Enforcement
Linked Braking Systems	Variable Message Signs
Pedestrian (and Bicycle) Detection System	Intelligent Speed Adaptation
Rear-View Displays	Navigation Systems
Road Surface Condition Monitoring and Warning	Slippery/Icy Road Warning
Roll Stability	Auto Blind Spot Detection

The project sought to determine the current state-of-the-practice regarding these 40 categories—meaning, which categories have been developed the most to date, which categories are seen as having the greatest potential, and where critical gaps exist in this diverse field of technologies. This process is described the Literature Review and Practitioner Interview sections and basic definitions for each of the 40 categories of investigation are provided below.

1. **Adaptive Front Lighting—**As part of the active safety system of middle to high end passenger cars, this lighting system provides an optimized vision to the driver during night time and other poor-sight conditions of the road by adapting the headlight angle and intensity and judging the speed of the car, the steering wheel angle, the weather condition, and yaw and tilt rate of the car.
2. **Advanced Driver Assistance Systems—**Vehicle-based systems to provide automated assistance for driver tasks such steering, braking for collision avoidance, lane departure warning, lane keeping, and adaptive cruise control.
3. **Alcohol Detection and Interlock—**Also known as an Ignition Interlock Service or Breath Alcohol Ignition Interlock Device, this mechanism is installed on a vehicle's dashboard. Before the vehicle's motor can be started, the driver first must exhale into the device; if the resultant breath-alcohol concentration is greater than the programmed blood alcohol concentration (which varies between countries), the device prevents the engine from being started.
4. **Animal Detection Systems—**Vehicle-based sensor system to detect and alert driver of an animal in the roadway; may be combined with pedestrian/bicycle detection and collision avoidance systems.
5. **Antilock Braking Systems—**A safety system that allows the wheels on a motor vehicle to maintain tractive contact with the road surface according to driver inputs while braking, preventing the wheels from locking up (ceasing rotation) and avoiding uncontrolled skidding.
6. **Brake Assist—**A provision that increases braking power when the computer detects that the driver is making a panic stop.
7. **Collision Warning and Avoidance Systems—**Vehicle-based sensor system that detects objects in the roadway and alerts the driver (warning); if the driver does not respond the system will apply brakes (avoidance).
8. **Curve Speed Warnings—**Infrastructure based system that uses vehicle-to-infrastructure (V2I) communications to alert drivers of the posted speed for an upcoming curve.
9. **Daytime Running Lights—**A lighting device on the front of a motor vehicle that is automatically switched on when the vehicle is moving forward, emitting white, yellow, or amber light to increase the conspicuity of the vehicle during daylight conditions.
10. **Driver Status Monitoring—**Also known as Driver Attention Monitoring, this vehicle safety system uses infrared sensors to monitor driver attentiveness. Systems may include cameras placed on the steering column that are capable of eye tracking, via infrared LED detectors. If the driver is not paying attention to the road ahead and a dangerous situation is detected, the system will warn the driver by flashing lights and making warning sounds. If no action is taken, the vehicle will apply the brakes. (A warning alarm will sound followed by a brief automatic application of the braking system.)
11. **Electronic Licenses, Smart Cards—**License tags or toll tags with embedded communications technology that will provide V2I and vehicle-to-vehicle (V2V) communications; they may be used for toll collections and identification for enforcement and compliance activities.
12. **Electronic Stability Programs—**Also known as Dynamic Stability Control, this computerized technology improves a vehicle's stability by detecting and reducing loss of traction (skidding). When the program detects loss of steering control, it automatically applies the brakes to help steer the vehicle in the direction the driver intends to go. Some programs also reduce engine power until control is regained.
13. **Following Distance Warning—**Vehicle-based sensor system that detects vehicles in front of the driver and warns the driver when following too close for the current speed. This technology may be combined with collision avoidance warning system and adaptive cruise control.

14. **Helmet-Mounted Displays—**System that projects alerts and warnings and possibly other information such as speed onto a helmet visor or as audible speech into the helmet.
15. **Inter-Vehicle Communication Systems—**Vehicle-based systems that facilitate communications between vehicles (e.g., car-to-car or motorcycle-to-car communications). It should be noted that inter-vehicle communications is commonly referred to as vehicle-to-vehicle (V2V) communications, but typically in the sense that cars or trucks would be communicating with one another. Inter-vehicle communications is also a key part of evolving connected vehicle technology (vehicles that can communicate with other vehicles, infrastructure, pedestrians, etc.) This report uses all terms, but the more general "Inter-Vehicle Communications Systems" was chosen as the term for the overall category in the literature review, while V2V and connected vehicles were included as search terms within this category.
16. **Lane Keeping and Departure Warning Systems—**Vehicle-based system that detects when the vehicle is crossing a lane line without using the turn-signal and alerts the driver (lane departure warning); the system may also nudge the vehicle back into the proper lane (lane keeping).
17. **Linked Braking Systems/Linked Braking Systems (for adaptive cruise control)—**The ITS application is to provide adaptive cruise control for motorcycles' initial systems may use sensors to keep vehicles at a safe distance, while later phases may use V2V communications. (The same definition is provided for both.)
18. **Pedestrian (and Bicycle) Detection System—**Vehicle-based sensor system to detect and alert driver of a pedestrian or bicycle in the roadway; it may be combined with animal detection and collision avoidance systems.
19. **Rear-View Displays—**Also known as backup cameras, these devices are attached to the rear of a vehicle to aid in backing up and to alleviate the rear blind spot. The devices are specifically designed to avoid backup collisions.
20. **Road Surface Condition Monitoring and Warning—**Sensor systems that collect information on road surface conditions and communicate that information to the driver via V2I and V2V systems. Road conditions reported may include weather (wet or icy), uneven pavement, grooved pavement, work zones and work zone metal plates, and bridge open gratings.
21. **Roll Stability—**These safety control systems take corrective action, such as throttle control or braking, when sensors detect that a vehicle is in a potential rollover situation.
22. **Speed Limiting Systems—**Governs to limit the top speed of a vehicle. For some classes of vehicle and in some jurisdictions they are a statutory requirement; for some other vehicles the manufacturer provides a non-statutory system that may be fixed or programmable by the driver.
23. **Vehicle Diagnostics—**On-board monitoring captures relevant information and presents it to the driver or transmits it off board. Vehicle diagnostic monitoring can provide advance notification of mechanical malfunctions, reducing repair costs and aiding freight carriers with contingency planning for disabled vehicles.
24. **Vision Enhancement—**Vehicle-based system that senses light conditions and adapts head lights to those conditions.
25. **Visibility Improving Helmet—**Sensors in a helmet that sense light conditions and adjust the darkness of the visor and provide night vision capabilities in very dark conditions.
26. **Airbag—**An occupant restraint system consisting of a flexible fabric envelope or cushion designed to inflate rapidly during an automobile collision.
27. **Airbag Jackets—**Functioning as a collision protection system for motorcyclists; when a motorcyclist is thrown from the motorcycle during a crash, the airbag jacket instantly inflates to protect the rider's upper body.

28. **Automated Crash Notification Systems—**May-day system for motorcycles; the system could alert a private company (like On-Star) or a 911 public-safety answering point (PSAP), including via V2I communications.
29. **Crash Data Recorder—**Also known as an Event Data Recorder, this device can be installed in vehicles to record information related to vehicle crashes.
30. **Emergency Hazard Light—**Visual warning lights fitted to a vehicle for use when the driver wishes to convey to other road users the urgency of their journey, to provide additional warning of a hazard when stationary, or in the case of law enforcement as a means of signaling another driver to stop for interaction with an officer.
31. **Impact Sensing Cut-Off Systems—**A system of impact sensors that shut off the fuel pump during a vehicle impact event.
32. **Pre-Crash Systems—**Vehicle-based system, possibly linked to collision avoidance/warning system that will deploy driver protection devices such as air bags.
33. **Lane-Change Warnings—**Vehicle-based system that detects when the vehicle is crossing a lane line without using the blinker and alerts the driver (lane departure warning); covered under lane departure system.
34. **Motorcycle Detection Systems—**Vehicle-based system that uses inter-vehicle communications to recognize other nearby vehicles and, perhaps more importantly, be recognized by other vehicles (i.e., motorcycle in a truck's blind spot).
35. **External Airbags—**External airbags on a vehicle act to disperse the force of the crash more slowly; rather than directly protecting the occupant, they prevent collision force from ever reaching the car.
36. **Pop-Up Bonnet—**Also known as a deployable bonnet or pop-up engine hood, this pop-up hood system was developed to reduce the severity of head injuries to pedestrians in pedestrian-to-automobile crashes.
37. **Automated Enforcement—**The use of cameras, or image capture technology, to monitoring and/or enforce traffic safety laws.
38. **Variable Message Signs—**Electronic signs along a highway (freeway or arterial). These signs may provide information needed by motorcyclists such as weather conditions, work zones, or congestion ahead.
39. **Intelligent Speed Adaptation—**Adaptive cruise control may be combined with following distance warning and linked braking system.
40. **Navigation Systems—**Vehicle-based GPS that provides location and mapping information to the driver. Systems can also provide speed limit, traffic congestion and weather information.

The Role of the U.S. Department of Transportation

This study was prepared for the U.S. DOT's Intelligent Transportation Systems Joint Program Office (ITS JPO) within the Office of the Assistant Secretary for Research and Technology (OST-R). The JPO "focuses on intelligent vehicles, intelligent infrastructure, and the creation of an intelligent transportation system through integration with and between these two components" as well as "supports the overall advancement of ITS through investments in major research initiatives, exploratory studies, and a deployment support program including technology transfer and training". (U.S. DOT ITS JPO Web site, https://www.its.dot.gov/.) The JPO coordinates ITS research programs and initiatives across all U.S. DOT modes. Further information of the JPO's wide range of completed and current ITS research projects can be found on its Web site: http://www.its.dot.gov/index.htm.

This study collects and analyzes the currently available research specifically on motorcycle safety and ITS technologies. It then synthesizes this knowledge to determine gaps and opportunities for

additional research on this topic. With the use of this study the JPO and the greater U.S. DOT will have valuable information to help define a strategy that steers research efforts in the most efficient and effective direction to advance research on ITS for motorcycle safety. Below are some key areas in the evolution of ITS for motorcycle safety in which the U.S. DOT could have an important impact going forward.

- Leading and supporting the increase in involvement from and collaboration between public transportation agencies (especially State DOTs), research organizations, manufacturers, and riders on ITS and motorcycle safety issues;
- Enhancing national data sets that are pertinent to the advancement of research on ITS and motorcycle safety, such as the Fatality Analysis Reporting System (FARS);
- Incorporating recommended areas of research on ITS and motorcycle safety research into the goals of federally funded research programs and initiatives; and
- Evaluating motorcycle safety regulations and requirements in other countries, and whether their application in the U.S. would be beneficial.

Literature Review

Methodology

The overall methodology for the literature review was to identify existing resources and develop a database with the most relevant research articles and documents on motorcycle safety and Intelligent Transportation Systems (ITS) applications. The literature review broadly surveyed all 40 categories of investigation provided by the United States Department of Transportation (U.S. DOT), shown in Table 1 above, in order to determine which categories currently contain the most resources relevant to motorcycles. In addition to these categories, the project team used four broader subject areas to search for resources: Strategic Planning, Behavior, Technology, and Manufacturing. Literature searches under these four subject areas supplemented the 40 categories of investigation by collecting different types of resources, such as plans and news articles.

In total, the research team found 2,410 unique resources across all categories and subject areas. Although the process began with a total of 44 categories and subject areas, oftentimes little information was publically available on motorcycling and ITS for a given topic. Additionally, as the literature review progressed it became clear that some closely related topics justified merging two topics into one larger topic. Therefore, by focusing on 17 revised topics, the majority of the original 44 categories and subject areas were addressed. The final 17 topics are listed below.

1. Adaptive Front Lighting and Daytime Running Lights
2. Advanced Driver Assistance Systems
3. Antilock Braking Systems
4. Collision Warning and Avoidance Systems
5. Curve Speed Warning
6. Electronic Stability Programs
7. Helmet Mounted Displays and Visibility Improving Helmet
8. Inter-Vehicle Communication Systems and Motorcycle Detection Systems
9. Lane Keeping and Departure Warning Systems
10. Road Surface Condition Monitoring and Warning
11. Automated Crash Notification Systems
12. Pre-Crash Systems and External Airbags
13. Variable Message Signs
14. Strategic Planning
15. Behavior
16. Technology
17. Manufacturing

The project team established a well-defined process for the literature searches to help clarify when and why materials were included. The process began with searches for all literature related to a particular topic using a set of predefined search terms. For the most part, the team included articles less than 10 years old (i.e., from 2005 or later). The initial identification of relevant articles was based on article titles. For each relevant result, basic citation information (authors, title, journal, year, and URL) was documented. To assess whether an article was related to motorcycles, a text search of the

results page was conducted for the terms “motorcycle,” “two wheel,” or “two-wheel”. For each topic, the fraction of articles related to motorcycles was calculated based on these terms. It is important to note that, for articles relevant to multiple categories of investigation, the article was included once in each relevant category to provide readers with the full range of research for each category. This means that the number of articles for each category does not add up to the total number of unique articles across all categories. The project team took measures to ensure that articles were not double counted in statistics related to the total number of unique articles.

For articles that were motorcycle related, the full article was accessed, if possible, and summarized based on its abstract, introduction, and conclusion. For these articles, the references section was then reviewed for additional relevant sources.

The following search engines and sources were used to develop the literature review:

1. http://www.tandfonline.com/ - Taylor and Francis Group Web site. An international company that publishes books and academic journals
2. http://melvyl.worldcat.org/ - The online catalog of the University of California Library System.
3. http://oskicat.berkeley.edu/ - The online catalog of the University of California at Berkeley Library System
4. http://trid.trb.org/ - The resource center for the Transportation Research Board
5. https://scholar.google.com/ - The Google search engine for academic publications and scholarly literature.
6. http://www.mendeley.com/ - A desktop and web program for managing and sharing research papers and collaborating online.
7. http://www.researchgate.net/ - A social network for scientists and researchers to share papers, ask and answer questions, and find collaborators
8. http://www.academia.edu/ - A social network for academics
9. http://ntlsearch.bts.gov/repository/index.do - The National Transportation Library, a repository of public research papers.

All materials found in the literature review were organized by topic in a Microsoft Excel workbook associated with this project. *Appendix A, Literature Review—Workbook Documentation*, provides a user guide for understanding and using the information in this workbook. The full Excel workbook contains all articles researched, therefore representing research in each category of ITS beyond what only applies to motorcycles. The workbook contents are also presented in a more reader-friendly format in *Appendix B, Detailed Literature by Topic Area* for those works that are related to motorcycles. Appendix B is organized into the 17 final topics and provides the full range of information compiled for each resource that is related to motorcycles; including title, author, publisher, year of publication, Web address (when possible), and a brief summary of the paper or report.

Literature Review Synthesis

Of the 2,410 unique entries found in the literature review, 283, or 12 percent, were related to motorcycles. While this percentage is based on whether a given article’s results page contained the terms “motorcycle,” “two wheel,” or “two-wheel,” the vast majority of these motorcycle related articles are indeed primarily focused on motorcycles since results pages generally only includes the title, abstract, and other essential information. Table 2 summarizes the percent of entries related to motorcycles within each of the final 17 topics. Again, note that because articles were included under all relevant topics, the cumulative total of all 17 topics does not equal the total of unique entries.

Table 2. Summary of articles related to motorcycles in the literature review.

Topic	Total number of entries	Number of entries related to motorcycles	% of total number of entries
Adaptive Front Lighting and Daytime Running Lights	60	14	23%
Advanced Driver Assistance Systems	446	46	10%
Antilock Braking Systems	124	18	15%
Collision Warning and Avoidance Systems	414	28	7%
Curve Speed Warning	124	17	14%
Electronic Stability Programs	272	41	15%
Helmet-mounted Displays and Visibility Improving Helmet	40	2	5%
Inter-Vehicle Communication Systems and Motorcycle Detection Systems	106	15	14%
Lane Keeping and Departure Warning Systems	283	19	7%
Road Surface Condition Monitoring and Warning	193	7	4%
Automated Crash Notification Systems	105	12	11%
Pre-Crash Systems and External Airbags	160	3	2%
Variable Message Signs	136	0	0%
Strategic Planning	10	10	100%
Behavior	9	7	78%
Technology	64	58	91%
Manufacturing	25	19	76%
Cumulative Total	2,571	317	12%
Total Unique Entries	**2,410**	**282**	**12%**

In order to determine important insights, trends, and gaps that can be observed in the literature, a more thorough analysis was made on the most relevant and robust categories of investigation for motorcycle safety. For this purpose, the project team selected the seven categories of investigation that appeared most relevant to motorcycles based on a combination of the category's percentage of motorcycle related articles and the category's number of motorcycle related articles. These seven categories are listed below and then discussed individually in detail. The four broader subject areas are also discussed in greater detail to provide additional perspective.

- Adaptive Front Lighting and Running Lights
- Advanced Driver Assistance Systems

- Antilock Braking Systems
- Collision Warning and Avoidance Systems
- Curve Speed Warning
- Electronic Stability Programs
- Inter-Vehicle Communication Systems and Motorcycle Detection Systems

The following summaries present a detailed description of the articles found for these categories of investigation and the four broader subject areas.

Adaptive Front Lighting and Daytime Running Lights

The literature review found 60 articles in the category of Adaptive Front Lighting and Daytime Running Lights. Of these 60 articles, 23 percent (or 14 articles) mentioned motorcycles, and 22 percent (13 articles) were specifically related to motorcycles. This was the largest percentage of motorcycle-related articles found for any category of investigation, although neither the number of total articles nor the number of motorcycle-related articles was the largest. Adaptive Front Lighting and Daytime Running Lights refer to technologies that improve drivers' vision during poor visual conditions. These technologies focus on two important safety aspects: the ability to improve conditions to see the roadway more clearly, and increasing the ability for other vehicles to see motorcyclists. Adaptive Front Lighting usually considers modulating headlights, which adjust the vehicle headlight position and intensity according to the time of day and lean angle. Daytime Running Lights seek to increase motorcyclists' conspicuity, to allow other vehicles to detect motorcycles to avoid collisions.

The majority of motorcycle-related articles in this category sought to better understand the effect of Daytime Running Lights on motorcycle conspicuity—and the potential consequences of this effect. Daytime Running Lights are required for all new vehicles in Europe; however, this is not the case in the United States. There is a recurrent hypothesis that enabling Daytime Running Lights in a large portion of the vehicle fleet is associated with increased risk for certain types of multi-vehicle crashes. Approximately half of the articles challenged this hypothesis through various approaches. These articles, however, found conflicting results that appear to depend on contextual factors such as urban and rural settings, driver age, and several other case-specific scenarios. There remains, therefore, no clear agreement on whether higher penetration of Daytime Running Lights increases multi-vehicle motorcycle crash rates. Although Daytime Running Lights on automobiles are commonly seen as having a positive effect on car safety, the literature suggests that more attention should be paid to motorcyclists and other vulnerable road users. Further studies are needed to determine the effect of promoting Daytime Running Lights in motorcycles and other new vehicles.

The remaining articles generally sought to describe and test new Adaptive Front Lighting technologies for motorcycles. These articles dealt with motorcycle design and mechanics to proposed systems that increase the visibility of riders during poor visual conditions. Such articles generally agreed that there is a need to improve motorcycles' front lighting systems to enhance visibility during more dangerous conditions. Researching Adaptive Front Lighting capabilities in motorcycles and analyzing designs that better address motorcycles' particularities remains an important challenge and is a research gap that needs to be addressed moving forward.

Advanced Driver Assistance Systems

The literature review found 446 articles in the category of Advanced Driver Assistance Systems (ADAS). Of these 446 articles, 10 percent (or 46 articles) mentioned motorcycles, and 43 of these articles were specifically related to motorcycles. It is important to note that while the ADAS category did not have a particularly large percentage of articles related to motorcycles (relative to other

categories of investigation in this study), this category did have both the largest number of total articles and the largest number of articles related to motorcycles. ADAS are, therefore, a large and important component of current research in ITS applications for motorcycles.

ADAS is an umbrella term that covers a number of ITS technologies, many of which fall into other independent categories of investigation in this literature review (such as Adaptive Front Lighting, Collision Warning and Avoidance Systems, Curve Speed Warning, Driver Status Monitoring, Lane Keeping and Departure Warning Systems, Intelligent Speed Adaption, and more). There is no exact definition of the technologies that fall under the category of ADAS, but generally speaking ADAS are systems that assist drivers and can include informing systems, warning systems, active assistance systems, and autonomous systems.

The majority of ADAS articles related to motorcycles focused entirely on the safety benefits of ADAS for motorcycles. This is partly because many of these articles were products of the European Commission's SAFERIDER project, which focused on identifying key ARAS (Advanced Rider Assistance Systems) functions for motorcycles, develop motorcycle-specific prototype systems for each of these key functions, and test motorcycle-friendly ARAS interfaces. SAFERIDER identified speed alert functionality, curve warning, frontal collision warning, improving safety at intersections, and lane change support as the five key ARAS functions for motorcycles and developed and tested prototype systems for each. The SAFERIDER articles generally documented this work and concluded that these ARAS functions had promising applications for motorcycle safety if further developed. The SAFERIDER project has created a body of work that future research into ARAS and motorcycle safety should build upon.

A portion of the motorcycle-related ADAS articles were less explicitly focused on safety and instead concentrated on the technical advancement of ADAS for motorcycles. For example, a number of articles studied new models of motorcycle steering control, handling, and roll angles, which can be used to better adapt ADAS to motorcycles. Likewise, several articles documented motorcycle riding simulators built specifically to test the effectiveness of ADAS for motorcycles. These articles acknowledged the necessity of such research to the advancement of ADAS for motorcycle safety, indicating that the research community is consciously building a foundation for future work in this area.

Interestingly, many of the ADAS articles on motorcycles investigated the acceptability of ADAS to riders. The trend among these articles was that the overall acceptability of ADAS is low, but it is relatively higher for:

- Riders that perceive greater risks,
- ADAS technologies that interfere less with the riding task,
- ADAS technologies that are useful in emergencies, and
- ADAS technologies that are widely used (i.e., Antilock Braking Systems (ABS)).

Similarly, researchers found that willingness to pay for ADAS was correlated with social norms and the usability of the interface. However, riders generally preferred existing safety equipment (e.g., helmets and protective clothing) because they considered it more reliable and cheaper. These studies highlighted that the acceptability of ADAS is a major obstacle to implementing ADAS for motorcycle safety and that further developing methods to test the acceptability of ADAS is needed.

Along the same lines, some articles focused on the need to adapt ADAS to the unique needs of motorcycles, thereby making the technologies more acceptable to riders. Such articles tested different methods of communicating warnings or information to riders (generally through audio, visual, or haptic means). No stark conclusions emerged, although some preference for haptic (glove or smart helmet) was observed.

The small remainder of ADAS articles related to motorcycle focused generally on ITS for motorcycle safety, concluding that ADAS is among the most promising areas of ITS for motorcycle safety and confirming its importance for future research agendas.

Antilock Braking Systems

The literature review found 124 articles in the category of Antilock Braking Systems (ABS). Of these 124 articles, 15 percent (or 18 articles) were related to motorcycles. This represents a relatively large percentage of motorcycle-related articles, although a roughly average number of total articles and motorcycle-related articles. ABS technology is a system that allows vehicles to maintain tractive contact with road surfaces while braking; preventing skidding and improving vehicle control while braking.

ABS technology was first implemented in motorcycles in the 1980s and has since been continuously applied to new products. In 2012 the European Commission passed legislation that required all new motorcycles above 125cc to have ABS fitted starting January 1, 2016. (125 cubic centimeters: cubic centimeters are used to measure the size of a motorcycle's engine chamber.) ABS is not mandatory in the United States; however, since this technology has been available commercially for decades many motorcycles in the U.S. are currently equipped with ABS technology. This has facilitated a large amount of research that analyzes crash data to determine the effect of ABS technology on crash rates. Twelve out of the total 19 motorcycle-related articles found in this category conducted a statistical analysis of crash data to determine the safety benefits of ABS-enabled motorcycles. Generally, motorcycles with ABS have proven to be 31 to 37 percent less likely to be involved in a fatal crash, 24 to 42 percent less likely to be involved in an injury crash, and 20 to 28 percent less likely to file an insurance claim than motorcycles without ABS. The remaining seven articles focused on research to further improve the performance and design of ABS for motorcycles; for example, improving the braking distance and time for motorcycles with ABS or adapting ABS to lighter motorcycles.

Although ABS technology is not new, it remains one of the categories with the greatest potential for motorcycle safety—especially due to its relatively widespread acceptance among the motorcycle community. Unlike many other ITS technologies for motorcycle safety, ABS have penetrated a significant portion of the market, and riders have both accepted and experienced its safety benefits. This is confirmed by research into the acceptance of other ITS technologies for motorcycles, which shows that acceptance is currently highest for ABS and other technologies that are not seen as interfering with riding tasks. Researchers and policy makers have the opportunity to build upon this momentum to extend the safety benefits of ABS to the entire motorcycle community.

Collision Warning and Avoidance Systems

The literature review found 414 articles in the category of Collision Warning and Avoidance Systems. Of these 414 articles, seven percent (or 28 articles) mentioned motorcycles, 6 percent (25 articles) were specifically related to motorcycles. While this category had a relatively small percentage of articles related to motorcycles, it did have the second largest number of total articles and the third largest number of articles related to motorcycles. Only the categories of Advanced Driver Assistance Systems and Electronic Stability Program had larger numbers of motorcycle related articles. Collision Warning and Avoidance Systems, therefore, are among the top ITS technologies currently being studied for motorcycle applications.

Collision Warning and Avoidance Systems refer to systems that detect objects in the roadway and warn the rider if objects become a collision risk. In most cases, Collision Warning and Avoidance Systems would then apply autonomous emergency braking if the rider does not respond to the collision risk. Many motorcycle-related articles in this category focused on a type of Collision Warning and Avoidance Systems known as Motorcycle Autonomous Emergency Braking (MAEB). MAEB systems generally detect obstacles through sensors in the front of the vehicle and apply an

emergency brake force if the rider does not respond. Several articles evaluated the effectiveness of MAEB using reconstructions of real-world motorcycle crashes and largely found that MAEB would have reduced impact speed by approximately 10 percent—mitigating crash severity in a majority of cases. Other articles documented research that supports the development of MAEB, such as research into the Last-Second Swerving Model. This model computes the minimum swerving distance needed to avoid a collision and activates MAEB when a collision is no longer avoidable. Research shows that this model has good predictive capability under different riding styles and collision scenarios. However, acceptability of systems like these require further research.

A smaller subset of articles discussed various concepts of Forward Collision Warning Systems (FCWS). For example, the European Commission's SAFERIDER project identified FCWS as one of the five key ARAS functionalities for which the project developed and tested motorcycle prototypes. A couple articles documented SAFERIDER's FCWS prototype, which simultaneously evaluates whether the rider is traveling at a safe following distance and at a safe speed relative to obstacles ahead. The system warns the rider if either the following distance or speed become unsafe. Other articles looked into various detection technologies that could be used in FCWS, including camera-based detection, vehicle-to-motorcycle Connected Vehicle technology, and a system where motorcycles carry transmitters that warn automobiles carrying a receiver.

The search terms for the Collision Warning and Avoidance Systems category also returned several articles on ABS, which is an independent category of investigation in this study, as well as a number of articles that were only distantly related to Collision Warning and Avoidance Systems. Nonetheless, the number of substantive articles on the motorcycle applications of Collision Warning and Avoidance Systems indicates that this category of investigation has strong potential to enhance motorcycle safety. Further, the similarities between Collision Warning and Avoidance System and ABS could be utilized to boost the advancement and acceptance of Collision Warning and Avoidance Systems, since ABS is widely implemented and accepted among motorcyclists. Future research should build off the existing developments in MAEB and FCWS technology with special attention towards designing and presenting these technologies to suit the needs and wants of motorcyclists.

Curve Speed Warning

The literature review found 124 articles in the category of Curve Speed Warning. Of these 124 articles, 14 percent (or 17 articles) mentioned motorcycles, while 12 percent (15 articles) were specifically related to motorcycles. Both the total number of articles and the number of motorcycle-related articles in this category were approximately average compared to other categories of investigation in this literature review. However, the percent Curve Speed Warning articles that were related to motorcycles (14 percent) was above average, suggesting that this area of ITS has good applicability and potential when it comes to motorcycle safety.

For the purposes of this report, Curve Speed Warning was defined as an infrastructure-based system that uses vehicle-to-infrastructure communications to warn drivers of safe speeds for an upcoming curve. The literature review results, however, suggest a broader interpretation of Curve Speed Warning, including vehicle-based technologies that use maps and models of motorcycle dynamics to determine safe speeds for curves. Additionally, several articles in the literature review focused on more traditional approaches (i.e., non-ITS approaches) to Curve Speed Warning, such as high visibility fluorescent background signage and innovative pavement marking. This serves as a reminder that ITS approaches to Curve Speed Warning will need to operate in concert with more traditional approaches.

Adding more complexity to this characterization, Curve Speed Warning technologies are also considered to fall under the umbrella of ADAS (or ARAS). The European Commission's SAFERIDER project identified "Curve Warning" as another one of the five key ARAS functionalities for which the project developed and tested motorcycle prototypes. As a result, the literature review contains a number of motorcycle-related articles on Curve Speed Warning systems (including a couple from the

SAFERIDER project) that only discussed these systems in the larger content of ADAS or ITS technologies with strong potential to improve motorcycle safety. While these articles did not focus entirely on Curve Speed Warning systems, it is clear that there is some consensus that these systems should be further developed for motorcycle use.

Two standout articles documented the development of prototype Curve Speed Warning systems for motorcycles. One, from the SAFERIDER project, uses map information, road geometry, motorcycle dynamic models, and rider inputs to establish an ideal reference maneuver to which the motorcycle's current position and speed can be compared. If the SAFERIDER system determines that a correction is needed, it warns the rider through an interface that includes a haptic accelerator throttle, vibrating glove and helmet, and visual display. Another Curve Speed Warning prototype tested the effectiveness and acceptability of warnings sent via force feedback throttle versus haptic glove. The researchers here found that both versions prompted an earlier and stronger adaptation of the motorcycle to the curve, but that riders expressed a preference for the haptic glove prototype. These studies serve as an important foundation for future efforts to design Curve Speed Warning systems for motorcycles.

The remaining motorcycle-related Curve Speed Warning articles covered research efforts that tangentially support the development of Curve Speed Warning for motorcycles. For example, one article developed a model of motorcycle speed reduction rates as riders approach intersections while another article established a method for computing the maximum safe speed for motorcycles along a curve.

The intersectionality of Curve Speed Warning with other ITS technologies and traditional safety strategies means that the motorcycle-related articles in the literature review were somewhat less focused on the development Curve Speed Warning systems. Nonetheless, the limited research into prototype systems for motorcycles is substantive and the consensus among researchers that Curve Speed Warning system show great potential and could incite further research.

Electronic Stability Programs

The literature review found 272 articles in the category of Electronic Stability Programs. Of these 272 articles, 15 percent (or 41 articles) mentioned motorcycles, 13 percent (36 articles) were specifically related to motorcycles. This category had a large number of total articles, a large number of motorcycle-related articles, and a high percentage of motorcycle articles. The individual articles show that there is a diversity of motorcycle-related research in the area of Electronic Stability Programs, which is also referred to as Electronic Stability Control (ESC), Dynamic Stability Control (DSC), and Traction Control. Generally, Electronic Stability Programs are computerized technologies that improve vehicle stability by detecting loss of traction (skidding) and steering control. When this happens, Electronic Stability Programs automatically apply the brakes to help regain traction and steering.

The large majority of motorcycle-related articles in this category were entirely focused on advancing Electronic Stability Programs for motorcycles (although a handful discussed applying this technology to new "narrow-tilting vehicles," which are three- or four-wheeled narrow vehicles whose body or wheels tilt in the direction of the turn). Most of these articles, however, did not directly discuss the safety implications of Electronic Stability programs and instead simply documented technical research supporting the advancement of certain components of this technology. For example, this research covered topics such as models of motorcycle handling and steering control; simulations of steer-by-wire systems; optimal controllers to improve handling; models and sensors for estimating roll angle; and a prototype sensor unit that provides information on acceleration, velocity, and inertia. These articles provide important foundational research for the implementation of Electronic Stability Programs in motorcycles and highlight the application of this technology to motorcycles even though the exact safety benefits have yet to be studied.

Several articles presented research on the implementation and performance of actual Electronic Stability Programs, typically focusing on conditions that are difficult for these systems in motorcycles. For example, researchers assessed Electronic Stability Programs in motorcycles during challenging maneuvers while braking, on curves, and on rough roads. Along with the technical research discussed above, these studies show a level of sophistication in efforts to develop Electronic Stability Programs for motorcycles. Future research on Electronic Stability Programs for motorcycles should continue efforts to improve this technology, especially on curves, and should initiate studies into the potential safety benefits of this technology—in addition to studying the benefits to maneuverability and control.

Inter-Vehicle Communication Systems and Motorcycle Detection Systems

The literature review found 106 articles in the category of Inter-Vehicle Communication Systems and Motorcycle Detection Systems. Of these 106 articles, 14 percent (or 15 articles) mentioned motorcycles, and 14 articles were specifically related to motorcycles. This represents a relatively large percentage of motorcycle-related articles, although neither the number of total articles nor the number of motorcycle-related article was large, compared to other categories of investigation. Inter-Vehicle Communication Systems and Motorcycle Detection Systems refer vehicle-to-vehicle (V2V) communication technologies that detect nearby vehicles and notify the driver of potential risks or other relevant information.

Such technologies are vehicle-based and, when applied to motorcycles, would be motorcycle-based as well. Due to the automobile-centric nature of current ITS research, however, the motorcycle-related articles in this category largely covered one-way technologies for automobiles to detect motorcycles. For example, a few researchers have been working to advance the Motorcycle Approaching Indication (MAI) function in V2V systems for automobiles. Another research effort tested a prototype detection system using radio waves where motorcycles carry transmitters and automobiles carry receivers. These technologies offer considerable safety benefits to motorcyclists because they lower the risk of automobile-motorcycle crashes. Still, future research efforts should investigate motorcycle-based communication and detection technologies as well, especially given that human-machine interfaces for these technologies will need to be specially designed for motorcyclists. One standout article documented a prototype vehicle-to-infrastructure (V2I) communication technology—closely related to V2V—for motorcycles, which uses smartphone and Bluetooth technology. Such research is a promising step in the direction of developing motorcycle-based communication and detection systems.

The remaining articles discussed prototypes for stationary Motorcycle Detection Systems. These systems generally consisted of multi-instrument sensors (stereo cameras, thermal infrared cameras, acoustic sensors, and/or unidirectional microphone arrays) that could be installed in intersections or along roadways. They have been designed to perform functions such as counting and differentiating between automobiles, motorcycles, and bicycles or determining whether riders are wearing helmets. Beyond collecting data, this research does not appear to have been applied to any tangible safety benefits, although there is certainly potential to build upon this research in order to develop V2V and V2I technologies for motorcycle safety.

Broader Subject Areas

To compliment the literature review, the project team collected additional articles from alternative sources, such as institutions' Web sites and news articles. To maintain a consistent structure within the larger literature review, the articles were categorized within four subject areas: Strategic Planning, Behavior, Technology, and Manufacturing.

The first search term, Strategic Planning, contained 10 articles written primarily by public agencies, describing efforts made to incorporate ITS technology in motorcycle safety planning endeavors. Articles found include national and international case studies. On the national level, articles related to policy strategies, like the National Highway Traffic Safety Administration's (NHTSA) efforts to investigate the effectiveness of rider training programs on riders' safety. Other national strategies found include the "Michigan Safety Action Plan 2009-2012", a document that defines strategies to steer riders' safety issues in Michigan towards a safer environment. Internationally, many countries have developed strategic safety plans. The "Action Plan for Improving Road Safety for Motorcyclists", by the Dutch Ministry of Infrastructure and the Environment, defines a strategic approach to reduce motorcycle crashes in the Netherlands, discussing topics such as braking and stability technologies. Other countries that have developed plans to deal with motorcyclists' safety include England and Ireland. Although a portion of these plans discuss the use of technology, the majority focus on education and enforcement issues.

The second search term focused on articles that discussed how rider behavior relates to safety. A total of nine articles are presented in the literature review, seven of them focusing on motorcycle issues. The authors of these articles include academic and public agencies. One article that stands out is the "Study of Motorcycle Rider Braking Control Behavior", by NHTSA. This article investigated possible relationships between rider characteristics, braking behavior, and event outcome. In general, these topics agree that riding behavior should be researched further to understand how rider behavior can be influenced to improve safety.

Given the nature of this study, a large effort focused on identifying technology-related articles. A total of 64 articles are included in this category, 58 of them focused particularly on motorcycle technology. The majority of these articles consist of specialized magazines or journal articles, describing new and upcoming technology. Among innovative technology improvements, these articles mention Intelligent Speed Adaption, Adaptive Front Lights, Helmet Technology, Heads-up Displays, Airbags, and V2V technologies. Many articles focused primarily on presenting the benefits of the technology under discussion, which, depending on the publisher's nature, made it difficult to draw unbiased insights. Furthermore, the scope of this search term was too broad to identify particular technological trends. However, these articles demonstrate an overwhelming sentiment across these journals: ITS technology has great potential to improve safety conditions across all motorcycle riders.

Finally, understanding that technologies are mostly delivered by manufacturer companies, an effort was made to capture manufacturers' publications regarding motorcycle safety and technology. A total of 25 articles were compiled, 19 of them focusing specifically on motorcycles. These articles focus on describing the manufacturers' perspective on upcoming technologies. Articles on the BMW company Web site, for example, describe their motorcycles' Automatic Stability Control an Adaptive Front Light technology. Honda's articles focus on promoting their research on enhancing connectivity between vehicles, or their airbag technology. Although these articles are biased in nature, they are useful to understand what different manufacturers are doing to keep track of and push state-of-the-art technologies in the motorcycle manufacturing industry.

Literature Review—Trends

The analysis presented above allowed for the identification of common trends across the different categories of investigation in the literature review. Identifying trends in current research helps to understand the direction of current research efforts, extract useful insights, and inform the project's recommendations and strategies for future research efforts. The section below describes the five main trends identified in the literature review.

Continuous Focus on Design Improvements

A common trend among the literature compiled was the desire to continually improve the technologies' design and operation, for a better fit to motorcycles' characteristics. Nearly all areas of ITS contained research related to design improvements. One example is Adaptive Front Lighting, for which researchers continued to study mechanical improvements that take into account lean angles, light intensities, and natural light, to improve the front lights of motorcycles. Similarly, ABS technology was shown to be continually evolving over time, as it has been bundled with other technologies such as Stability Control, for better braking. Curve Speed Warning and Collision Warning Systems were also shown to be evolving, as research efforts continue to focus on identifying operational frameworks that target particular motorcycle safety issues while seeking to address motorcyclists' wants and needs for greater acceptability.

Multi-Instrumented Vehicles

As technologies continue to evolve, the instrumentation costs decrease—allowing researchers to develop and test more instrumented prototypes. ITS research areas such as Collision Warning Systems, Electronic Stability Programs, and Inter-Vehicle Communication Systems are now including new instruments such as sensors and camera-detection technology to improve system performance. Automated systems, like the Motorcycle Autonomous Braking System, can now be robustly tested, as instrumentation costs continue to decrease. Furthermore, technologies such as Inter-Vehicle Communication Systems are becoming more popular as communication between vehicles (V2V), infrastructure (V2I), and other components of the transportation system, such as pedestrians and bicyclists, (V2X) become a reality.

Technology Analysis Tools

A considerable portion of existing research on ITS and motorcycle safety focused on models, simulators, and algorithms, to better understand how the technology works. Technological improvements such as Electronic Stability Programs and Speed Warning Systems continue to develop the required technical aspects that describe in detail the operation of each technology. Although there is a need to test technologies through prototypes, there is also a need to understand and evaluate in depth the mechanics of these technologies so that they can be improved to promote safety during diverse conditions. Technology analysis tools will likely continue to be an important focus of research activities in the field of ITS for motorcycle safety.

Statistical Analysis

An important analytical tool in the field of ITS for motorcycle safety has been statistical analysis of technologies already operating in the market. Technologies such as ABS and Daytime Running Lights have been subject to statistical analysis, to determine the real impact they have on safety issues. With detailed enough data, researchers have been able to isolate the effect of these technologies, and determine if a technology has successfully improved safety conditions for motorcyclists. As new technologies continue to roll out and data becomes more available, researchers will be able to provide a clearer picture of the real effects that different technologies have on safety issues, which could then help direct research and development as well as lead to policy recommendations.

Increase Motorcycle Conspicuity

A notable trend across several areas of ITS technologies was that researchers have continuously tried to increase motorcycles' conspicuity, as they interact with other vehicles. Researchers understand that an important factor to increase motorcycle safety is to make riders more visible, particularly during low visibility conditions. Technologies such as Daytime Running Lights and Inter-Vehicle Communication Systems have sought to increase vehicles' ability to detect motorcycles to avoid collisions. Furthermore, as communication technologies between vehicles (V2V) continue to evolve, motorcycle conspicuity will continue to increase too.

Support for Developing Intelligent Transportation Systems for Motorcycle Safety

Finally, there was an appreciable amount of literature that evaluated which areas of ITS hold the most potential for motorcycle safety, with a clear consensus that developing ITS for motorcycle safety in general is an important research concern. There appears to be some agreement that ABS, ADAS, Collision Warning and Avoidance Systems, and Curve Speed Warning are priority areas for the development of motorcycle ITS in the near future. However, this should not deter research efforts into the application of other ITS technologies for motorcycles—especially those that have been, relatively, less studied.

Literature Review—Gaps

In addition to the trends discussed above, the literature review revealed some important gaps in current research on ITS and motorcycle safety. The following gaps were identified across all categories of investigation in the literature review. Future research—and research funding programs—should endeavor to promote more work in these areas.

Complete Prototype Systems for Motorcycles

With the exception of standout research efforts like the SAFERIDER project, relatively few articles discussed prototypes of complete, applied Intelligent Transportation Systems for motorcycles. Given the large number of articles focused on models, simulators, algorithms, devices, and other smaller, technical components of these systems, it appears that the field of ITS for motorcycle safety has amassed a good deal of technical research that researchers can now build upon to develop complete prototypes for motorcycles. Without undercutting the necessity and significance of existing research, this gap highlights an important next step in the development of ITS for motorcycle safety. Future research should follow the lead of the SAFERIDER project and others to investigate the real-world applications of ITS prototypes for motorcycles. This will help the full range of motorcycle ITS technologies advance to the very important next stage of development: implementation.

Assessment of Safety Benefits

In certain categories of ITS—such as Adaptive Front Lighting and Running Lights, ADAS, and ABS—there has been an appreciable amount of research into the empirical and simulated safety benefits for motorcycles. In other categories, however, such research is somewhat lacking, specifically: Curve Speed Warning, Electronic Stability Programs, and Inter-Vehicle Communication Systems and Motorcycle Detection Systems. It is important that research efforts do not automatically assume that technical advancements in motorcycle maneuverability lead to safety benefits, as the interaction between new technologies and rider behavior can result in unintended safety impacts. For example, the ability to remain stable and brake quickly on curves and at high speeds may or may not result in riskier riding behavior. For this reason, the potential safety impacts for motorcycles should be explicitly investigated for all categories of ITS.

Acceptability of Intelligent Transportation Systems to Riders

Similarly, certain categories of ITS—primarily those that fall under the umbrella of ADAS—have focused to some degree on the acceptability of ITS to riders as well as the need to custom-design ITS technologies for motorcycles. In most categories, however, research along these lines was relatively limited. User acceptability is key for the successful implementation of ITS—particularly for ITS technologies that interfere more with operating tasks, such as ADAS and Collision Warning and Avoidance Systems—as these encounter more resistance from riders. In concert with the development of prototypes, researchers should be evaluating what riders need and want from ITS systems and incorporating these insights into prototype systems.

Research and Regulations in the United States

The European Commission's SAFERIDER project arguably represents the most comprehensive effort to develop ITS for motorcycles. This research is very applicable to ITS and motorcycle safety in the U.S.; however, it is important to acknowledge that this work developed in a European context and that European roadways and riders differ from American roadways and riders in ways that may influence safety impacts. In this light, researchers should use the SAFERIDER project as a springboard and source of insight to independently develop ITS prototypes for the U.S. context, in order to avoid issues with transferability. The same applies for other research and prototypes developed abroad.

The U.S. also differs from European countries in that it does not mandate the inclusion of ABS or Daytime Running Lights in all new vehicles. Future research efforts should investigate the potential benefits and costs of adopting such regulations in the U.S. If such regulations do have the potential to increase motorcycle safety through greater ITS penetration, it will be important to have ample research to verify and document these impacts.

Harmonization of Intelligent Transportation Systems

There was virtually no research on harmonizing ITS technologies so that they are interoperable across all vehicles and roadways. This concept has recently entered the global dialogue on ITS and motorcycle safety with the launch of the Connected Motorcycle Consortium at the ITS World Congress in October 2015. This consortium is spearheaded by BMW Motorrad, Honda, and Yamaha and aims to promote Cooperative-Intelligent Transportation Systems (C-ITS) with a focus on interoperable inter-vehicle communication systems. The Connected Motorcycle Consortium is notable for promoting cooperation rather than competition between manufacturers. In light of this new development, however, it is especially noteworthy that existing research on ITS and motorcycle safety does not address the important issue of ITS harmonization and interoperability.

Understudied Areas of Intelligent Transportation Systems Research

Finally, it is important to mention the areas of ITS where either little motorcycle-related research or little research of any kind has been documented. The literature review revealed that the vast majority of articles fell within 17 areas of ITS; however, six of these areas had a relatively low percentage of motorcycle-related research: (1) Helmet-Mounted Displays and Visibility Improving Helmets, (2) Lane Keeping and Departure Warning Systems, (3) Road Surface Condition Monitoring and Warning, (4) Automated Crash Notification Systems, (5) Pre-Crash Systems and External Airbags, and (6) Variable Message Signs. Additionally, the literature review found little research of any kind on over half of the 40 categories of investigation provided by the U.S. DOT for this study. The lack of research or motorcycle-related technology does not necessarily mean that these understudied areas of ITS do not have the potential to improve motorcycle safety. Researchers should continue to consider and explore the potential safety benefits that these areas of ITS might offer to motorcycles.

Privacy

The potential privacy concerns of the motorcycle community were generally not covered in existing research. While motorcycle ITS will not collect Personally Identifiable Information (PII)—and there is no desire and no need to collect PII—it will be important for all stakeholders to voice and cooperatively address any concerns in order to fully realize the benefits of ITS for motorcycle safety. Otherwise, unaddressed privacy concerns may decrease the acceptability of motorcycle ITS to riders, restrict widespread deployment, and ultimately detract from the full, potential safety benefits of having widely-implemented motorcycle ITS.

Practitioner Interviews

Methodology

Recognizing that research activities are continually underway, it was important to further inform this literature review by interviewing leading practitioners. The goal of this outreach was to capture a more nuanced state of the practice and to further explore the categories of investigation. The interviews allowed practitioners to discuss their interest areas and their perspectives on the categories of investigation, along with other technology and safety advancements in the motorcycling area.

The interviews were conducted via telephone. Stakeholders were identified, selected and contacted to participate voluntarily in this activity. To reduce response bias, participants were guaranteed anonymity. The interview process followed defined guidelines according to the four stakeholders categories identified:

- Manufacturers.
- State Departments of Transportation and Public Safety Agencies.
- Academia.
- Industry Associations and Research Organizations.

The section below summarizes these perspectives and presents the more refined state of the practice that was gleaned from this outreach. For more detail information on the interview process, the interview guidelines are presented as Appendix C of this document.

Practitioners Interviews Synthesis

Manufacturers

The manufacturers approached provided rich insights on the development and application of motorcycle technology. It was clear that there are different approaches to Intelligent Transportation Systems (ITS) technology and implementation according to the manufacturer size. For small manufacturers (manufacturers that focus on motorcycle vehicles exclusively and do not have Research and Development (R&D) departments), keeping up with technology implementation and innovation represents a challenge. While large manufacturers have the resources to invest and develop new technology, small manufacturers struggle to keep up with the vehicle's evolution, and their adoption for market competitiveness. Even so, for large manufacturers advancing motorcycle technologies was still a small part of their very large operations in comparison to other vehicles being manufactured in the same company. However, there is a consensus that technology innovation and application provides important safety benefits to the motorcycle community. A common gap identified by all manufacturers was communication technology, and not only among vehicles, but with the motorcyclist as well. The manufacturers expressed a need to define best practices for technologies that alert and inform motorcyclists without distracting them. Furthermore, practitioners discussed new opportunities that are occurring as communication technology continues to grow and improve. For instance, some practitioners mentioned the ability to develop and update software and firmware on vehicle's computers, without the need for new hardware. An example can be found in Tesla Motors'

system updates, which enhance their vehicles' operations through wireless software updates. However, while the proliferation of technological connectivity opens a world of opportunities for motorcycles, some manufacturers were concerned that these technological improvements might disproportionally affect small manufacturers. There is a need to study further how these technologies should be developed for upcoming vehicles, seeking to foster cooperation and inclusion among all stakeholders involved.

State Departments of Transportation and Public Safety Agencies

There is a lack of involvement from public agencies in motorcycle research and technology applications and often motorcycle specific activities fell into the safety divisions of State Departments of Transportation (DOT). Few State DOTs have specific divisions for motorcycle issues, most of their involvement is through the State's Strategic Highway Safety Plans (SHSP). Such is the case of California and Oregon's "Team Oregon." Through these entities, these states are focusing on improving motorcyclists' safety through policy application and design considerations with little emphasis given to technology solutions. With respect to technology applications, agencies are aware that there is a need to incorporate motorcycle vehicles in upcoming ITS innovations, and promote an integrated system where technology improvements consider not only cars, but multiple modes of transportation and behaviors. The State DOTs commented that detection technologies and research came to the top of their wish list for motorcycle safety and ITS implementation.

Academia

Technology in the motorcycle research community is currently an important and vibrant topic. In spite of being a relatively small community, their work and collaborative efforts, at an international level, continue to test and promote different technologies to improve riders' safety and mobility. Although research efforts are advancing, the general feeling of the research community is that there is a desire of larger funding alternatives and greater involvement from public agencies and manufacturers in research activities. An important insight is the difference between motorcycle use in the United States and in European and Asian countries. In the U.S., motorcycles are often used for leisure trips, while in European and Asian countries motorcycles are more frequently used for commuting and other essential trips. In the recent development of motorcycle technology there has been a distinction between road bikes (touring) and "scooters" and mopeds—generally used in dense urban areas. These differences have lead research efforts towards different focuses, which needs to be considered when evaluating the results of such studies.

Industry Associations and Research Organizations

The work of industry associations and research organizations, has helped define the safety benefits of technology improvements in the motorcycle community. Industry associations have followed up on new technology and its impact on safety. As an example, they have conducted research that documents how Antilock Braking Systems (ABS) have increased riders' safety and are now a seamless and accepted technology for most users and manufacturers. These organizations have helped link research activities to policy integration in order to promote technology development for future products. The main bottlenecks voiced during the interview was the lack of quality data, which would help isolate the specific role of technologies in motorcycle crashes, and the need to better define the safety benefits of new technologies. These interviews also helped define other needs and gaps in current policies that do not involve technology applications, but that would have a significant impact on riders' safety. For example, policies related to helmet use, alcohol limits, and training and credentials are crucial to improved safety in the motorcycle community.

Practitioners Interviews—Themes

Evaluating common threads among the practitioner interviews revealed five overarching themes in the field of motorcycle safety and ITS:

Strong Motorcycle Community

A common denominator throughout the practitioner interviews was the sense of community that the stakeholders have helped built. The number of motorcyclists in the US is relatively small in comparison to users of other modes of transportation. However, the voice of the motorcycle community is strong. There is consensus within the community that technology improvements have been beneficial for riders' safety. In particular, most interviewees defined ABS and lean stability improvements as applications that have not only improved safety issues, but enhanced the overall riding experience. This portrays a positive horizon for future technology improvement, testing, and adoption.

Connectivity

Most of the stakeholders interviewed identified connectivity as an important technology application for the near-term future. The interviewees recognized current trends in road transportation, like Connected Vehicle technology and communication enhancements (V2V, V2I, and V2X), and wanted motorcyclists to be considered during the evaluation of this technology. Furthermore, practitioners identified opportunities to further develop vehicle's performance through system, software, and firmware updates, enabling vehicles to enhance their performance. With current technologies, these updates could take place wirelessly and frequently. Most interviewees also identified communication enhancement between users and their vehicle as a technology area with great potential to improve safety and enhance the riding experience. However, the application of such technologies specifically to motorcyclists should be further investigated as the engagement and focus of a motorcyclist is very different from that of an automobile driver. It would, therefore, be beneficial to study communication enhancement technologies for motorcyclists independently from similar technologies for other vehicles. It is also important to consider how these technologies could affect vehicle production. Some stakeholders mentioned their concern that as technology evolves, it could hamper small manufacturers to compete in the market.

System-Wide Approach

Practitioners also highlighted that new technologies benefit from interacting with each other. They considered most of the potential technologies (the categories of investigation) beneficial, but also identified the need to group them and roll them out as a system, instead of as separate technology enhancements. Of the categories of investigation, ABS (particularly seeking to improve ABS performance), Adaptive Front Lighting, Dynamic Stability Control, and Advanced Driver Assistance Systems (particularly looking to enhance communication with riders) were the most commonly voiced applications for advancing motorcycling safety and mobility. There were categories that were noted as not having much applicability to motorcycling; like the Pop-Up Bonnet, Intelligent Speed Adaption, and Impact Sensing Cut-Off Systems. Otherwise, these topics were rarely discussed during the interviews.

Riding Experience

Although practitioners expressed openness to new technologies, they wanted to further discuss the design of such technologies as it relates to motorcyclists' riding experience. Identifying the technologies needed is only the first step, designing them is equally important. One of the main topics discussed on this area was maintaining user control over the vehicle. There is little support in the community for automation in this respect. Technology improvements should help riders avoid and react to undesirable events, but not by distracting riders and causing unnecessary crashes.

Technologies considered for other modes of transportation are tailor-made for their operations, and so should technologies targeting motorcycles. After all, as one interviewee pointed out, “one can fall off your motorcycle, but you can’t fall off your car!”

Bottlenecks: Funding and Robust Data

One of the main bottlenecks identified for technology research and promotion was funding. From initial research to technology testing, the stakeholders involved believe that there should be more funding opportunities for research and development across the entire spectrum of motorcycle safety research activities. Interviewees also identified the relative lack of comprehensive and accurate data on motorcycle safety and usage as another important bottleneck. The interviewees recognized that having more robust crash data sets available would enable a greater understanding of different motorcycle technologies and their role during these events. Being able to isolate and understand these benefits would help develop ITS technologies specifically for motorcycle safety.

Motorcycle Safety and ITS—Overall Trends

Having collected a significant amount of data from the current literature and practitioner interviews, the project identified the overall trends in motorcycle safety and Intelligent Transportation Systems (ITS) research. Defining these trends provides the foundation to understand the gaps and opportunities for future research efforts. This section synthesizes key findings from the literature review and practitioner interviews sections to identify and discuss overarching trends in the current field of motorcycle safety and ITS.

Consensus That Intelligent Transportation Systems Can Improve Motorcycle Safety

One of the most important trends identified was the overarching sense that ITS technology can have a significant, positive impact on safety-related issues in transportation. From the literature articles compiled and the interviews conducted, there was a general consensus that motorcyclists' safety can improve with the use of several of the ITS technologies evaluated. A clear example of technology being successful in improving safety conditions for motorcyclists was Antilock Braking Systems (ABS) braking technology. Authors and interviewees alike highlighted that with the roll-out of ABS technology in the motorcycle market, riders are now safer and have greater control of the vehicle, resulting in better riding experiences. This finding shows potential for new and upcoming technologies to enhance motorcycle safety.

Need for Tailored Solutions

A second trend identified was the need to focus specifically on *motorcycle* safety issues, and not automobile or commercial vehicle safety issues, in order to address them correctly. The general perception of authors and interviewees was that solutions for other vehicles are not always the solutions required to improve motorcycle safety. In this case, one size does not fit all. In recognition of this, research efforts have sought to address issues that, sometimes, are not even exclusive to motorcycles, but are focused on a specific motorcycle type. Manufacturers and researchers are conscious that ITS technologies for motorcycles require a deeper understanding of the issue the technology is facing, the type of vehicle and user, and the conditions around the event that the technology is being designed to address. However, while this need is widely acknowledged, the ITS and motorcycle research community has only begun to address it. Creating tailored ITS solutions for motorcycle safety will be a priority area for future work.

Increase in Connectivity

The desire to increase connectively (Inter-Vehicle Communication Systems, vehicle-to-infrastructure (V2I) systems, or, more generally, connected vehicles) was a trending topic across all categories of ITS investigated by the project. A large amount of the interviewees mentioned how connected vehicles showed great potential to improve safety conditions for motorcyclists, along with the rest of the

transportation community. Stakeholders discussed Inter-Vehicle Communications Systems frequently, but also commented on the need to improve the connection between the rider and vehicle—by providing the rider better information on the vehicle performance and road conditions for a safer ride. Furthermore, the opportunity to enhance vehicle performance through dynamic software and firmware updates was also identified. During the 2015 ITS World Congress, three of the largest motorcycle manufacturers agreed to establish a new consortium named the Connected Motorcycle Consortium. This consortium will focus on accelerating the development of interoperable, connected motorcycles through the implementation of Cooperative—Intelligent Transportation Systems (C-ITS) applications. Connectivity will continue to be a trending topic in the near future for motorcycles, and transportation services in general. The ability to communicate with other vehicles, infrastructure, and users through a secure bandwidth (Dedicated Short Range Communication, or DSRC), will enable a world of opportunities to improve transportation safety.

Bundling Technologies

A common trend discussed during the interviews, and observed in research efforts such as the European Commission's SAFERIDER project, was the need to develop and deploy ITS technologies in parallel with one another. Manufacturers emphasized that the benefits of each ITS technology would be amplified if they operate in parallel with other technologies. An example of this trend can be observed on the newest development of ABS technologies, which have both improved their own performance by reducing size and increasing efficiency and improved system-wide performance by interacting with other technologies like Dynamic Stability Control to take into consideration the motorcycle's lean-angle to improve braking conditions. Another example can be seen in the development of the SAFERIDER program: "SAFERIDER intends to learn from the problems in ADAS/IVIS [Advanced Driver Assistance Systems/In-Vehicle Information Systems] application in cars, where single applications with dedicated HMI [Human-Machine Interface] were built and are currently striving to achieve integration in terms of functions and HMI. Instead, a parallel and concurrent development of key functionalities, under a unified HMI concept, is planned." (http://www.saferider-eu.org/about.html.)

Not Just Improve Safety, Improve Riding Experience

Another important trend identified across the literature review and practitioner interview was acceptability of ITS to riders. Stakeholders identified the need to include technologies in motorcycles that would not only improve safety conditions, but also enhance the riding experience. Time and research efforts should focus on technologies that riders find useful and convenient to use, without being distractive or interruptive. One of the main challenges that motorcycle ITS currently faces is the interface with the rider. Again, while this need is widely acknowledged, considerable work remains to be done on this issue. There is a need to consider further research on technology that will be embraced by riders, in addition to improving their safety.

Motorcycle Safety and ITS—Overall Gaps

The literature review and practitioner interviews also revealed some key gaps in the current state of Intelligent Transportation Systems (ITS) for motorcycle safety. Proactively and collaboratively addressing these gaps holds the potential to advance and improve ITS for motorcycle safety.

Motorcycle Safety Data

Leading practitioners in motorcycles and ITS—in particular, industry associations—identified the relative lack of rich and accurate data sets as a primary gap. The National Highway Traffic Safety Administration (NHTSA) currently operates the Fatality Analysis Reporting System (FARS) and requires all states to report fatalities and other related information to this database. The sentiments of practitioners suggest that they are seeking information beyond the purview of FARS and that it may be beneficial to further develop a national database on crash statistics. For example, FARS only covers fatal crashes and there is currently no national database on injury crashes. States have been unable to agree on a uniform definition of a serious injury and attempts to remedy this will not take effect until 2020 at the earliest. In this light, accelerating the roll out of an injury crash database on uniform definitions may be worthwhile in order to promote the development of ITS for motorcycle safety. Additionally, decision-makers should consider the benefits of working with motorcycle and ITS practitioners to identify other fields of data that may help boost research and development efforts in this area.

The need to revisit and enhance data collection and analysis for motorcycles is even greater in light of the emerging trend of "big data." The increasing availability of rich real-time data from ITS technologies presents an important opportunity to increase the safety and efficiency of transportation systems. This is a key opportunity that researchers, manufacturers, and public agencies should start preparing to take advantage of today. Learning how to harness the potential of big data in tandem with efforts to create more robust motorcycle data sets for researchers will produce synergies and create many new opportunities in the field of ITS for motorcycle safety.

Multi-Sector Collaboration and the Harmonization of Intelligent Transportation Systems

An overarching theme from the practitioner interviews was that more collaboration between different sectors would help advance ITS for motorcycle safety. Practitioners in academia expressed the need for public agencies to become more involved in research initiatives and their applications. Practitioners from State Departments of Transportation (DOT) and public safety agencies independently noted that public agency involvement is largely limited to safety divisions and, in particular, work on Strategic Highway Safety Plans (SHSP). In the private sector, practitioners commented on tensions between large and small manufacturers as both work to develop and stay competitive with new technology. Here, large manufacturers with more resources typically have the advantage, although they also compete internally with automobiles and other motor vehicles. More collaboration and sharing between stakeholders in all sectors can help make better use of limited resources.

The Connected Motorcycle Consortium, which promotes cooperation between manufacturers over competition, is an important step in this direction. The ultimate goal of this consortium is to launch interoperable, or harmonized, Cooperative-Intelligent Transportation Systems (C-ITS). While there is currently little research into C-ITS, the ITS and motorcycle safety community should take advantage of this promising new initiative to foster both collaboration and new research.

Acceptability and Customization of Motorcycle Intelligent Transportation Systems

The literature review and practitioner interviews emphasized that the acceptability of ITS to riders and the customization of ITS to motorcycles are key to achieving the full benefits and widespread implementation of ITS for motorcycle safety. Overall, recognition of these needs appears to be fairly ubiquitous and some areas of ITS—primarily those that fall under the umbrella of Advanced Driver/Rider Assistance Systems (ADAS/ARAS)—have begun exploring the acceptability and customization of motorcycle ITS. For most areas of ITS, however, research along these lines is relatively lacking. Acceptability is critical to the widespread implementation of ITS as many areas of ITS—particularly those that interfere with operating tasks—are met with resistance from riders. Customization of ITS to motorcycles is similarly important as the experience of riding a motorcycle is very different from driving an automobile or truck. ITS technologies designed for automobile drivers may be ineffective—or even distracting and unsafe—for motorcyclists. Both of these challenges can be addressed with the strategic design of ITS technologies to take into account both the needs (customization) and wants (acceptability) of motorcyclists.

The acceptability and customization of motorcycle ITS will be especially important for connectivity and communication technologies, which both the literature review and practitioner interviews emphasized as an area of ITS with particularly high potential to improve motorcycle safety. The literature review revealed that much of the current work on inter-vehicle communication technology has resulted in automobile-based devices, as opposed to motorcycle-based devices. Practitioners emphasized that such technology should be independently researched for motorcycles as the engagement and experience of riders is very different from that of vehicle operators so connectivity and communication devices designed for automobile drivers may be unsafe or distracting for riders.

Assessment of Safety Benefits

A comprehensive assessment of the safety benefits of ITS for motorcycles was another primary gap in the literature review that was echoed in the practitioner interviews. While some areas of ITS have an appreciable amount of research into the empirical and simulated safety benefits for motorcycles, other areas of ITS generally lack such research—particularly, Curve Speed Warning, Electronic Stability Programs, and Inter-vehicle Communication Systems and Motorcycle Detection Systems. As discussed earlier, it is important to not automatically assume that technical advancements in motorcycle maneuverability lead to safety benefits, as the interaction between new technologies and rider behavior could potentially result in riskier riding behavior and unintended safety impacts. In addition, industry associations have expressed the need to better define the safety benefits of various ITS technologies to help guide the development of research, programs, and policies. There are, therefore, multiple reasons why investigating and quantifying safety benefits will help advance ITS for motorcycle safety.

Research in the United States

Finally, the literature review revealed that much of the applied research into ITS for motorcycle has been conducted outside of the United States. While this research provides important insights for improving motorcycle safety in the U.S., its conclusions are not entirely transferable as U.S. roadways and riders differ in many ways from roadways and riders in other countries. Leading practitioners in academia also noted this issue, confirming that contextual and cultural difference must be keep in mind when considering research conducted abroad. For example, motorcycles are often used for leisure trips in the U.S., while in European and Asian countries motorcycles are more frequently used for commuting and other essential trips. These differences can impact the focus and conclusions of motorcycle research conducted abroad. To ensure that ITS for motorcycle safety is designed for maximum effectiveness in the U.S., efforts should be made to independently research and develop these technologies in a U.S. context. Given limited funding for research, incorporating motorcycle safety and ITS research into existing federal programs or projects that focus on highway safety or ITS is one possible way to synergistically advance this research in a U.S. context.

Privacy

The potential privacy concerns of the motorcycle community were generally not addressed in the literature review or practitioner interviews. While motorcycle ITS will not collect Personally Identifiable Information (PII)—and there is no desire and no need to collect PII—it will be important to give all stakeholders the opportunity to voice any concerns and reach a common consensus in order to fully realize the benefits of ITS for motorcycle safety. Otherwise, unaddressed privacy concerns may decrease the acceptability of motorcycle ITS to riders, restrict widespread deployment, and ultimately detract from the full, potential safety benefits of having widely-implemented motorcycle ITS. While there is no reason to expect that motorcycle ITS will face privacy concerns that cannot be fully assuaged, public engagement and a two-way dialogue on this issue will be key to the ultimate acceptance and success of ITS for motorcycle safety.

Recommendations

The above analysis of trends and gaps indicates several opportunities to advance the state of research on motorcycle safety and Intelligent Transportation Systems (ITS) by addressing key gaps and needs. The project team has translated these opportunities into two types of recommendations for action: (1) Recommended areas of research for practitioners throughout the industry to focus on, and (2) recommended strategies to advance research and address identified gaps and needs. These recommendations are followed by a discussion on how the United States Department of Transportation (U.S. DOT) can lead the industry to act upon these recommendations.

Recommended Areas of Research

Based on the analysis presented, the following research areas have been identified as having strong potential to improve motorcycle safety and rider experience.

Technology Synergy with Antilock Braking Systems

Antilock Braking Systems (ABS) stood out in both the literature review and the practitioner interviews as one of the most promising and mature areas of motorcycle ITS. This momentum should be sustained and built upon with further research. Researchers should explore synergies between ABS and other areas of ITS to help promote and implement less mature ITS technologies. The relatively widespread acceptance and implementation of ABS in motorcycles may help increase the adaptation of other technologies by association.

Rider-Motorcycle Interface

The acceptability and customization of ITS for motorcycles was a major theme in almost all resources consulted for this report. The embodiment of this theme moving forward will be through the rider-motorcycle interface (also known as the human-machine interface, or HMI) of ITS devices for motorcycles. Therefore, as ITS for motorcycle safety advances, the interface between the rider and motorcycle will become an increasingly critical feature in both the success and acceptance of these technologies. Key ITS technologies that interact with riders—such as ADAS (Advanced Driver Assistance Systems), Collision Warnings and Avoidance Systems, Curve Speed Warning, and Inter-Vehicle Communication Systems—should be researched further with a strong focus on the effectiveness and design of the rider interface in the near future. Engaging the motorcycle community—see below—may provide particularly helpful insights towards this effort.

Motorcycle Safety Data

Improving the availability of rich, comprehensive, and accurate data on motorcycle safety and usage will help efforts to develop ITS for motorcycle safety across the board. As mentioned earlier, the National Highway Traffic Safety Administration (NHTSA) may consider enhancing the Fatality Analysis Reporting System (FARS) by working with practitioners and the professionals involved in FARS data collection to ensure that FARS includes the type of data needed to advance ITS for motorcycle safety. Another possible way to improve available data is through Automatic Crash Notification Systems, which would provide an easy and reliable way to obtain crash data. The inherent privacy issues of this technology, however, may encounter resistance from the motorcycle community that could be difficult to overcome. Regardless of the method, a collaborative effort

between public agencies, research institutions, manufacturers, and riders to improve the scope and accuracy of data on motorcycle usage and safety will offer huge benefits to future research on ITS and motorcycle safety.

Applied Research and Assessment of Safety Benefits

Pushing research towards more applied real-world work is an important next step in the development of ITS for motorcycle safety. For example, the literature review revealed that applied research on ITS prototypes for motorcycles is relatively lacking outside of the European Commission's SAFERIDER project. Similarly, both the literature review and the practitioner interviews pointed to the limited amount of research on the real-world safety impacts of various ITS technologies. Building off existing research and turning towards more applied topics and research questions will help accelerate the adaptation and implementation of ITS for motorcycles.

Harmonization of Intelligent Transportation Systems

Several trends and gaps throughout this report indicate that the harmonization of ITS technologies and standards—meaning developing intelligent transportation systems that are interoperable across all roadways and vehicles—will become a critical research focus moving forward. The recent launch of the Connected Motorcycle Consortium called attention to the dearth of research on the type of interoperable Inter-Vehicle Communication Systems that the Consortium aims to develop (called Cooperative-ITS by the Consortium). The practitioner interviews confirmed this gap—citing connectivity as a major research focus for motorcycle ITS in the near future. Opportunities related to harmonization and connectivity were identified not only to improve safety through Cooperative-ITS, but to improve vehicle's performance overall through dynamic updates of vehicle's firmware and software. Altogether, it is clear that harmonization and connectivity are trending topics that will be essential to the next stage of motorcycle ITS. This trend can also be seen in the push towards bundling ITS technologies and adopting a system-wide approach towards motorcycle ITS, where researchers have also recognized the benefits of having intelligent transportation systems interact with one another.

Recommended Strategies to Address Gaps and Needs

In order to address the gaps and needs identified, the following strategies are recommended as a way to comprehensively promote the development of ITS applications for motorcycle safety.

Actively Promote Research

Academic institutions and research organizations emphasized that there is not enough funding for research on ITS and motorcycle safety. However, limited funding for research is a chronic problem in many fields and is not an easy problem to solve. Researchers and other champions in the field of ITS and motorcycle safety (public agencies, industry associations, riders, etc.), therefore, should explore opportunities to include motorcycle ITS research in other closely related, funded research initiatives (e.g., existing federal research programs) and promote the synergies of including motorcycle ITS (e.g., interoperability and high implementation rates improve the function of all ITS). For example, the U.S. DOT's Intelligent Transportation Systems Joint Program Office (ITS JPO) has sponsored and conducted significant research on ITS for safety as well as intermodal ITS—both of these research initiatives would be potentially well-suited for the integration of motorcycle ITS research.

Whenever possible, researchers and champions should also make the case to increase or obtain new funding for research exclusively focused on motorcycle ITS. Successful examples have been made abroad, through research programs such as the European's Commission SAFERIDER, which provides a framework that can be built upon to engage research for North American characteristics.

There is broad area where research can be actively promoted. An as example, researchers could evaluate the areas identified and proposed in this report.

Engage the Motorcycle Community and the General Public

Although the motorcycle community is strong, it is also small and relatively uninvolved in research activities. There are limited opportunities for riders to interact or provide feedback to research institutions, manufacturers, and public agencies on the issue of ITS and motorcycle safety. Engaging the motorcycle community more on this topic will ensure that the unique safety needs of motorcyclists are met as ITS technologies continue to develop. This engagement will be particularly important in customizing and increasing the acceptance of motorcycle ITS—as well as addressing any privacy concerns of the motorcycle community. Research should also be presented and discussed with the general public to help the greater motoring community understand new technologies and provide feedback on how non-motorcyclists will interact with new technologies.

Embrace Upcoming Technology

With the upcoming deployment of connected vehicles and big data, practitioners need to be prepared to take advantage of these opportunities to increase safety, enhance mobility, and create a much more robust data set of motorcycle usage (speeds, volumes, etc.) and safety. Conducting foundational research on these topics will help all practitioners make better use of these upcoming technologies once they have matured.

Collaborate

Following the lead of the Connected Motorcycle Consortium, collaboration between all sectors and stakeholders will be key to the fast and successful development and implementation of harmonized ITS for motorcycle safety. Practitioners are beginning to recognize that no stakeholders stand to gain from competition in this emerging field, especially in areas such as Inter-Vehicle Communication Systems where harmonization/interoperability is key. Widespread implementation and usage will also greatly improve the benefits of all categories of ITS for motorcycle safety, and therefore, collaboration going forward will be important. Promoting and supporting this collaboration from a federal level has the potential to be especially impactful, especially when it comes to the involvement of State Departments of Transportation (DOT) and other public transportation agencies around the country.

Next Steps

All of these recommended areas of research and strategies hinge to some degree on increased communication between stakeholders and a clear commitment to pursuing the safety benefits of motorcycle ITS. As immediate next steps, stakeholders—public agencies, manufacturers, research organizations, and riders—should explore innovative ways to expand communications (steering groups, public meetings, conferences, webinars, and “datathons”, among other activities) and voice their commitment to advancing ITS for motorcycle safety.

In the implementation of these strategies, the U.S. DOT is in the position to set the tone for the rest of the industry. By establishing a national commitment to finding innovative ways to advance the motorcycle ITS research agenda, the U.S. DOT could help incentivize researchers to explore synergistic ways to include motorcycle ITS in existing research programs, as well as prompt the industry to start making plans for connected vehicles and big data. By initiating and encouraging additional channels of communication between industry stakeholders and the motorcycle community, the U.S. DOT can help promote a culture of collaboration and engagement that supports the development of harmonized, widely accepted motorcycle ITS technologies. As an example of how this could be executed, the Fixing America’s Surface Transportation (FAST) Act, the Federal funding

and authorization bill for surface transportation spending passed in 2015, reestablished the Motorcycle Advisory Council to advise the U.S. DOT on motorcycle issues. This council of leaders and experts in the motorcycle community may be effective body to spearhead, advise, and support the U.S. DOT in promoting collaboration and engagement around the issue of motorcycle ITS and safety.

The U.S. DOT should also consider the costs and benefits of promoting the recommended areas of research through federally funded research or other sponsored development activities. Some of these areas have been selected due to their potential to widely benefit motorcycle ITS devices and, therefore, represent high-impact research investments. For example, developing an effective and acceptable rider-motorcycle interface will be critical to the successful implementation of many promising motorcycle ITS devices. Likewise, improved data for research will benefit virtually any future effort to improve motorcycle safety

Appendix A. Literature Review—Workbook Documentation

The literature review findings have been summarized in a Microsoft Excel workbook in the format of a tabular database organized by topic. This appendix explains the organization of this workbook and describes the data fields that are provided for each topic.

The Summary Sheet

This first sheet of the workbook summarizes the findings for each of the priority topics that were investigated for this literature review. A total of 17 topics were identified as priority ones, out of an initial set of 40 categories of investigation. Columns F and G list the original 40 topics, and include highlighting to indicate the 17 priority topics featured in this literature review. In four cases, multiple topics were merged into a single coherent unit based on their highly interrelated nature and the potential for significant overlapping of literature review results. The topics that were merged are:

1. Adaptive front lighting **AND** daytime running lights
2. Helmet-mounted displays **AND** visibility-improving helmets
3. Inter-vehicle communication system **AND** motorcycle detection system
4. Pre-crash systems **AND** external airbags.

Columns A and B provide a listing of the topics that were included, along with the search terms that were used to find relevant literature for each one. Columns C and D indicate for each topical unit the number of sources found and the subset of those sources that were additionally identified as being explicitly relevant to motorcycles. At the bottom of this topic listing is an overall total for the number of papers found across all topics. Taken together, these four columns effectively function as a table of contents and summary of findings for the rest of the workbook.

The Results by Topic

All remaining sheets in the workbook provide the results of the literature review, organized by topic. Most of the sheets are labeled with the topic numbers, based on the list of topics provided in the summary sheet. Four of these sheets, however, incorporate the 125 results found in broader topical searches outside of the 40 categories of investigation. These four sheets follow the same topical structure as the Task 2 report appendix (sheet names in bold):

1. **Strategic Planning:** Sources relevant to Strategic Planning
2. **Behavior:** Sources relevant to Rider Behavior
3. **Technology:** Sources relevant to Motorcycle Technology
4. **Manufacturing:** Sources relevant to Manufacturing

In each of the numbered workbook sheets, a topic title and description are provided in the upper left, followed by a list of the keyword phrases used to search for relevant works specific to this topic. The initial list of keyword phrases was developed based on the topic's description. Additional keyword

phrases could then be added to the list as needed after the literature review process had begun, if it were apparent from the search results that certain other keyword phrases would also be applicable.

For broader topics, only equally broad works were targeted for the literature review. For example, for the "Inter-vehicle communication system" topic, the search terms were selected to capture more general, inclusive works on the topic, rather than works that were narrowly concerned with individual vehicle-to-vehicle communication technologies or commercial products. However, in some cases, specific aspects of a particular topic were excluded from the literature review search terms if those were found to be more directly relevant to another separate topic. For example, the keyword phrase "lane keeping" was excluded from the "advanced driver assistance systems" topic, as it was determined to be a more precise fit for the "lane keeping and departure warning systems" topic instead.

Process for Populating the Numbered Worksheets with Results (Detailed Methodology)

The process used to find and identify relevant sources for each numbered topic is as follows.

1. Use the following list of academic literature aggregators, which has been compiled by a panel of transportation PhDs, to search for each of the keyword phrases for the topic. Filter search results to include only sources that are from 2005 or later, to reflect the rapid pace of technological advancement in ITS and its general effect on the diminishing relevance of older works.
    a. http://www.tandfonline.com/
    b. http://melvyl.worldcat.org/
    c. http://oskicat.berkeley.edu/
    d. http://trid.trb.org/
    e. https://scholar.google.com/
    f. http://www.mendeley.com/
    g. http://www.researchgate.net/ (though originally included in this list, this search engine was later dropped when it was discovered that no mechanism exists for searching by custom keyword phrases).
    h. http://www.academia.edu/ (though originally included in the list, this search engine was later dropped when it was discovered that only members of academic institutions are allowed to access its database).
    i. http://ntlsearch.bts.gov/repository/index.do
    j. http://itsamerica.org/knowledge-center/

2. Identify those search results that are relevant to the topic, based on the information conveyed through the titles.
3. For each search result (i.e., "work") that was evaluated to be relevant, record the following:
    k. **Authors,** whether individuals or corporate entities. In some cases, authorship may not be indicated, in which case this field may be labeled as "Unspecified" or replaced with the publisher information.
    l. **The title of the work,** which may be a journal article, academic paper, final project report, conference proceedings, textbook chapter, academic film, thesis, or other type of material.

m. **Basic publisher information,** such as the name of the journal, conference, sponsoring organization, publication, funding agency, academic institution, or other parent entity. If this information is not available, as may be the case with references that were found in other works but did not include publisher information and for which additional information could not be located, it may be listed as "Unspecified" or "Unknown."

n. **Year published.** If listed as "Unknown" or "Unspecified," it indicates that the precise year was not listed with the basic description for the work, though it will still have been a date between 2005 and 2015, as the searches were configured to provide only results in this date range.

o. **Link,** which provides a URL (i.e., Web address) for the online description of the work or material. Whenever possible, a link to a Web page describing the work is provided, rather than a direct link to the work (if available online). It is generally the case that the Web page describing the work will also include a link to the work itself (when available), such that more value is achieved through providing a link to the description page than would be obtained through a direct link to the work itself.

p. **Indication of whether the work was found to be explicitly relevant to motorcycles.** This was evaluated by performing a text search of the work's basic descriptive information for any of these textual phrases: "motorcycle," "two-wheel," or "two wheel." A work whose basic descriptive information was found to contain any of these three text search phrases was considered explicitly relevant to motorcycles.

   i. Note that searching for these terms automatically captures their common derivative forms, such as "two wheeled," "two-wheeler," or "motorcycles."

   ii. Basic descriptive information was taken to include all of the following (when available): title, abstract, introduction, conclusions, and summary.

4. Continue documenting search results until at least 5 out of the last 10 did not appear relevant to the topic, or alternatively, until 50 search results have been considered and processed (whether they were identified as being relevant or not). These termination criteria are intended to keep the procedure tractable and to ensure continual progress across all topics and literature aggregators. It is based on the realization that search aggregators typically sort their results in order of relevance, with the earlier documents being the ones that best fit the search terms.
5. For those works that were found to be explicitly relevant to motorcycles, provide a summary. This is generally written to capture the basic purpose, objectives, and/or outcomes of the work, and also indicate the context in which motorcycles were mentioned or the role that motorcycles took. It is typically limited to a few sentences only, and is not meant to be a complete executive summary description of the work. If the original work were not available in its entirety, it may still be possible to provide a summary by reviewing the provided descriptive information. In other cases, if the descriptive information were insufficient for this purpose, the summary would be omitted with an explanation stating that the original work was unavailable (or similar note).
6. Additionally, for those works that were found to be explicitly relevant to motorcycles, review the work's references according to the same procedures and criteria as any other search results from the literature aggregators. This step was contingent on the availability of the work in its entirety, such that the list of references was accessible for review.

The results from the literature review process start at Row 21 of each numbered sheet, and continue until the process was completed for each topic. A summary of the findings is provided near the top of the sheet in Columns D and E, and includes:

1. The overall number of works found for the topic.

2. The number of works that were identified as being explicitly relevant to motorcycles.
3. A calculation expressing the number of works relevant to motorcycles as a percentage of the overall total.

Appendix B. Detailed Literature by Topic Area

Adaptive Front Lighting and Daytime Running Lights

As part of the active safety system of middle- to high-end passenger cars, Adaptive Front Lighting systems provide an optimized vision to the driver during nighttime and other poor sight conditions of the road by adapting the headlight angle and intensity and judging the speed of the car, the steering wheel angle, the weather condition, and yaw and tilt rate of the car. Daytime Running Lights are lighting devices on the front of a motor vehicle that are automatically switched on when the vehicle is moving forward emitting white, yellow, or amber light to increase the conspicuity of the vehicle during daylight conditions.

Table B-1. Search terms.

Search Terms
Daytime Running Lights
Adaptive Front Lighting
Adaptive Front Lighting Automotive
Adaptive Front Lighting Motor Vehicle
Adaptive Front Lighting Motorcycle
Adaptive Headlights
Daytime Running Lamp

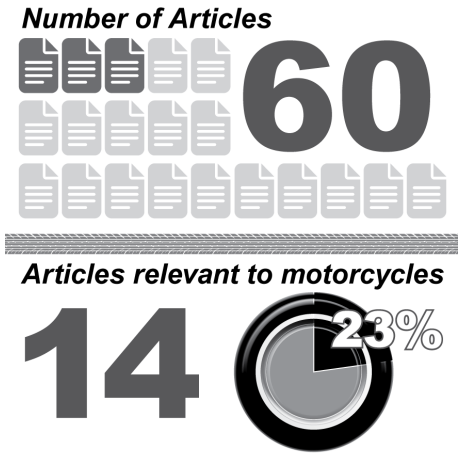


Table B-2. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
R. Mohd Khairudin; M.I. Mohd Hafzi; and H. Azhar	Amber Position Lamp as Daytime Running Light for Motorcycle	Advanced Engineering Forum	2013	http://www.scientific.net/AEF.10.357	This article, published in the Advanced Engineering Forum, documents an experiment designed to evaluate the conspicuity levels of motorcycle headlamps and tail lamps equipped with amber position lamps (APL) over motorcycle headlamps and tail lamps with the standard daytime running light (DRL) settings (baseline). Fifteen participants simultaneously rated both motorcycles, which were placed in parallel, at different distances and times of day. Motorcycles with APL were noticeably better detected from rear at the 50 meter and 100 meter distance, as well as during night time and twilight. The authors concluded that APL has the potential to enhance motorcycle conspicuity, especially for rear lamps.
National Center for Statistics and Analysis	An Assessment of Crash-Reducing Effectiveness of Passenger Vehicle Daytime Running Lamps (DRL)	NHTSA Technical Report	2005	https://trid.trb.org/view/756576	This report, published by the National Highway Traffic Safety Administration (NHTSA), estimated the effectiveness of passenger vehicle daytime running lights (DRLs) in reducing two-vehicle opposite direction crashes, pedestrian/bicycle crashes, and motorcycle crashes. The authors chose the generalized simple odds, a conventional statistical technique, to analyze the data. Results based on simple odds indicated that from 1995 to 2001: DRLs reduced opposite direction daytime fatal crashes by 5%; DRLs reduced opposite direction/angle daytime non-fatal crashes by 5%; DRLs reduced non-motorist, pedestrian and cyclist daytime fatalities in single-vehicle crashes by 12%; and DRLs reduced daytime opposite direction fatal crashes of a passenger vehicle with a motorcycle by 23%. Reviewers of this paper required the inclusion of results using the odds ratio technique. The estimated effect of DRLs based on the odds ratio technique was -6.3%, -7.9%, 3.8%, and 26%, respectively. None of these results were statistically significant.

Table B-2. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Viola Cavallo and Maria Pinto	Are car daytime running lights detrimental to motorcycle conspicuity?	Accident Analysis and Prevention	2012	https://trid.trb.org/view.aspx?id=1238184	This article, published in Accident Analysis and Prevention, asked the question: are car daytime running lights detrimental to motorcycle conspicuity? The study conducted an experiment designed to assess the effects of car DRLs on motorcycle perception in a situation that specifically brought attentional conspicuity to bear. Photographs representing complex urban traffic scenes were displayed briefly (250 ms) to 24 participants who had to detect vulnerable road users (motorcyclists, cyclists, pedestrians) appearing at different locations and distances. Car DRLs hampered motorcycle perception compared to conditions where car lights were not on, especially when the motorcycle was at a greater distance from the observer and when it was located in the central part of the visual scene. Car DRLs also hampered the perception of cyclists and pedestrians. Although the globally positive safety effect of car DRLs is generally acknowledged, the authors concluded that more attention should be paid to motorcyclists and other vulnerable road users when introducing car DRLs.
N. Takenobu; B. Schoettle; and M. Sivak	Availability and implementation trends of daytime running lights in the U.S.	University of Michigan Transportation Research Institute	2007	http://deepblue.lib.umich.edu/bitstream/handle/2027.42/58729/99846.pdf?sequence=1 ; https://trid.trb.org/view.aspx?id=850123	This report, from the University of Michigan Transportation Research Institute, documented the availability of DRL on vehicles for best-selling vehicle models over the years leading up to 2007 and investigated how DRLs were implemented. The research found that the availability of DRL as standard equipment increased from 2004 to 2007.

Table B-2. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Michael Paine; David Paine; Jack Haley; and Samantha Cockfield	Daytime Running Lights for Motorcycles	Proceedings—19th International Technical Conference on the Enhanced Safety of Vehicles	2006	https://trid.trb.org/view.aspx?id=809318	This article, included in the Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles, examined the feasibility of applying daytime running lights (DRLs) to motorcycles. A difficulty with DRL for motorcycles has been lack of space. Initial research demonstrated that bright yellow DRLs could be highly cost effective for preventing motorcycle accidents. The authors concluded with the recommendation that bright yellow front turn signals as DRLs be applied to motorcycles, but continue to be disallowed for other vehicles.
M. A. Symmons	Daytime running lights: a closer look at their justification for Australia	ATRF 2009: 32nd Australasian Transport Research Forum	2009	https://trid.trb.org/view.aspx?id=914641	This study, included in proceedings of the 32nd Australasian Transport Research Forum, analyzed a database of road crashes in Victoria, Australia for crashes that might have been averted or reduced in severity through implementation of DRL. Meteorology data was used to eliminate crashes that occurred during hours of darkness and twilight, times during which drivers were likely to have turned their lights on anyway. The study also considered the possibility that DRLs may reduce or actually improve motorcycle safety.
Stephanie Binder	Motorcycle Conspicuity and the Effect of Fleet Daytime Running Lights	National Highway Traffic Safety Administration	2009	https://trid.trb.org/view.aspx?id=1259573	This study, conducted by the National Highway Traffic Safety Administration (NHTSA), is examining whether frontal conspicuity of motorcycles could be improved to reduce their chances of being struck by other motorists. This research is currently still in progress.

Table B-2. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
James W. Jenness; Frank Jenkins; and Paul Zador	Motorcycle Conspicuity and the Effect of Fleet DRL: Analysis of Two-Vehicle Fatal Crashes in Canada and the United States 2001-2007	National Highway Traffic Safety Administration	2011	https://trid.trb.org/view/1136542	This study, published by the National Highway Traffic Safety Administration (NHTSA), involved testing the Fleet DRL Hypothesis that widespread use of daytime running lights (DRL) among the motor vehicle fleet is associated with an increased risk for certain types of multi-vehicle motorcycle crashes. Crash data from Canada, where DRL use was mandatory, were compared against data from US, where DRL was not mandatory. The results showed that, on urban roadways, widespread use of DRL in vehicle fleets increased the relative risk of certain motorcycle crashes.
Janan Al-Awar Smither and Lorenzo I. Torrez	Motorcycle Conspicuity: Effects of Age and Daytime Running Lights	Human Factors: The Journal of the Human Factors and Ergonomics Society	2010	https://trid.trb.org/view.aspx?id=1085174	This article, published in Human Factors: The Journal of the Human Factors and Ergonomics Society, investigated how motorcycle lighting, age of the rider, and vehicular daytime running lights (DRLs) contribute to motorcycle conspicuity. The research studied 75 participants as they watched a series of videos clips and indicated when they saw a hazardous situation. Motorcycle and vehicle lights were manipulated and participant reaction times were collected. Findings showed a link between DRLs and the effective detection of motorcycles and suggested that age-related changes affect the ability to detect and respond to a motorcycle effectively.
S. Varlakati; V. Yogaraja; and S. Sudharsan	Self-Adaptive Front Lighting Mechanism for the Fixed Headlamp Mounted Two-Wheelers	SAE Technical Paper	2013	http://papers.sae.org/2013-26-0065/	This SAE International technical paper tackled a problem common to motorcycles: headlamps that do not rotate with the steering system, causing visibility issues to the rider during cornering. In order to correct these visibility issues, a self adaptive front lighting mechanism was constructed to rotate the headlamp about its vertical and longitudinal axes during cornering based on the steering angle and the vehicle lean angle.

Table B-2. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Motoki Masanor; Hashimoto Hiroshi; and Hirao Tamotsu	Study on the Visibility and Discomfort Glare of Adaptive Front Lighting System (AFS) for Motorcycle	JSAE Transactions	2009	http://ci.nii.ac.jp/naid/130004515389/	This study, published by JSAE Transactions (Society of Automotive Engineers of Japan), was conducted to clarify the effects of a system to adjust the horizontal inclination of the motorcycle headlamp (motorcycle AFS) on visibility, and to examine the side-effects of the motorcycle AFS (i.e., the discomfort glare for oncoming drivers).
Amir Asyraf	The Development Of Adaptive Lighting System For Motorcycles	University Technical Malaysia Melaka	2011	http://eprints.utem.edu.my/6200/2/The_Development_Of_Adaptive_Lighting_System_For_Motorcycles_-_24_pages.pdf	This paper from the University Technical Malaysia Melaka provides a literature review on vehicle lighting systems; documents the design and development of an Adaptive Lighting System to be implemented in motorcycles; and proposes a commercialized lighting system.
John Pierowicz; Valerie Gawron; Glenn Wilson; and Amy Bisantz	The Effects of Motor Vehicle Fleet Daytime Running Lights (DRL) on Motorcycle Conspicuity	National Highway Traffic Safety Administration	2011	https://trid.trb.org/view.aspx?id=1136539	This report, published by the National Highway Traffic Safety Administration (NHTSA), evaluated the effects of motorcycle conspicuity treatments on other drivers' left turn gap acceptance. This study was comprised of three phases. In Phase 1, a test track study measured participants' left turn gap judgment as a function of motorcycle DRL treatments. This study was designed to determine which treatments yielded the largest gaps, thereby making that treatment a good candidate for the on-road portion. No treatment was clearly better, so lighting systems currently in use on motorcycles were selected for the on-road study. In Phase 2, an on-road study measured gap acceptance, then followed up with intercept surveys of observed drivers. This phase included data collection in the United States (low fleet DRL use) and Canada (high fleet DRL use) in order to evaluate the effect of DRL use in the vehicle fleet. However, due to concerns about the comparability of the U.S. and Canadian data, the results are inconclusive, and additional research is suggested. In Phase 3, motorcycle side conspicuity treatments (retro-reflectors and marker lamp) were compared. Results indicated that there were no differences in detection distance between the treatments.

Table B-2. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Viola Cavallo and Maria Pinto	Visual factors affecting motorcycle conspicuity: Effects of car daytime running lights and motorcycle headlight design. In: Increasing Motorcycle Conspicuity: Design and Assessment of Interventions to Enhance Rider Safety	Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux (IFSTTAR)	2014	https://trid.trb.org/view.aspx?id=1340202	This study, from the Institut Francais des Sciences et Technologies des Transports, de l'Amenagement et des Reseaux (IFSTTAR), identified several visual factors that influence motorcycle visual conspicuity in a complex environment and under time constraints—conditions that are likely to produce perceptual errors when automobile drivers interact with motorcyclists. The research further clearly demonstrated the detrimental effects of car DRLs in the vicinity of motorcycles, acting as visual distractors. Several innovative motorcycle headlight configuration were tested to improve motorcycle detectability in a car-DRL environment. While both a yellow headlight and a light on the helmet were effective in improving motorcycle visual conspicuity, color coding, by its highly distinctive features, had the greatest potential for offsetting the detrimental effects of car DRLs. Both configurations represent quite simple and ergonomically realistic solutions.

Advanced Driver Assistance Systems

Vehicle-based systems to provide automated assistance for driver tasks such as steering, braking for collision avoidance (covered separately), lane departure warning (covered separately), lane-keeping (covered separately), and adaptive cruise control. Note: Adaptive cruise control is covered specifically in topic 17, “Linked Braking Systems/Linked Braking Systems,” which was not a priority literature review topic.

Table B-3. Search terms.

Search Terms
Advanced Driver Assistance Systems
Advanced Driver Assistance Systems Motorcycle
Advanced Rider Assistance Systems
Automated Steering
Autonomous Steering

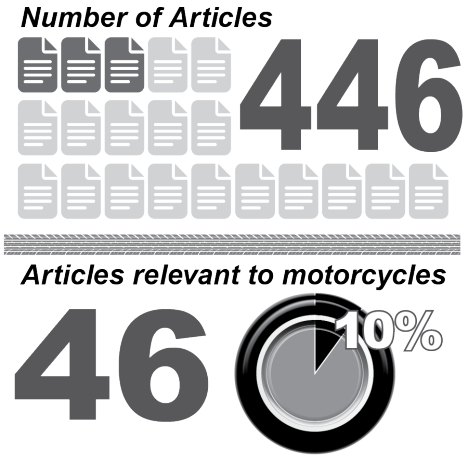


Table B-4. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
V. Cossalter; A. Doria; R. Lot; and M. Maso	A motorcycle riding simulator for assessing the riding ability and for testing rider assistance systems	Proceedings DsC	2006	http://scholar.googleusercontent.com/scholar?q=cache:crd5g77qk-gJ:scholar.google.com/+Advanced+Rider+Assistance+Systems&hl=es&as_sdt=0,22	This article was included in the 2006 proceedings of the Driving Simulation Conference (DSC). It discusses a motorcycle riding simulator that has been developed at the University of Padova's Department of Mechanical Engineering (DIM) in order to assess the riding ability of motorcycles and to study man-vehicle interaction in safe conditions. The simulator consists of four sub-systems: a 5 degree-of-freedom serial motion system that generates motion cues; a visual system that generates visual cues; a sensors system that monitors rider's control actions; and a powerful multi-body code that simulates vehicle dynamics. Only one PC is needed to control the whole system. The project's research objective was to increase the accuracy of motorcycle simulation, reduce overall simulator dimensions, and reduce costs.
J.D.G. Kooijman and A.L. Schwab	A review on bicycle and motorcycle rider control with a perspective on handling qualities	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2013	http://www.tandfonline.com/doi/abs/10.1080/00423114.2013.824990?src=recsys#.VTaeJSFVhBc	This paper was published in Vehicle Systems Dynamics: International Journal of Vehicle Mechanics and Mobility by researchers at Delft University of Technology's Laboratory for Engineering Mechanics. It is a review study on handling and control of bicycles and motorcycles, the so-called single-track vehicles. It concludes with open ends and promising directions for future work in the field of handling and control of single-track vehicles.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
A. A. Popov; S. Rowell; and J. P. Meijaard	A review on motorcycle and rider modeling for steering control	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2010	http://www.tandfonline.com/doi/full/10.1080/00423110903033393#abstract	This paper was published in Vehicle Systems Dynamics: International Journal of Vehicle Mechanics and Mobility. It is a review of the state of knowledge of steering control in motorcycles and of the existing rider models. Since riders apply control based on available sensory information, predominantly from visual perception of a target path, the review also covers the state of knowledge of and research pertaining to road preview control. Here, some more emphasis is placed on recent applications of optimal control and model predictive control to the riding task and the motorcycle–rider interaction. The review concludes with key questions and a scope for further study.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Vanessa Beanland; Michael G. Lenné; Elisabeth Fuessl; Manuel Oberlader; Somya Joshi; Thierry Bellet; Aurélie Banet; Lars Rößger; Lars Leden; Ioanna Spyropoulou; George Yannis; Hugo Roebroeck; José Carvalhais; and Geoffrey Underwood	Acceptability of rider assistive systems for powered two-wheelers	Transportation Research Part F: Traffic Psychology and Behaviour	2013	https://trid.trb.org/view/1251747	This paper was published in the journal Transportation Part F: Traffic Psychology and Behavior. The research sought to understand general and system-specific factors that are likely to influence acceptability of powered two-wheeler (PTW) assistive systems through a large-scale survey of European riders. The survey was available in seven languages and attracted 6297 respondents. Respondents were frequent riders, who rode primarily for leisure purposes and had high awareness of assistive systems. Cluster analysis revealed two groups based on overall acceptability of assistive systems. The moderate and low acceptance clusters differed in terms of riding practices, risk perception, attitudes towards rule breaking, and some personality traits. Overall acceptability was low, but riders who perceive greater risk in riding display higher acceptability. Acceptability was highest for systems that do not interfere with the riding task, are well-known and/or considered reliable (e.g., night vision, ABS, call, advanced front-lighting system). In general, riders believe that existing safety equipment (e.g., helmets, protective clothing) is more reliable, provides greater resistance, and is considerably cheaper than more sophisticated assistive technology. Riders believe that innovations should focus on protective equipment, since they believe crash prevention is better addressed through rider training. Finally, riders felt there should be more emphasis on vehicle tire condition, while tire pressure control systems were identified as potentially helpful.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Thomas Hummel; Matthias Kuhn; Jeno Bende; and Antje Lang	Advanced Driver Assistance Systems: An investigation of their potential safety benefits based on an analysis of insurance claims in Germany	German Insurance Association	2011	http://udv.de/sites/default/files/tx_udvpublications/RR_12__fas.pdf	This report, published by the German Insurance Association, sought to determine the potential safety benefits of select advanced driver assistance systems. While the scope of the report covers all motor vehicles, it does contain a short chapter on motorcycles ADAS, in which it concludes: "Due to the fact that little research has been carried out into ADAs for single-track vehicles, it was not possible to calculate their safety potential values for motorcycles." Instead, the main accident scenarios for motorcycles were described. It emerged that measures to reduce the accident rates of motorcycles should focus on the following scenarios: collision with an oncoming vehicle, collision with a vehicle that is stationary, parking or stopping for traffic, fall when traveling straight ahead, and coming off the road to the right.
H. Slimi; H. Ariouri; L. Nouveliere; and S. Mammar	Advanced motorcycle infrastructure driver roll angle profile for loss control prevention	12th International IEEE Conference on Intelligent Transportation Systems, 2009. ITSC '09.	2009	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5309702&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5309702	This paper was published in Intelligent Transportation Systems, as part of the proceedings from the 12th International IEEE Conference on Intelligent Transportation Systems (ITSC 2009). It presents a new method for calculating the maximum roll angle that is authorized for a motorcycle while driving in a curve situation. The proposed approach takes into account the three elements of the driving situation: the vehicle, the driver, and the infrastructure.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Achim Kuschefski; Matthias Haasper; and André Vallese	Advanced Rider Assistance Systems for Powered Two-Wheelers (ARAS-PTW)	Institut für Zweiradsicherhei	2009	http://www-esv.nhtsa.dot.gov/Proceedings/22/files/22ESV-000123.pdf	This report, published by the Institut für Zweiradsicherhei (IFZ) in Germany, presents the results of a survey on Advanced Rider Assistance Systems for Powered Two-Wheelers (ARAS-PTW). The survey showed that both male and female motorcycle riders have knowledge deficiencies when it comes to ARAS-PTW. Given this, the project further investigated current literature on the topic and found a wide variety of definitions for ARAS-PTW, which likely contributed to this demonstrated confusion. The project responds by offering a general synoptic view of current ARAS-PTW and attempts to clearly define the term.
Francesco Biral; Mauro Da Lio; Roberto Lot; and Roberto Sartori	An Intelligent Curve Warning System for Powered Two-Wheel Vehicles	European Transport Research Review	2010	https://trid.trb.org/view/1086248	This article, published in the European Transport Research Review-Special Issue on Safety of Vulnerable Road Users, illustrates a novel Curve Warning (CW) system for motorcycles which has been developed as part of the European Commission SAFERIDER project. The CW function described in this report follows a holistic approach, combining road geometry, motorcycle dynamics, rider input, and riding styles. The warning strategy is based on the correction of longitudinal dynamics derived from a previewed ideal maneuver (reference maneuver) continuously computed from the actual state of the vehicle. Under normal driving conditions the reference maneuver matches the rider's and no correction is needed and no warning is given. But if large differences between actual and ideal accelerations are found the rider is warned to decelerate or brake. As soon as the correct value of deceleration is achieved the warning disappears, improving system acceptability. Warnings are given to the rider via an HMI, which uses a haptic accelerator throttle, a vibrating glove and helmet, and a visual display.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
V. Beanland and M. Lenne	An international study of the factors associated with the acceptability of advanced rider assistive systems for powered two-wheelers	Australasian Road Safety Research Policing Education Conference, 2013, Brisbane, Queensland, Australia	2013	https://trid.trb.org/view.aspx?id=1279316	This article was included in the proceedings from 2013 Australasian Road Safety Research Policing Education Conference in Australia. It discusses a large-scale survey on motorcycle riders' acceptance of assistive systems that was conducted across Europe and Australia as part of the European Commission's Two-wheeler Behaviour and Safety (2-Be-Safe) project. The sample included 6297 respondents (257 Australians) who were typically frequent riders and rode primarily for leisure purposes. Several individual traits predicted overall levels of acceptability of assistive systems in general, including self-reported risky riding practices and attitudes towards rule-breaking and speeding. Overall levels of acceptability were relatively low; however, acceptability levels varied considerably between specific systems. Acceptability was highest for systems that are well known and considered reliable (e.g., night vision, ABS) and lowest for systems that interfere with the task of riding (e.g., ISA, adaptive cruise control). The results indicate that riders remain resistant to the use of assistive systems and highlight several barriers to the uptake of assistive systems by riders, but also suggest possible strategies for overcoming these barriers and ultimately improving riders' acceptance of motorcycle assistive systems.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Giovanni Savino; Federico Giovannini; Niccolò Baldanzini; Marco Pierini; and Matteo Rizzi	Assessing the Potential Benefits of the Motorcycle Autonomous Emergency Braking Using Detailed Crash Reconstructions	Traffic Injury Prevention	2013	http://www.tandfonline.com/doi/abs/10.1080/15389588.2013.803280?src=recsys	The objective of this study, published in Traffic Injury Prevention, was to assess the feasibility and benefits of autonomous emergency brakes in motorcycles (MAEB). MAEB represents an innovative safety device in the field of PTWs, and the feasibility of such a system was investigated with promising results. Nevertheless, this technology is not mature yet for PTW application. Research in the field of passenger cars does not directly apply to PTWs because the activation logic of a braking system is more challenging on PTWs. The deployment of an autonomous deceleration would affect the vehicle dynamics, thus requesting an additional control action of the rider to keep the vehicle stable. The study recommended that the potential effectiveness of MAEB be investigated on a wider set of crash scenarios in order to avoid false triggering of autonomous braking.
Véronique Huth; Francesco Biral; Óscar Martín; and Roberto Lot	Comparison of two warning concepts of an intelligent Curve Warning system for motorcyclists in a simulator study	Accident Analysis and Prevention	2011	http://www.sciencedirect.com/science/article/pii/S0001457511001047	This article, published in Accident Analysis & Prevention, discusses an intelligent Curve Warning system designed to give riders support when negotiating a curve. The system was tested in a simulator study carried out with 20 test riders. The subjects performed three rides: one without the system (baseline) and two experimental rides using different versions of the Curve Warning system (one providing the warnings by a force feedback throttle and one by a haptic glove). The effects of the two system versions were evaluated both in terms of the simulated riding performance and the subjective assessment by the riders. A descriptive analysis of the riders' reactions to the warnings showed that the warnings provided by both system versions provoke an earlier and stronger adaptation of the motorcycle dynamics to the curve than when the riders did not use the system.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Yoshitaka Marumo and Nozomi Katagiri	Control effects of steer-by-wire system for motorcycles on lane-keeping performance	Vehicle System Dynamics	2011	https://trid.trb.org/view.aspx?id=1126936	This study, published in Vehicle System Dynamics, discusses the control effects of the steer-by-wire (SBW) system for motorcycles in terms of lane-keeping performance by examining a computer simulation with a rider-vehicle system that consists of a simplified vehicle model, a rider control model, and the controller of the SBW system. A lane-keeping assistance (LKA) system was applied to the SBW system and the cooperativeness of the SBW and the LKA systems was examined as well. The LKA system improved the lane-keeping performance of the SBW system under not only the steering torque disturbance but also under lateral force disturbance.
Stefano Valtolina; Sara Vanzi; Roberto Montanari; Luca Minin; and Stefano Marzani	Design of Warning Delivery Strategies in Advanced Rider Assistance Systems	ASME 2011 World Conference on Innovative Virtual Reality	2011	http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1623600	This paper was included in the proceedings of the ASME (American Society of Mechanical Engineers) 2011 World Conference on Innovative Virtual Reality. It presents innovative research for the improvement of Powered-Two-Wheelers (PTW) safety by means of developing effective and rider-friendly interfaces and interaction elements for on-bike assistance systems. In particular, the paper presents experimental results on how two advanced rider assistance systems—the Frontal Collision Warning (FCW) and the Lane Change Support (LCS) systems—impact comfort and safety. The paper describes how these warning delivery strategy were implemented in a HMI (Human Machine Interface) installed on motorbikes. This HMI was thought to offer an effective FCW system based on an understandable but, at the same time, discreet and unobtrusive rider-friendly solution.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
V.A.W.J. Marchau; R.E.C.M. van der Heijden; and E.J.E. Molin	Desirability of advanced driver assistance from road safety perspective: the case of ISA	Safety Science	2005	http://www.sciencedirect.com/science/article/pii/S0925753504000682	This article, published in Safety Science, investigated how different Advanced Driver Assistance Systems (ADAS) contribute to public goals on road traffic safety, based on accident statistics in the Netherlands. It also studied the societal costs of ADAS implementation. Intelligent speed adaptation (ISA) proved to be one of the most promising devices in terms of cost-effectiveness, as compared to other ADAS applications. Finally, the study explored levels of acceptance among potential ISA users through a survey. The findings showed that although the advantages of ISA were recognized by car drivers, their willingness to purchase and use ISA was strictly conditioned by the costs and functionality of the system.
V. Cossalter; R. Lot; M. Massaro; and R. Sartori	Development and validation of an advanced motorcycle riding simulator	Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering	2011	https://trid.trb.org/view.aspx?id=1125697	This paper was included in the Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. It illustrates and discusses the main features of a motorcycle riding simulator designed and built at the University of Padua over recent years. The simulator was developed for a variety of purposes: to develop and test electronic devices aimed at improving rider safety and vehicle performance (antilock braking systems, traction control systems, etc.); to investigate different design choices and parameter effects on vehicle dynamics; to train riders; and to study their behaviors in different scenarios (normal riding, dangerous situations, etc.). The study concluded that external devices such as advanced rider assistant systems, on-bike information systems, and human–machine interfaces can be easily integrated into the simulator by means of a standard controller area network.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Daniel Beisel; Thorsten Facius; Nina Helling; and Eckehard Schnieder	Does Today's Driving Education Consider the Requirements for Handling Modern Driving Assistance System?	ICTIS 2011: Multimodal Approach to Sustained Transportation System Development: Information, Technology, Implementation	2011	https://trid.trb.org/view.aspx?id=1111949	This study, by the American Society of Civil Engineers for the First International Conference on Transportation Information and Safety (ICTIS), considered how modern driving assistance systems might factor into driving education. The study's central question was: are current training and education curricula for driving fit to handle critical driving situations that may arise from a malfunctioning assistance system. The study concluded that both legally prescribed instructional contents and their exam contents, from present view, do not sufficiently train drivers to respond to the demands of assistance systems.
G. Roll; O. Hoffman; and J. Koenig	Effectiveness Evaluation of Antilock Braking Systems (ABS) for Motorcycles in Real-World Accident Scenarios	Proceedings of the 21st (ESV) International Technical Conference on the Enhanced Safety of Vehicles, Held June 2009, Stuttgart, Germany	2009	https://trid.trb.org/view/1099851	This paper was included in the Proceedings of the 21st (ESV) International Technical Conference on the Enhanced Safety of Vehicles, held June 2006 in Stuttgart, Germany. To better understand the relationship between motorcycle ABS and safety, this paper investigated several real accident scenarios without ABS and analyzed them under the condition that an ABS system would have been installed on the motorcycle. This methodology demonstrated a tremendous reduction in accident severity for motorcycles equipped with ABS. For example, up to 50 percent of the selected accidents could have been avoided by a simple 2 channel ABS.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Highway Loss Data Institute	Evaluation of motorcycle antilock braking systems, alone and in conjunction with combined control braking systems	Highway Loss Data Institute Bulletin	2013	https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CB4QFjAA&url=http%3A%2F%2Fwww.iihs.org%2Fmedia%2Fd9b615d8-7720-4428-84d0-f43de70974ed%2F1175364287%2FHLDI%2520Research%2FBulletins%2Fhldi_bulletin_30.10.pdf&ei=NKVoVaiZIoeuyQSi-oGwAw&usg=AFQjCNHvz9fna-nOCmLuXqulTpZWJMk6Xg&sig2=vTyf_p-DnrGdy-YlfKatLQ&bvm=bv.94455598,d.b2w	The purpose of this study, published in the Highway Loss Data Institute Bulletin, was to update prior analysis on the relationship between ABS and insurance losses under collision, medical payments, and bodily injury liability coverages and to conduct a similar evaluation of motorcycles equipped with both ABS and combined control braking systems (CCBS). For the motorcycles in the study group used to evaluate the effects of ABS alone, ABS was associated with large reductions in claim rates for all three coverage types studied—20 percent for collision, 28 percent for medical payment, and 22 percent for bodily injury liability. Due to the limited number of motorcycles in ABS/CCBS study population, analysis of these systems was limited to collision coverage. The reduction in collision claim frequency associated with ABS/CCBS (31 percent) was larger than the reduction for ABS alone.
Katerina Touliou; Dimitris Margaritis; Pavlos Spanidis; Stella Nikolaou; and Evangelos Bekiaris	Evaluation of Rider's Support Systems in Power Two-Wheelers (PTW)	Procedia—Social and Behavioral Sciences	2012	https://trid.trb.org/view.aspx?id=1255171	This study, published in Procedia - Social and Behavioral Sciences, evaluated the potential of in-vehicle information systems (IVIS) on motorcycles, with an emphasis on rider comfort and safety. Three different modalities were tested: visual (display), acoustic, and haptic (smart helmet). Results showed that motorcyclists were more attracted to the haptic modality. Riders believed that they would use it in urban as well as unfamiliar traffic environments.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Giovanni Savino; Matteo Rizzi; Julie Brown; Simone Piantini; Lauren Meredith; Bianca Albanese; Marco Pierini; and Michael Fitzharris	Further Development of Motorcycle Autonomous Emergency Braking (MAEB), What Can Indepth Studies Tell Us? A Multinational Study	Traffic Injury Prevention	2014	http://www.tandfonline.com/doi/abs/10.1080/15389588.2014.926009#	This article, published in Traffic Injury Prevention, sought to develop triggering algorithms for Motorcycle Autonomous Emergency Braking (MAEB) systems that function well over a wide spectrum of motorcycle crash scenarios. The researchers collected crash data for non-MAEB equipped motorcycles and assessed the potential impact of MAEB by applying a decision tree method. The study found that MAEB applies across a broad range of multivehicle motorcycle crash scenarios and that MAEB systems mitigated crash severity by reducing impact speed up to approximately 10 percent.
Avinash P. Penumaka; Giovanni Savino; Niccolò Baldanzini; and Marco Pierini	In-Depth Investigations of PTW-Car Accidents Caused by Human Errors	Safety Science	2010	https://trid.trb.org/view/1316311	This article, published in Safety Science, conducted an in-depth investigation of motorcycle-car crashes where human errors were the sole causative factors in order to isolate and evaluate the true potential of rider and driver assistance systems. The typical characteristics of the human errors in these crashes were thoroughly examined and classified as either perception, comprehension, and/or execution errors. The investigation findings showed that car drivers made perception and comprehension failures in a large proportion of cases; while motorcycle riders typically made perception and execution failures resulting in accidents. This research was intended to prompt discussions and further research on possible countermeasures to improve rider safety. The study identified some preliminary actions for riders and drivers, such as the training of riders to improve braking efficiency in emergency situations.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Kamarudin Ambak; Riza Atiq; and Rozmi Ismail	Intelligent Transport System for Motorcycle Safety and Issues	European Journal of Scientific Research	2009	http://www.researchgate.net/profile/Kamarudin_Ambak/publication/241917211_Intelligent_Transport_System_for_Motorcycle_Safety_and_Issues/links/00b7d53c62d7ec4ceee000000.pdf	This paper, published in the European Journal of Scientific Research, provides an overview of Intelligent Transportation Systems (ITS) for motorcycles safety. ITS technologies have significant potential to enhance traffic safety but very few have been developed especially for motorcycles. This research identified several priority ITS technologies to be adapted and developed for motorcycles, including advanced driver assistance systems, intelligent speed adaptation, driver monitoring systems, collision warning and avoidance systems, lane keeping and lane-change warning systems, visibility enhancing systems, and seat belt/helmet reminder systems. However, the researchers stressed the need to develop design standards for ITS technologies adapted to motorcycles.
Megan Bayly; Simon Hosking; and Michael Regan	Intelligent Transport Systems and Motorcycle Safety	Monash University Accident Research Centre	2006	https://www-nrd.nhtsa.dot.gov/pdf/nrd-01/ESV/esv20/07-0301-O.pdf	This research, published by the Monash University Accident Research Centre, investigated the extent to which ITS have been applied to motorcycles (including both existing and emerging technologies) and discussed these ITS according to their likely safety benefits to motorcycle safety. The research also highlighted emerging and existing ITS for other vehicles that have the potential to be adapted to motorcycles. It observed that technologies that were seen to enhance the stability and braking power of motorcycles have been regarded with highest priority so far as these are most likely to be relevant to almost all motorcycle crash types, particularly loss of control crashes. The researchers emphasized that future motorcycle ITS developments must be safety-driven but also consider issues such as acceptability.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Evangelos Bekiaris; Roberto Montanari; and Stella Nikolaou	In-Vehicle ITS Adaptation and Integration In Powered Two-Wheelers: The SAFERIDER European Project	15th World Congress on Intelligent Transport Systems and ITS America's 2008 Annual Meeting	2008	https://trid.trb.org/view/902824	This paper was included in the proceedings of the 15th World Congress on Intelligent Transport Systems and ITS America's 2008 Annual Meeting. It describes the SAFERIDER project as it applies to improving the safety of powered two-wheelers (PTW). SAFERIDER was a 3-year research project, launched in January 2008 and funded by the 7th Framework-Programme of the European Commission. The project aimed to study the potential of Advanced Driver Assistance Systems (ADAS) and In-Vehicle Information Systems (IVIS) to enhance the most crucial PTW functionalities and to develop efficient and rider-friendly interfaces that contribute to rider comfort and safety. This paper describes how SAFERIDER aimed to design, adapt and develop eight ADAS/IVIS subsystems and their elements and integrate them in different combinations on demonstration vehicles.
Elisabeth Füssl; Manuel Oberlader; Vanessa Beanland; Ioanna Spyropoulou; Michael G. Lenné; Somya Joshi; Lars Rößger; Lars Leden; Geoff Underwood; and Jose Carvalhais	Methodological development of a specific tool for assessing acceptability of assistive systems of powered two-wheeler riders	IET Intelligent Transport Systems	2015	https://trid.trb.org/view/1342054	This study, published in IET Intelligent Transport Systems, describes the methodological development of a specific tool for assessing motorcyclists' acceptability of ITS, as part of the motorcyclists' profiling questionnaire (MOPROQ). The study designed the questionnaire so that it can be used to help determine levels of rider acceptability for ITS systems in the future.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
A. Pauzie	Methodology for safety and usability assessment of ITS for riders	Proceedings of European Conference on Human-Centered Design for Intelligent Transport Systems, April 29-30, 2010, Berlin, Germany	2010	https://trid.trb.org/view.aspx?id=1150581	This paper was included in the Proceedings of the European Conference on Human Centered Design for Intelligent Transport Systems, April 2010 in Berlin, Germany. It presents and discusses methodologies developed in the framework of the European Commission's SAFERIDER project, which aimed to study the potential of advanced rider assistance systems/on bike information systems integration on motorcycles for the most crucial functionalities. The proposed methodologies are based upon some of the available studies in the PTW area in addition to the automotive area, with the purpose of adapting available tools and techniques from driver behavioural studies to the specific context of PTWs.
Véronique Huth	Motorcycle Riders' Acceptance of Advanced Rider Assistance Systems: chapter 13. In: Driver Acceptance of New Technology: Theory, Measurement and Motorcycles—The Saferider Approach Optimization	Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux (IFSTTAR)	2014	https://trid.trb.org/view/1340099	This study was published by the Institut Francais des Sciences et Technologies des Transports, de l'Amenagement et des Reseaux (IFSTTAR). It presents research on the acceptability and acceptance of Advanced Rider Assistance Systems to motorcycle riders. The study identifies and discusses factors that influence riders' acceptance. It also contrasts indicators of the need for assistance technologies to enhance safety with riders' views of different types of systems.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
J. P. Frederik Diederichs; Marco Fontana; Giacomo Bencini; Stella Nikolaou; Roberto Montanari; Andrea Spadoni; Harald Widlroither; and Niccolò Baldanzini	New HMI Concept for Motorcycles–The Saferider Approach	Engineering Psychology and Cognitive Ergonomics	2009	http://link.springer.com/chapter/10.1007/978-3-642-02728-4_38	This paper, published in Engineering Psychology and Cognitive Ergonomics, presents the outline of the European Commission's SAFERIDER project and focuses on the new human-machine interface (HMI) concept and haptic interface devices that were developed within the project.
V. Cossalter; R. Lot; and S. Rota	Objective and subjective evaluation of an advanced motorcycle riding simulator	European transport research review	2010	http://link.springer.com/article/10.1007/s12544-010-0041-2#page-1	This paper outlines the characteristics of a top-of-the range motorcycle simulator designed and built at the University of Padua over a period of several years. The simulator consists of a motorcycle mock-up with functional throttle, brakes, clutch and gearlever mounted on a five 'degrees of freedom' platform, a real-time multibody model of the motorcycle, and an audio and visual systems. The paper evaluated objective and subjective data showing that the proposed simulator is adequate for handling tests. The paper concluded that the proposed method is suitable to be extended to vehicle simulators in general.
S. Rowell; A. A. Popov; and J. P. Meijaard	Optimal control to modeling motorcycle rider steering: local versus global coordinate systems in rider preview	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2010	http://www.tandfonline.com/doi/full/10.1080/00423110902815238#abstract	This paper was published in Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility. The paper's primary objective was to develop effective path-following simulations and to better understand how riders control motorcycles. The simulations suggested that for accurate path following, using optimal control, the problem must be solved by the local coordinates approach in order to achieve accurate results with short preview horizons. The study also highlights some weaknesses of the optimal control approach.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
R. S. Sharp	Optimal linear time-invariant preview steering control for motorcycles	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2006	http://www.tandfonline.com/doi/full/10.1080/00423110600871509#abstract	This paper was published in Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility. The paper covers the development and testing of a motorcycle steering model. The researchers concluded that the motorcycle rider model developed in this work successfully represented a useful combination of steering control capability and computational economy. They further concluded that the model yields new insights into rider and motorcycle behaviour.
Veronique Huth and Christhard Gelau	Predicting the acceptance of advanced rider assistance systems	Accident Analysis and Prevention	2013	https://trid.trb.org/view/1239313	This paper examines the particularities of motorcycle riding and the characteristics of this user group that should be considered when predicting the acceptance of advanced rider assistance systems. Since actual usage cannot be measured in the development stage of the systems, the willingness to have the system installed on their own motorcycle, and the willingness to pay for the system are analyzed, constituting relevant conditions that allow for actual usage at a later stage. Its validation with the results from user tests on four advanced rider assistance systems allows confirming the social norm and the interface design as powerful predictors of the acceptance of ARAS, while the extent of perceived safety when riding without support did not have any predictive value in the present study.
R. S. Sharp	Rider control of a motorcycle near to its cornering limits	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2012	http://www.tandfonline.com/doi/abs/10.1080/00423114.2011.607899?src=recsys#.VTaeySFVhBc	This paper was published in Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility. The paper covers the development and testing of a motorcycle steering model. The researchers concluded that the motorcycle rider model developed in this work successfully represented a useful combination of steering control capability and computational economy. They further concluded that the model yields new insights into rider and motorcycle behaviour.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Elisabeth Füssl; Manuel Oberlader; M. Lenné; V. Beanland; M. Pereira; A. Simoes; Ch. Turetschek; C. Kaufmann; S. Joshi; L. Rößger; L. Leden; I. Spyropoulou; H. Roebroeck; J. Carvalhais; and J. Underwood	Riders Acceptance of Advanced Rider Assistance Systems	19th ITS World Congress, Vienna, Austria, 22 to 26 October 2012	2012	https://trid.trb.org/view.aspx?id=1258821	This study, included in the proceedings of the 19th ITS World Congress in 2012, conducted a literature review, focus group interviews, and an online survey on the topic of rider acceptance of Advanced Rider Acceptance Systems (ARAS). The results showed that the acceptability of systems depends on their function. Acceptability was higher for systems that were perceived to be more useful in emergencies. Survey respondents raised several concerns regarding the acceptance of assistive systems for PTWs. Respondents of the on-line survey felt that there was too much focus on assistive systems as a means of improving PTW rider safety, and less on the dangers that motorcyclists face actually from the actions of other road users.
Niccolò Baldanzini; Giacomo Bencini; Marco Pierini; Aline Delhaye; Roberto Montanari; and Evangelos Bekiaris	Riders' Needs and Wants—The SAFERIDER Approach	16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services	2009	https://trid.trb.org/view.aspx?id=907835	This paper was included in the proceedings of 16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services. It presents and discusses the SAFERIDER project's approach to understanding riders' needs and wants for motorcycle ITS. SAFERIDER employed two strategies to capture riders' needs and wants: (1) a Focus Group with expert rider trainers to find out needs and (2) a Public Survey to investigate riders' opinions about usefulness of several ADAS and IVIS systems (wants).

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
M. Schlipsing; J. Salmen; B. Lattke; K.G. Schroter; and H. Winner	Roll angle estimation for motorcycles: Comparing video and inertial sensor approaches	Intelligent Vehicles Symposium (IV), 2012 IEEE	2012	http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6232200&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6232200	This paper was published as part of the Intelligent Vehicles Symposium (IV) in 2012. The study presents alternative approaches to roll angle estimation based on inertial measurement units (IMU) as well as video only. It gives an evaluation of real video data along with three valuable improvements and an extensive parameter optimization using the Covariance Matrix Adaptation Evolution Strategy. For comparison of the very dissimilar approaches, a test vehicle was equipped with IMU, a camera, and a highly accurate reference sensor. The results showed high performance of about 2 degrees error for the improved vision method and, therefore, proved the proposed concept on real-world data. The IMU-based Kalman filter estimation performed on par.
Evangelos Bekiaris; Stella Nikolaou; Roberto Montanari; Andrea Spadoni; Andrea Borin; Marco Pieve; Roberto Lot; Roberto Sartori; Veronique Huth; Frederik Diederichs; and Francesco Biral	SAFERIDER—Advanced Telematics for Enhancing the Safety and Comfort of Motorcycle Riders	17th ITS World Congress	2010	https://trid.trb.org/view.aspx?id=1115821	This paper, included in the proceedings of the 17th ITS World Congress in 2010, presents the SAFERIDER project outline, with a focus on the functionality developed and the activity completed at the time of the congress. The paper provides a detailed account of architecture developed for the simulator and demonstrators testing, the HW components implemented, and the HWs integration of the innovative vehicle demonstrators. At the time of the congress, the researchers were still waiting for project conclusion.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
J. P. Frederik Diederichs; Melanie Ganzhorn; Harald Widlroither; Evangelos Bekiaris; Stella Nikolaou; Roberto Montanari; Andrea Spadoni; Marco Fontana; Giacomo Bencini; Niccolò Baldanzini; and Sara Granelli	SAFERIDER HMI Strategies for Motorcycles' ARAS and OBIS	17th ITS World Congress	2010	https://trid.trb.org/view.aspx?id=1089538	The paper, included in the proceedings of the 17th ITS World Congress in 2010, focuses on the assignment of HMI elements to specific ARAS and OBIS and the design of intuitive haptic warnings in the SAFERIDER project. The authors stressed that acceptance and compliance toward safety warnings was considered in the presented HMI strategies that were developed within the project. The intention of this research was to, after iterative testing, lead to a highly acceptable and effective HMI concept for motorcycle riders.
E. D. Bekiaris; A. Spadoni; and S. I. Nikolau	SAFERIDER Project: New safety and comfort in Powered Two-Wheelers	2nd Conference on Human System Interactions, 2009. HSI '09.	2009	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5091045&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5091045	This article, published in Human System Interactions, 2009, conducted a priori in-depth accident analyses to discover the causes and most common scenarios leading to PTW accidents. This research was intended to support the work of the SAFERIDER project, including its development of a common architecture to host ARAS and IVIS as well as its design of a rider friendly HMI.
Roberto Montanari; Andrea Spadoni; Evangelos Bekiaris; and Stella Nikolaou	Saferider: CAN based architecture on two-wheelers domain	Road safety on four continents: 15th international conference, Abu Dhabi, United Arab Emirates, 28-30 March 2010. Paper	2010	https://trid.trb.org/view.aspx?id=968760	This article, included in the proceedings of Road Safety on Four Continents: 15th Annual Conference in 2010, presents a new concept of CAN-based (Controller Area Network) architecture developed within the SAFERIDER 7 Framework Project, which aimed to improve motorcycle safety by introducing new ITS functionalities, specifically ARAS and OBIS. ARAS and OBIS are supported by multi-points high speed CAN installed in the motorcycle. This paper describes the operations and information flow of the CAN-based architecture in relation to this project.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
R. Montanari; A. Borin; and A. Spadoni	Saferider: Results from Yamaha test site on advanced rider assistance system	Proceedings of the 9th ACM SIGCHI Italian Chapter International Conference on Computer-Human Interaction: Facing Complexity	2011	http://dl.acm.org/citation.cfm?id=2037329	This paper was included in the Proceedings of the 9th ACM SIGCHI Italian Chapter International Conference on Computer-Human Interaction: Facing Complexity. It presents the results of the SAFERIDER project's Yamaha test site on Advanced Rider Assistance Systems (ARAS). SAFERIDER was a research project aimed at studying the potential of ARAS and On Bike Information Systems (OBIS) integration on motorcycles and developing a rider-friendly interface. The functionalities were evaluated Europe-wide in simulators and in motorcycle demonstrators, testing them on functional, usability and acceptance point of views. The results of SAFERIDER testing demonstrated that Intelligent Technology Systems in motorcycles can significantly improve riders' safety and comfort.
C. Spelta; V. Manzoni; A. Corti; A. Goggi; and S. M. Savaresi	Smartphone-Based Vehicle-to-Driver/Environment Interaction System for Motorcycles	Embedded Systems Letters, IEEE	2010	http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=5482096&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5482096	This article, published in Embedded Systems Letters IEEE, documents the definition and implementation of an add-on interaction system for motorcycles. This system consists of a vehicle-to-driver and a vehicle-to-environment communication mechanism, which is based on a smartphone core and on a wireless Bluetooth medium. The system is focused to increase the safety level of a motorcycle and it is constituted by a vehicle with a CAN bus, a compact embedded electronic unit implementing a CAN-to-Bluetooth gateway, a smartphone and a Bluetooth helmet. The paper presents the hardware architecture, the software architecture, and some case-study implementation issues. It also provides an evaluation of the critical aspects of the system.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Shigeru Fujii; Souichi Shiozawa; Akinori Shinagawa; and Tomoaki Kishi	Steering characteristics of motorcycles	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2012	http://www.tandfonline.com/doi/abs/10.1080/00423114.2011.607900?src=recsys#.VTafQCFVhBc	This study, published in Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, presents the results of a steady-state cornering test that used a sport-touring motorcycle. This test was conducted in an effort to realize a quantitative development method for motorcycles. The study made measurements using not only the normal rider's lean angle (lean-with posture), but also measurements in the case where the rider's lean angle was intentionally changed, in order to investigate the effects that a change in the rider's posture has on the variation in the measurement results of the motorcycle's dynamics. Furthermore, these measurements were compared with the results obtained from simulations. Additionally, steering index values were calculated from the measurement results. The authors concluded that this will open a new path for more detailed investigations of motorcycle dynamics.
L. L. Di Stasi; D. Contreras; J.J. Cañas; A. Cándido; A. Maldonado; and A. Catena	The consequences of unexpected emotional sounds on driving behavior in risky situations	Safety Science	2010	http://www.sciencedirect.com/science/article/pii/S092575351000192X	This study, published in Safety Science, aimed to uncover whether emotional auditory stimuli can affect risky behaviour in hazardous situations. Forty-nine volunteers rode a motorcycle in a virtual environment and went through a number of preset risky scenarios, some of which were cued by a sound (a beep, a positive emotional sound, or a negative sound). Results showed that hearing the beep reduced the frequency of accidents in the upcoming risky situation, while the emotional cues did not. The authors concluded that these findings could provide important information for the development of new advanced driver assistance systems and in general for the specification of future Human–Machine-Interaction design guidelines.

Table B-4. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Oliver Hoffmann; Alfred Eckert; James Remfrey; and Jürgen Woywod	The Motorcycle Integral Brake System MIB—An Advanced Brake Solution For High-Performance Motorcycles	NRD-NHTSA	2012	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv20/07-0312-O.pdf	The purpose of this study, published in the Highway Loss Data Institute Bulletin, was to update prior analysis on the relationship between ABS and insurance losses under collision, medical payments, and bodily injury liability coverages and to conduct a similar evaluation of motorcycles equipped with both ABS and combined control braking systems (CCBS). For the motorcycles in the study group used to evaluate the effects of ABS alone, ABS was associated with large reductions in claim rates for all three coverage types studied—20 percent for collision, 28 percent for medical payment, and 22 percent for bodily injury liability. Due to the limited number of motorcycles in ABS/CCBS study population, analysis of these systems was limited to collision coverage. The reduction in collision claim frequency associated with ABS/CCBS (31 percent) was larger than the reduction for ABS alone.
Holger Berndt and Klaus Dietmayer	Timing Analysis for Motorcycle Intersection Assistance Systems	15th World Congress on Intelligent Transport Systems and ITS America's 2008 Annual Meeting	2008	https://trid.trb.org/view.aspx?id=905323	This paper, included in the proceedings of the 15th World Congress on Intelligent Transport Systems and ITS America's 2008 Annual Meeting, analyzed typical intersection scenarios with respect to the feasibility of motorbike-based warnings or automatically intervening assistance systems that protect motorbike drivers from dangerous situations induced by surrounding car drivers. The paper assessed the potential of these motorbike-based assistance systems and derived the necessary sensor and environmental perception requirements.

Antilock Braking System

A safety system that allows the wheels on a motor vehicle to maintain tractive contact with the road surface according to driver inputs while braking, preventing the wheels from locking up (ceasing rotation), and avoiding uncontrolled skidding. See also “electronic stability program.”

Table B-5. Search terms.

Search Terms
Antilock Braking System
ABS
Antiskid Braking System

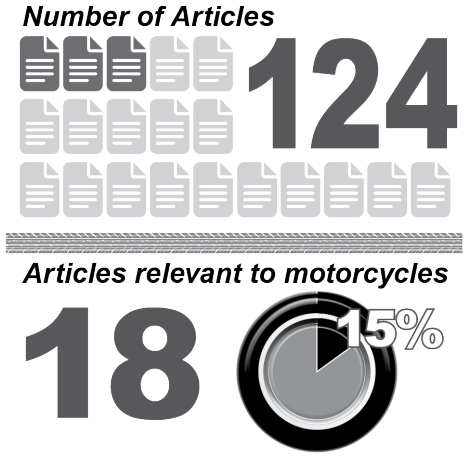


Table B-6. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
J. Gail; J. Funke; P. Seiniger; and U. Westerkamp	Antilock Braking and Vehicle Stability Control for Motorcycles—Why or Why Not?	Proceedings of the 21st (ESV) International Technical Conference on the Enhanced Safety of Vehicles	2009	https://www-nrd.nhtsa.dot.gov/pdf/esv/esv21/09-0072.pdf	This paper, published by the National Highway Traffic Safety Administration, was included in the Proceedings of the 21st (ESV) International Technical Conference on the Enhanced Safety of Vehicles, held in Germany in 2009. The paper evaluated the safety potential of Anti Lock Braking Systems (ABS) and Vehicle Stability Control (VSC) for motorcycles by means of accident analysis, driving tests, and economical as well as technical assessment of the systems. With regard to ABS, test persons were assigned braking tasks (straight and in-curve) with five different brake systems with and without ABS. The potential of VSC for motorcycles was estimated in two steps. First the kinds of accidents that could be prevented by such a system at all were analyzed. For these accident configurations, simulations and driving tests were then performed to determine if a VSC was able to detect the critical driving situation and if it was technically possible to implement an actuator which would help to stabilize the critical situation.
Insurance Institute for Highway Safety	Antilock brakes on motorcycles prevent crashes	IIHS Status Report	2010	http://www.iihs.org/iihs/sr/statusreport/article/45/3/3	This article, published by the Insurance Institute for Highway Safety, covers results from two new studies on ABS benefits for motorcycles. The main takeaway was that motorcycles with ABS versus motorcycles without ABS were found to be 37 percent less likely to be in fatal crashes per 10,000 registered vehicle years. A separate Highway Loss Data Institute (HLDI) analysis of insurance claims filed for damage to motorcycles supported this finding. Bike models with ABS had 22 percent fewer claims for damage per insured vehicle year than the same models without ABS.

Table B-6. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Insurance Institute for Highway Safety	Antilock brakes on motorcycles reduce both crash frequencies and deaths	IIHS Status Report	2008	http://www.iihs.org/iihs/sr/statusreport/article/43/9/1	This article, published by the Insurance Institute for Highway Safety, covers two new studies (one by IIHS and one by HLDI) indicating that crash reductions are associated with antilock brakes. The first study revealed that both the frequency of crashes for which insurance claims are filed and the rate of fatal motorcycle crashes go down among bikes with antilock brakes. Antilock brakes appeared to reduce collision claims, but not the severity of the crashes for which claims are filed. In the second study, the rate of fatal crashes normalized by motorcycle registrations decreased by 38% for motorcycles with ABS. These findings were statistically significant at the 90 percent confidence level. The researchers also looked at the combined effect of ABS and CBS (combined braking systems, which integrate a motorcycle's front and rear brake controls), and found that the two technologies together reduced collision claim frequency by about a third.
C. Thamotharan; S. Prabhakar; S. Vanangamudi; and R. Anbazhagan	Antilock braking system in two-wheelers	Middle-East Journal of Scientific Research	2014	https://www.mendeley.com/research/antilock-braking-system-two-wheelers/	This paper, published in the Middle-East Journal of Scientific Research, documented the development of an antilock braking control system integrated with active suspensions and applied to a two wheeler. The researchers found that braking time and distance can be further improved if the normal force generated from active suspension systems is considered simultaneously with control torque.

Table B-6. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Alexander Muller and Yildirim Fevzi	Bosch Motorcycle ABS: Safety for All	Proceedings of the 18th ITS World Congress	2011	https://trid.trb.org/view/1253088	This article, included in the Proceedings of the 18th ITS World Congress, documents the history of the development of motorcycle ABS, with a focus Bosch, which introduced ABS for automobiles in 1978. Six years later, the company started the development of antilocking systems for motorcycles, introducing the first system to the market in 1995. Based on decades of experience, Bosch continuously reduced the size and the weight of the motorcycle ABS: while the first ABS system weighed more than 4 kg, the ABS base variant of the newest Generation 9 weighs only 700 g. New small and light motorcycle ABS systems opened the technical possibility to equip even small two-wheelers and thereby accelerated the proliferation of this life-saving safety system in the market.
Matteo Rizzi	Can a boxer engine reduce leg injuries among motorcyclists? Analysis of injury distributions in crashes involving different motorcycles fitted with antilock brakes (ABS).	Traffic Injury Prevention	2015	http://www.tandfonline.com/doi/full/10.1080/15389588.2015.1007224#abstract	This paper, published in Traffic Injury Prevention, analyzed injury distributions in crashes involving ABS-equipped motorcycles with boxer-twin engines, compared with similar ABS-motorcycles with other engine configurations. The findings indicated that boxer-twin engines can reduce leg injuries among riders of motorcycles fitted with ABS.

Table B-6. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Herbert Baum	Cost-benefit analysis for ABS of motorcycles	Institute for Transport Economics, University of Cologne	2008	http://oskicat.berkeley.edu/record=b11717435~S1	This study was produced by the Institute for Transport Economics at the University of Cologne. It performed a cost-benefit analysis to clarify whether or not the economic benefit of ABS for motorcycles is greater than the consumed resources. The study found that all benefit-cost ratios were over the critical barrier of 1.0. Thus, the researchers concluded that ABS is worthwhile on economic level. In the scenarios with high effectiveness the benefit-cost ratios range between 4.6 and 4.9. Thus, the values were even above the barrier of 3.0 in these scenarios and ABS can be considered worthwhile for most motorcycle riders.
C.Y. Lu and M.C. Shih	Design of a hydraulic antilock braking modulator and an intelligent brake pressure controller for a light motorcycle	Vehicle System Dynamics	2005	http://www.tandfonline.com/doi/abs/10.1080/00423110412331282878#abstract	The object of this research, published by Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, was to design a new hydraulic modulator and an intelligent sliding mode pulse width modulation (PWM) brake pressure controller for an antilock braking system, for application to light motorcycles. A three-phase pavement experiment and a rear brake influence test were undertaken to verify the performance of the controller and the modulator. A light motorcycle was built to conduct real vehicle antilock braking experiments. The experimental results showed that both the intelligent controller and the hydraulic modulator designed in the study performed well in the antilock braking operation.
Chun Kuei Huang and Ming Chang Shih	Design of a hydraulic antilock braking system (ABS) for a motorcycle	Journal of Mechanical Science and Technology	2010	https://www.mendeley.com/research/design-hydraulic-antilock-braking-system-abs-motorcycle/	This research, published in the Journal of Mechanical Science and Technology, presents a hydraulic antilock braking system (ABS) for motorcycles, with a hydraulic modulator and an intelligent controller. The hydraulic modulator was analyzed, and then equipped on a scooter for road tests. The paper details the methodology behind and results of these tests.

Table B-6. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
C.K. Huang and M.C. Shih	Dynamic analysis and control of an antilock brake system for a motorcycle with a camber angle	Vehicle System Dynamics	2011	http://www.tandfonline.com/doi/full/10.1080/00423111003663568#abstract	This paper, published in Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, analyzed the dynamic response of a motorcycle with an antilock brake system (ABS) and camber or steering angle. This motorcycle model combined a mathematical equation of the ABS modulator, tire model and controller in simulations.
G. Roll; O. Hoffman; and J. Koenig	Effectiveness Evaluation of Antilock Braking Systems (ABS) for Motorcycles in Real-World Accident Scenarios	Proceedings of the 21st (Esv) International Technical Conference on the Enhanced Safety of Vehicles	2009	https://trid.trb.org/view/1099851	This paper was included in the Proceedings of the 21st (ESV) International Technical Conference on the Enhanced Safety of Vehicles. It conducted a detailed analysis of different accident scenarios involving PTWs using the DEKRA PTW database. From this database containing 350 real-world accidents, 51 cases were selected by imposing a reaction demand and a following braking of the motorcycle rider in order to evaluate the benefit of advanced brake control systems. Several real accident scenarios without ABS were analyzed under the condition that an ABS system would have been installed on the motorbike. The results demonstrated a tremendous reduction in accident severity. For example up to 50% of the selected accidents could have been avoided by a simple 2 channel ABS.
Eric R. Teoh	Effectiveness of Antilock Braking Systems in Reducing Motorcycle Fatal Crash Rates	Traffic Injury Prevention	2011	http://www.tandfonline.com/doi/full/10.1080/15389588.2010.541308#abstract	The objective of this study, published in Traffic Injury Prevention, was to evaluate the effect of ABS in fatal motorcycle crashes. The researchers compared the number of motorcycle riders involved in fatal crashes per 10,000 registered vehicle years for 13 different motorcycle models with optional ABS and those same models without the option during 2003–2008. The rate of fatal motorcycle crashes per 10,000 registered vehicle years was 37 percent lower for ABS models than for their non-ABS versions. The study concluded that ABS appears to be highly effective in preventing fatal motorcycle crashes based on some early adopters of motorcycle ABS technology.

Table B-6. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Matteo Rizzi; Johan Strandrothb; Anders Kullgren; Claes Tingvall; and Brian Fildes	Effectiveness of Motorcycle Antilock Braking Systems (ABS) in Reducing Crashes, the First Cross-National Study	Traffic Injury Prevention	2015	http://www.tandfonline.com/doi/full/10.1080/15389588.2014.927575#abstract	The objective of this study, published in Traffic Injury Prevention, was to evaluate the effectiveness of motorcycle antilock braking systems (ABS) in reducing real-life crashes. Using police reports from Spain, Italy, and Sweden, the same motorcycle models, with and without ABS, were compared and the calculations were carried out for each country. The effectiveness of ABS in reducing crashes ranged from 24% to 42% for motorcycles and 27% to 31% for scooters (at least 250 cc). The authors concluded that, at this stage, there is more than sufficient scientific-based evidence to support the implementation of ABS on all motorcycles, even light ones.
Eric R. Teoh	Effects of Antilock Braking Systems on Motorcycle Fatal Crash Rates: An Update	Insurance Institute for Highway Safety	2013	http://www.iihs.org/frontend/iihs/documents/masterfiledocs.ashx?id=2042	The objective of this research, published by the Insurance Institute for Highway Safety, was to provide an updated examination of the effects of ABS on fatal motorcycle crash rates. Motorcycle drivers involved in fatal crashes per 10,000 registered vehicle years during 2003-11 were examined for 13 motorcycle models offering optional ABS. Fatal crash rates for motorcycles with ABS were compared to rates for the same models without ABS. This methodology showed that ABS was associated with a 31 percent reduction in the rate of fatal motorcycle crashes per 10,000 registered vehicle years.
Highway Loss Data Institute	Evaluation of motorcycle antilock braking systems, alone and in conjunction with combined control braking systems	Highway Loss Data Institute	2013	http://www.iihs.org/media/ddcf0bce-ca7a-47f2-90a6-f2226d7316c8/-1693001650/Petitions/petition_2013-05-30.pdf	The purpose of this study, published by the Highway Loss Data Institute, was to update prior analysis on the relationship between ABS and insurance losses under collision, medical payments, and bodily injury liability coverages and to conduct a similar evaluation of motorcycles equipped with both ABS and combined control braking systems (CCBS). For the motorcycles in the study group used to evaluate the effects of ABS alone, ABS was associated with large reductions in claim rates for all three coverage types studied—20 percent for collision, 28 percent for medical payment, and 22 percent for bodily injury liability.

Table B-6. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Insurance Institute for Highway Safety	Insurance Special Report: Motorcycle Antilock Braking System (ABS)	Insurance Institute for Highway Safety	2009	http://www.iihs.org/media/72941842-3a67-4e6b-8d86-a8fa73b68369/852086724/HLDI%20Research/Insurance%20reports/hldi_abs_A81.pdf	This report, published by the Insurance Institute for Highway Safety Results, updates and expands an earlier analysis conducted by the Highway Loss Data Institute (HLDI) that looked at how motorcycle ABS and other characteristics impact insurance claim frequencies and overall losses from motorcycle crashes. This report added the 2008 model year, increasing the number of make/series from 12 to 18, and doubling the collision exposure. It provides a detailed analysis of these impacts across many dimensions.
Insurance Institute for Highway Safety	New research adds to the evidence that motorcycle ABS prevents crashes	IIHS Status Report	2013	http://www.iihs.org/iihs/sr/statusreport/article/48/4/2	This article, published by the Insurance Institute for Highway Safety, explored the impact that ABS has on motorcycle crashes and fatalities. Motorcycles with antilock braking systems (ABS) were found to be 31 percent less likely to be involved in fatal crashes than those same motorcycles without ABS, according to a recent IIHS analysis. Meanwhile, a new HLDI study showed a 20 percent reduction in the rate of collision claims with ABS and a 28 percent reduction in the frequency of claims for rider injuries. The article also provided additional background and methodology information.
Matteo Rizzi; Johan Strandroth; and Claes Tingvall	The effectiveness of antilock brake systems on motorcycles in reducing real-life crashes and injuries	Swedish National Road and Transport Research Institute (VTI)	2010	https://trid.trb.org/view.aspx?id=901100	This study from the Swedish National Road and Transport Research Institute (VTI) analyzes fatal crash data in Sweden during 2005–2008 to estimate of the effectiveness of ABS in crash reduction. The results showed that head-on collisions were the least ABS-affected crash types and collisions at intersections were the most influenced. Induced exposure analysis showed that the overall effectiveness of ABS was 38 percent on all crashes with injuries and 48 percent on all severe and fatal crashes, with a minimum effectiveness of 11 and 17 percent, respectively. The study recommended the fitment of ABS on all new motorcycles as soon as possible and that customers only purchase motorcycles with ABS.

Collision Warning and Avoidance Systems

Vehicle-based sensor system that detects objects in the roadway and alerts the driver (warning); if the driver does not respond the system will apply brakes (avoidance).

Table B-7. Search terms.

Search Terms
Collision Warning and Avoidance Systems
Collision Warning
Collision Avoidance Systems
Collision Detection
Accident Avoidance Systems
Collision Avoidance Motorcycles
Collision Avoidance Braking
Autonomous Braking

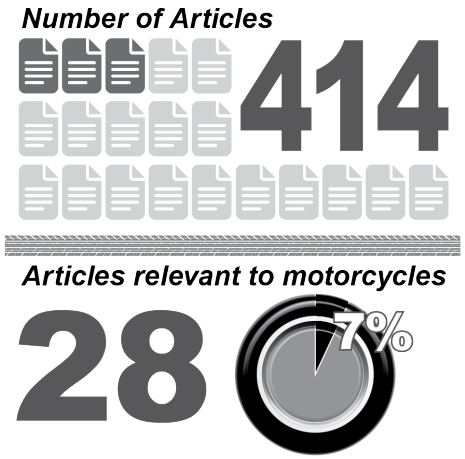


Table B-8. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
Sophia University	A Proposal of Detection Method to avoid collision between vehicle and motorcycle in an intersection	15th World Congress on Intelligent Transport Systems	2008	Not available online.	This paper was presented at the 15th World Congress on Intelligent Transport Systems in 2008. It proposes a detection method to avoid collisions between vehicles and motorcycles in intersections using radio wave DOA estimation by ESPRIT. The detection system is based on a distributed system that requires no road side infrastructure. The researchers installed the transmitter in the motorcycle and the receiver in the vehicle. The vehicle then receives the radio waves arriving from different directions due to reflections from buildings and diffraction around the corner of building. By Direction of Arrival Estimation, the receiver is gripped the basic characteristic of the propagation of the radio wave. The results made possible the calculation of whether the motorcycle is in Line of Sight (LOS) or Non Line of Sight (NLOS), and right or left of the vehicle.
Mara Tanelli; Matteo Corno; Ivo Boniolo; and Sergio M. Savaresi	Active braking control of two-wheeled vehicles on curves	International Journal of Vehicle Autonomous Systems (2009)	2009	https://www.mendeley.com/research/active-braking-control-twowheeled-vehicles-curves/	This paper, published in the International Journal of Vehicle Autonomous Systems, documents the design of an innovative active braking control system for two-wheeled vehicles that can handle panic braking on curves. At the time of this research only a few commercial motorbikes were equipped with Antilock Braking Systems (ABS). Moreover, the few ABS systems available were certified to work only when panic braking occurred on straight road. The active braking control system described in this report was slated to be tested further on a very detailed multibody simulation model of a two-wheeled vehicle, MSC BikeSim®.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Mercedes Bueno; Colette Fabrigoule; Philippe Deleurence; Daniel Ndiaye; and Alexandra Fort	An Electrophysio-logical Study of the Impact of a Forward Collision Warning System in a Simulator Driving Task	Brain Research	2012	https://trid.trb.org/view/1212453	The main objective of this paper, published in Brain Research, was to evaluate the impact and reliability of a surrogate FCWS according to the driver's attentional state by recording both behavioral and electrophysiological data. Participants drove following a lead motorcycle in a simplified simulator with or without a warning system which gave forewarning of the preceding vehicle braking. Behavioral and electrophysiological data revealed that the warning system had a positive effect. Participants were faster in detecting the brake light when the system was perfect or imperfect, and the time and attentional resources allocation required for processing the target at higher cognitive level were reduced when the system was completely reliable. The researchers concluded that electrophysiological data could be a valuable tool to complement behavioral data and to have a better understanding of how these systems impact the driver.
F. Biral; R. Lot; R. Sartori; A. Borin; and B. Roessler	An intelligent Frontal Collision Warning system for Motorcycles	Proceedings, Bicycle and Motorcycle Dynamics 2010	2010	Not available online.	This article introduced a novel Frontal Collision Warning system for motorcycles, which was developed as part of the European Commission's SAFERIDER project. The Frontal Collision Warning Function (FCW) described in the article is based on a holistic approach, which localizes the motorcycle in the road geometry, estimates the motorcycle dynamics state and rider input, and senses obstacles in the motorcycle lane. The warning strategy is based on the correction of longitudinal dynamics as suggested by an optimal previewed maneuver (reference maneuver), which is continuously computed from the actual state of the vehicle.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Federico Giovannini; Giovanni Savino; Marco Pierini; and Niccolò Baldanzini	Analysis of the minimum swerving distance for the development of a motorcycle autonomous braking system	Accident Analysis and Prevention	2013	http://www.sciencedirect.com/science/article/pii/S0001457513002194	This paper, published in Accident Analysis and Prevention, presents a model to compute the minimum swerving distance needed by a powered two-wheeler (PTW) to avoid collisions with fixed obstacles, named the last-second swerving model (LSW). The effectiveness of the model was investigated in an experimental campaign involving 12 volunteers riding a scooter equipped with a prototype autonomous emergency braking, named motorcycle autonomous emergency braking system (MAEB). The tests showed the performance of the model in evasive trajectory computation for different riding styles and fixed obstacles.
Ioannis Symeonidis; Gueven Kavadarli; Schuller Erich; Matthias Graw; and Steffen Peldschus	Analysis of the stability of PTW riders in autonomous braking scenarios	Accident Analysis and Prevention	2012	https://trid.trb.org/view/1238198	This paper, published in Accident Analysis and Prevention, addressed rider stability concerns related to autonomous braking systems for PTWs. Experiments with volunteers were performed in order to find out whether autonomous braking for PTWs produced greater instability of the rider in comparison to manual braking. The results showed that autonomous braking at low deceleration does not cause significant instabilities of the rider in comparison to manual braking in idealized laboratory conditions. Based on this, the researchers recommended further research into the development and implementation of autonomous braking systems for PTWs, e.g. by extensive riding tests.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Giovanni Savino; Federico Giovannini; Niccolò Baldanzini; Marco Pierini; and Matteo Rizzi	Assessing the Potential Benefits of the Motorcycle Autonomous Emergency Braking Using Detailed Crash Reconstructions	Traffic Injury Prevention	2013	http://www.tandfonline.com/doi/pdf/10.1080/15389588.2013.803280	The objective of this study, published in Traffic Injury Prevention, was to further assess the feasibility and the quantitative potential benefits of the Motorcycle Autonomous Emergency Braking system (MAEB) with special focus on fatal rear-end crashes; and to identify possible criticalities of MAEB in the field of powered two-wheelers (PTWs) in fatal rear-end crashes; for example, any additional risk to the rider due to the system itself. This study confirmed the applicability of MAEB in real crash cases in car-following scenarios, showing possible impact speed reductions in a range of initial conditions. The results also showed the positive effects of ABS, although relevant speed reductions were achieved both by autonomous braking (in the case of no reaction) and emergency braking (when the rider operated the brakes).
Giovanni Savino	Autonomous Emergency Braking for Powered Two-Wheeler Application Rationales, Implementation and First Tests	Saarbrücken LAP LAMBERT Academic Publishing 2013	2013	http://melvyl.worldcat.org/title/autonomous-emergency-braking-for-powered-two-wheeler-application-rationales-implementation-and-first-tests/oclc/863943639&referer=brief_results	This eBook, published by Saarbrücken LAP LAMBERT Academic Publishing in 2013, discusses autonomous emergency braking in motorcycles—particularly application rationales, implementation, and initial tests.
B. Anderson and A. Baxter	Comparison of Motorcycle Braking System Effectiveness	SAE Technical Paper (2010)	2010	https://www.mendeley.com/research/comparison-motorcycle-braking-system-effectiveness/	This paper, published as a SAE Technical Paper in 2010, presents a comparison of motorcycle braking data for five different types of braking systems: standard brakes, integrated brakes, independent ABS brakes, integrated ABS brakes, and linked brakes. Integrated ABS brakes generated the highest negative acceleration rates. While there was no mention of ITS technology mentioned in the abstract, the paper covers relevant subject matter such as ABS.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Giovanni Savino; Marco Pierini; and Niccolò Baldanzini	Decision logic of an active braking system for powered two-wheelers	Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering	2012	https://trid.trb.org/view.aspx?id=1144201	This paper, published in the Proceedings of the Institution of Mechanical Engineers Part D: Journal of Automobile Engineering, reports on the design of a decision logic structure for deploying a PTW autonomous braking system to help prevent imminent collisions. The authors give rationales and limitations for this pioneering application. The feasibility of the autonomous deceleration was demonstrated by an experimental study conducted with the PISa test bike that implemented a prototype of the autonomous braking system, named the Active Braking (AB) system.
E. Raphael; R. Kiefer; P. Reisman; and G. Hayon	Development of a camera-based forward collision alert system	SAE International	2011	http://papers.sae.org/2011-01-0579/	This paper, published by SAE International, discusses the development of a camera-based Forward Collision Alert (FCA), also known as a Forward Collision Warning (FCW), that uses a camera in place of a radar device for sensing rear-end crash situations. The paper provides an overview of the system, including how the system detects vehicles, tracks vehicles, projects collision course trajectories, and estimates time-to-collision (TTC) using image scale change. Results from test track and public road testing support the deployment of a camera-based FCA system, and indicate this system would meet the United States Department of Transportation New Car Assessment Program (NCAP) Forward Collision Warning confirmation test requirements. Furthermore, the conditions under which most rear-end crashes occur suggests that this system provides a promising approach to reduce the harm caused by rear-end crashes.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Patricia Turner; Laura Higgins; and Srinivas Geedipally	Development of a statewide motorcycle safety plan for Texas: technical report.	Texas Department of Transportation. Research and Technology Implementation Office	2013	http://ntl.bts.gov/lib/47000/47700/47731/0-6712-1.pdf	The objective of this research project, conducted by the Texas Department of Transportation, was to develop a statewide plan to reduce motorcycle crashes and injuries in the state of Texas. The project included a review of published literature on current and proposed countermeasures for reducing the incidence and/or severity of motorcycle-involved crashes and related injuries, a review of existing and emerging Intelligent Transportation System (ITS) and other advanced technologies for motorcycles and other vehicles, an analysis of Texas motorcycle crash and injury data, and a statewide survey of Texas motorcycle riders that explored the demographics, riding histories, training and licensing status, use of protective gear, crash involvement, and attitudes toward various motorcycle safety countermeasures. These data collection activities culminated in a list of potential motorcycle crash and injury countermeasures; these countermeasures were then evaluated and prioritized in a workshop attended by motorcycle safety experts and advocates.
Jian Luo; Wanxia Zhuo; and Haiyu Xiao	Dynamic Simulation for Car-Bicycle Collisions Based on PC-CRASH	2014 International Conference of Logistics Engineering and Management (ICLEM)	2014	https://trid.trb.org/view.aspx?id=1326612	This paper, presented at the 2014 International Conference of Logistics Engineering and Management (ICLEM) in China, discusses a model, PC-CRASH, used to establish collision dynamic simulation models for cars and bicycles. In China, the mixed pattern of motor and non-motor vehicles results in frequent accidents. The paper concludes with a series of recommended preventative measures based on the results of the model.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Eric R. Teoh	Effectiveness of Antilock Braking Systems in Reducing Motorcycle Fatal Crash Rates	Traffic Injury Prevention	2011	http://www.tandfonline.com/doi/full/10.1080/15389588.2010.541308#abstract	The objective of this study, published in Traffic Injury Prevention, was to evaluate the effect of ABS in fatal motorcycle crashes. Motorcycle drivers involved in fatal crashes per 10,000 registered vehicle years were compared for 13 motorcycle models with optional ABS and those same models without the option during 2003–2008. Motorcycles with optional ABS were included only if the presence of the option could be identified from the vehicle identification number. The rate of fatal motorcycle crashes per 10,000 registered vehicle years was 37 percent lower for ABS models than for their non-ABS versions. Given this, the authors concluded that ABS appears to be highly effective in preventing fatal motorcycle crashes based on some early adopters of motorcycle ABS technology.
Matteo Rizzi; Johan Strandroth; Anders Kullgren; Claes Tingvall; and Brian Fildes	Effectiveness of Motorcycle Antilock Braking Systems (ABS) in Reducing Crashes, the First Cross-National Study	Traffic Injury Prevention	2015	http://www.tandfonline.com/doi/full/10.1080/15389588.2014.927575#abstract	The objective of this study, published in Traffic Injury Prevention, was to evaluate the effectiveness of motorcycle antilock braking systems (ABS) in reducing real-life crashes. Using police reports from Spain, Italy, and Sweden, the same motorcycle models, with and without ABS, were compared and the calculations were carried out for each country. The effectiveness of ABS in reducing crashes ranged from 24% to 42% for motorcycles and 27% to 31% for scooters (at least 250 cc). The authors concluded that, at this stage, there is more than sufficient scientific-based evidence to support the implementation of ABS on all motorcycles, even light ones.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Giovanni Savino; Marco Pierini; Matteo Rizzi; and Richard Frampton	Evaluation of an Autonomous Braking System in Real-World PTW Crashes	Traffic Injury Prevention	2013	http://www.tandfonline.com/doi/full/10.1080/15389588.2012.725878#abstract	The aim of this study, published in Traffic Injury Prevention, was to assess the potential effectiveness of the Automatic Braking (AB) system developed in the European project Powered Two Wheeler Integrated Safety (PISa) taking into account the specific system characteristics that emerged during the design, development and testing phases. Fifty-eight PTW cases representing European crash configurations were examined, in which 43 percent of riders sustained a Maximum Abbreviated Injury Scale (MAIS) 2+ injury. An expert team analyzed the in-depth material of the sample crashes and determined a posteriori to what extent the AB would have affected the crash. In 67 percent of cases, the application of AB could have mitigated the crash outcome.
Hesham A. Rakha; Gregory M. Fitch; Mazen Arafeh; Myra Blanco; and Richard J. Hanowski	Evaluation of Safety Benefits from a Heavy-Vehicle Forward Collision Warning System	Transportation Research Record: Journal of the Transportation Research Board	2010	https://trid.trb.org/view.aspx?id=909362	This paper, published in the Journal of the Transportation Research Board, estimated the safety benefits that may be attained by deploying an FCW system across the national fleet of heavy vehicles. The approach involved identifying rear-end (RE) conflicts within a heavy-vehicle naturalistic driving data set with the use of algorithms that identified potential RE events and removed nonthreatening events. Driver RE collision avoidance behavior, both with and without FCW alarm feedback, was then simulated with a Monte Carlo simulation approach. This methodology estimated that FCW systems may afford a 21% reduction in heavy-vehicle RE crashes, which translates to 4,800 crashes per year on U.S. highways.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Giovanni Savino; Matteo Rizzi; Julie Brown; Simone Piantini; Lauren Meredith; Bianca Albanese; Marco Pierini; and Michael Fitzharris	Further Development of Motorcycle Autonomous Emergency Braking (MAEB), What Can Indepth Studies Tell Us? A Multinational Study	Traffic Injury Prevention	2014	http://www.tandfonline.com/doi/full/10.1080/15389588.2014.926009	This article, published in Traffic Injury Prevention, sought to (1) better understand the full spectrum of motorcycle crashes and (2) further develop triggering algorithms for Motorcycle Autonomous Emergency Braking (MAEB) systems that apply to a wider spectrum of crash scenarios in order to assess the full potential benefit of MAEB. The study used in-depth crash data from three different countries: Australia, Italy, and Sweden. The potentially applicability of MAEB to each crash was assessed using a decision tree and the potential benefit of MAEB was examined using numerical computer simulations. The principal finding was that, using the new triggering algorithm, MAEB is seen to apply to a broad range of multivehicle motorcycle crashes. Crash mitigation was achieved through reductions in impact speed of up to approximately 10 percent, depending on the crash scenario and the initial vehicle pre-impact speeds.
I. Potts; S. Garets; T. Smith; R. Pfefer; T.R. Neuman; K.L. Slack; K.K. Hardy; and J. Nichols	Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Vol. 22: A Guide for Addressing Collisions Involving Motorcycles.	Transportation Research Board	2008	http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v22.pdf	This report from the National Cooperative Highway Research Program helps to illustrate potential countermeasures to reduce motorcycle collisions in the U.S. The report offers strategies to: reduce the number of motorcycle crashes by incorporating motorcycle-friendly roadway design, traffic control, construction, and maintenance policies and practices; reduce the number of motorcycle crashes due to rider impairment; reduce the number of motorcycle crashes due to unlicensed or untrained riders; reduce the number of motorcycle crashes by increasing the visibility of motorcyclists; reduce the severity of motorcycle crashes; increase motorcycle rider safety awareness; increase safety enhancements for motorcyclists; and improve motorcycle safety research, data, and analysis.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Honda News	Honda Demonstrates Advanced Vehicle-to-Pedestrian and Vehicle-to-Motorcycle Safety Technologies	Honda News	2013	http://www.hondanews.com/channels/corporate/releases/honda-demonstrates-advanced-vehicle-to-pedestrian-and-vehicle-to-motorcycle-safety-technologies/videos/honda-demonstrates-advanced-vehicle-to-pedestrian-and-vehicle-to-motorcycle-safety-technologies	This news article, from Honda News, covers two experimental safety technologies from Honda aimed at reducing the potential for collisions between automobiles and pedestrians and between automobiles and motorcycles. These advanced Vehicle-to-Pedestrian (V2P) and Vehicle-to-Motorcycle (V2M) technologies, while still in the research and testing phase at the time this story was published, demonstrate Honda's vision to advance safety for all road users, including pedestrians and motorcycle riders, as well as automobile occupants. These new technologies are part of a comprehensive effort being undertaken by Honda to develop leading-edge safety and driver assistive systems that can help predict and avoid traffic accidents through advanced sensing and communications technologies.
Federico Giovannini; Giovanni Savino; and Marco Pierini	Influence of the Minimum Swerving Distance on the Development of Powered Two-Wheeler Active Braking	Proceedings of the 22nd ESV Conference, Washington, D.C.	2011	https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CB4QFjAA&url=http%3A%2F%2Fwww-esv.nhtsa.dot.gov%2FProceedings%2F22%2Ffiles%2F22ESV-000258.pdf&ei=ui9SVcCXHIGusAXWv4D4Dw&usg=AFQjCNGvRaz1NCO5HFTNDSj0jwXI8CrkEg&sig2=LaqZ2MKMD0HZruEKzgxsZw	This paper, produced by researchers at the University of Florence in Italy, analyzed the last-second swerving (LSW) maneuver to identify the minimum swerving distance required by riders to avoid collisions against an obstacle. The paper proposed a physical model to define the minimum swerving distance. Tests showed that the last-second swerving maneuver algorithm has good prediction capability for different riding styles and different scenarios with fixed obstacles.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Kamarudin Ambak; Riza Atiq; and Rozmi Ismail	Intelligent Transport System for Motorcycle Safety and Issues	European Journal of Scientific Research	2009	https://trid.trb.org/view/1155103	This paper, published in the European Journal of Scientific Research, provides an overview of Intelligent Transportation Systems (ITS) for motorcycles safety. ITS technologies have significant potential to enhance traffic safety but very few have been developed especially for motorcycles. This research identified several priority ITS technologies to be adapted and developed for motorcycles, including advanced driver assistance systems, intelligent speed adaptation, driver monitoring systems, collision warning and avoidance systems, lane keeping and lane-change warning systems, visibility enhancing systems, and seat belt/helmet reminder systems. However, the researchers stressed the need to develop design standards for ITS technologies adapted to motorcycles.
Seyed Rasoul Davoodi; Hussain Hamid; Sulistyo Arintono; Ratnasamy Muniandy; and Seyed Farzin Faezi	Motorcyclist Rear Brake Simple Perception-Response Times in Rear-End Collision Situations	Traffic Injury Prevention	2011	http://www.tandfonline.com/doi/full/10.1080/15389588.2010.533314#abstract	The purpose of this study was to determine the baseline motorcycle riders' perception–response times (PRTs) in an expected object braking task and to determine the significant difference between PRTs of older and younger riders. Riders' age and gender were not found to be significant variables for PRT.
Matteo Corno; Sergio Matteo Savaresi; Mara Tanelli; and Luca Fabbri	On optimal motorcycle braking	Control Engineering Practice	2008	http://www.sciencedirect.com/science/article/pii/S0967066107001384	This paper, published in Control Engineering Practice, discusses in detail the dynamic of motorcycle braking, particularly optimal braking strategy in a high-performance motorbike. The paper also presents a possible policy for semi-active suspension control during braking.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
R. Grant; R. Frampton; S. Peldschus; E. Schuller; V. StClair; M. McCarthy; R. Babu; M. Pierini; and G. Savino	PISa: powered two-wheeler integrated safety: project objectives, achievements and remaining activities	7th International Motorcycle Conference, 2008, Essen, Germany	2008	https://trid.trb.org/view/1151797	The aim of this project, presented at the 7th International Motorcycle Conference in 2008, was to identify, develop, and test new technologies to provide integrated safety systems for a range of motorcycles that will greatly improve primary safety and link to secondary safety systems. Regarding PTW safety, the authors considered the following priorities: (1) warning the PTW of the presence of the other vehicle to improve crash avoidance and (2) improvements to the PTW braking system including semi-autonomous braking to improve casualty reduction. Priority systems that fell within the scope of PISa were translated into a system specification and the relevant technologies were later developed and implemented in PISa demonstration vehicles.
James V. Ouellet and Vira Kasantikul	Rider Training and Collision Avoidance in Thailand and Los Angeles Motorcycle Crashes	International Motorcycle Conference 2006	2006	http://www.msf-usa.org/downloads/imsc2006/Ouellet-Rider_Training_and_Evasive_Action_in_Thailand_and_LA-Paper.pdf	This study, presented at the 2006 International Motorcycle Conference, discusses two studies that demonstrate that, typically, the time between the event that begins a collision sequence in a motorcycle crash and the impact itself is so short—less than three seconds in the great majority of cases—that even a well-chosen, well-executed evasive action is unlikely to be effective. From this, the authors conclude that rider training should emphasize teaching riders the knowledge and skills needed to prevent a precipitating event from occurring, rather than how to react after it has already occurred.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
J. P. Frederick; Melanie Ganzhorn; Harald Widlroither; Evangelos Bekiaris; Stella Nikolau; Roberto Montanari; Andrea Spadoni; Marco Fontana; Giacomo Bencini; Niccolò Baldanzini; and Sara Granelli	SAFERIDER HMI Strategies for Motorcycles' ARAS and OBIS	17th ITS World Congress	2010	https://trid.trb.org/view.aspx?id=1089538	This paper, presented at the 17th ITS World Congress, focuses on the assignment of human-machine interface (HMI) elements to specific ARAS and OBIS and the design of intuitive haptic warnings. The research emphasizes acceptance and compliance toward safety warnings in the HMI strategies developed within the project. The authors conclude that, after iterative testing, this approach will lead to a highly acceptable and effective HMI concept for motorcycle riders.
Matteo Rizzi; Johan Strandroth; and Claes Tingvall	The Effectiveness of Antilock Brake Systems on Motorcycles in Reducing Real-Life Crashes and Injuries	Traffic Injury Prevention	2009	http://www.tandfonline.com/doi/full/10.1080/15389580903149292#abstract	This study, published in Traffic Injury Prevention, analyzes fatal crash data in Sweden during 2005–2008 to estimate of the effectiveness of ABS in crash reduction. The results showed that head-on collisions were the least ABS-affected crash types and collisions at intersections were the most influenced. Induced exposure analysis showed that the overall effectiveness of ABS was 38 percent on all crashes with injuries and 48 percent on all severe and fatal crashes, with a minimum effectiveness of 11 and 17 percent, respectively. The study recommended the fitment of ABS on all new motorcycles as soon as possible and that customers only purchase motorcycles with ABS.

Table B-8. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Rudi Lindl and Leonhard Walchshausl	Three-Level Early Fusion for Road User Detection	PReVENT Fusion Forum e-Journal	2006	http://campar.in.tum.de/pub/lindl2006prevent/lindl2006prevent.pdf	This paper, from BMW Group Research and Technology, describes a three-level sensor fusion approach that can detect and track cars and pedestrians. The underlying perception system is composed of a far infrared imaging device, a laser scanner and several radar sensors, which operate integrated into a BMW sedan. At three different levels fusion is applied to approach the generation of a robust and accurate description of the area in front of the vehicle. Based on this environment perception, the paper outlines a preventive safety application that can autonomously brake in case of an inevitable accident.

Curve Speed Warning

Infrastructure-based system that uses V2I communications to warn drivers of safe speed for an upcoming curve.

Table B-9. Search terms.

Search Terms
Curve Speed Warning
Curve Speed Warning Motorcycle

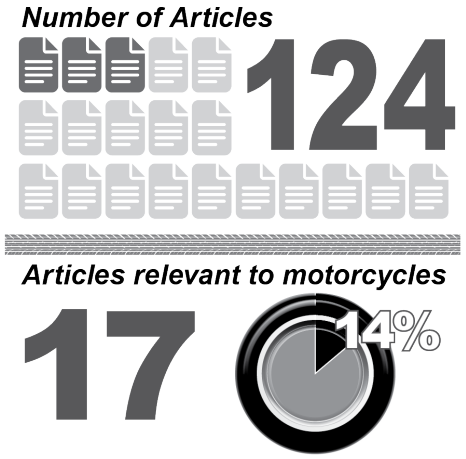


Table B-10. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
Francesco Biral; Mauro Da Lio; Roberto Lot; and Roberto Sartori	An Intelligent Curve Warning System for Powered Two-Wheel Vehicles	European Transport Research Review	2010	https://trid.trb.org/view/1086248	This article was published in the European Transport Research Review Journal. The premise of this article is to illustrate a novel Curve Warning System for motorcycles which has been developed in the SAFERIDER project. The Curve Warning function (CW) described follows a holistic approach, combining road geometry, motorcycle dynamics, rider input and riding styles. The warning strategy is based on the correction of longitudinal dynamics derived from a previewed ideal maneuver (reference maneuver) continuously computed from the actual state of the vehicle. Under normal driving conditions the reference maneuver matches the rider's and no correction is needed and no warning is given. But if large differences between actual and ideal accelerations are found the rider is warned to decelerate or brake. As soon as the correct value of deceleration is achieved the warning disappears, improving system acceptability. Warnings are given to the rider via an HMI, which uses a haptic accelerator throttle, a vibrating glove and helmet, and a visual display.
F. Biral; R. Lot; R. Sartori; A. Borin; and B. Roessler	An intelligent Frontal Collision Warning system for Motorcycles	Proceedings, Bicycle and Motorcycle Dynamics 2010	2010	http://www.bicycle.tudelft.nl/ProceedingsBMD2010/papers/biral2010intelligent.pdf	This article was included in the Proceedings of the Bicycle and Motorcycle Dynamics Meeting of 2010. The article introduces a project for a novel Frontal Collision Warning system for motorcycles, which has been developed in the SAFERIDER project of the 7th EU FP. The project schedule includes development of five rider assistance functions, embedded in a unified hardware and software framework, namely Speed Alert, Curve Warning, Frontal Collision Warning, Intersection Support and Lane Change Support. The link to this article is not longer operating.

Table B-10. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Aquilino Molinero; Oscar Martín; José Miguel Perandones; David Pedrero; Dimitris Margaritis; and Christhard Gelau	Characteristics of Powered Two-Wheelers Accidents susceptible to be Avoided and Minimized through ADAS and IVIS implementations	NRD-NHTSA	2009	http://www-nrd.nhtsa.dot.gov/pdf/ESV/esv21/09-0543.pdf	This paper was presented in the 2009 ESV Conference compilation of papers. The paper presents an analysis of Spanish crash data DIANA, to determine crash factors that could be addressed with ADAS and the operation of SAFERIDER. According to this study, the Curve Warning system effectively warned riders about the appropriateness of the current riding conditions in order to ride safely through the curve. If the rider reduces speed, it is likely that he/she keeps the motorcycle under control and no accident occurs.
Véronique Huth; Francesco Biral; Óscar Martín; and Roberto Lot	Comparison of two warning concepts of an intelligent Curve Warning system for motorcyclists in a simulator study	Accident Analysis and Prevention	2011	http://www.sciencedirect.com/science/article/pii/S0001457511001047	This paper was published in Accident Analysis and Prevention. This study tested the effect of Curve Speed Warning through a simulator, across 20 test riders. The subjects performed three rides: one without the system (baseline) and two experimental rides using a version of the Curve Warning system, one providing the warnings by a force feedback throttle and one by a haptic glove. The effects of the two system versions were evaluated both in terms of the simulated riding performance and the subjective assessment by the riders. A descriptive analysis of the riders' reactions to the warnings showed that the warnings provided by both system versions provoke an earlier and stronger adaptation of the motorcycle dynamics to the curve than when the riders do not use the system. The comparison of the riders' opinions about the system reveals a preference of the Curve Warning system with the haptic glove. The better acceptance of this system version suggests a higher potential in the enhancement of riding safety.

Table B-10. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
V. Cossalter; R. Lot; M. Massaro; and R. Sartori	Development and validation of an advanced motorcycle riding simulator	Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering	2011	https://trid.trb.org/view.aspx?id=1125697	This paper was published in the Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. The study illustrates and discusses the main features of the motorcycle riding simulator designed and built at the University of Padua over recent years. Within the simulator the rider sits on a motorcycle mock-up provided with all the inputs available on a real motorcycle (throttle, clutch, brakes, etc.). These controls are used as inputs for an advanced virtual motorcycle model which computes the real-time vehicle dynamics. To validate the simulator, a specific protocol which includes both an objective evaluation and a subjective evaluation was designed and carried out. External devices such as advanced rider assistant systems, on-bike information systems, and human–machine interfaces can be easily integrated into the simulator by means of a standard controller area network.
Kamarudin Ambak; Riza Atiq; and Rozmi Ismail	Intelligent Transport System for Motorcycle Safety and Issues	European Journal of Scientific Research	2009	http://www.researchgate.net/profile/Kamarudin_Ambak/publication/241917211_Intelligent_Transport_System_for_Motorcycle_Safety_and_Issues/links/00b7d53c62d7ec4cee000000.pdf	This article, published in the European Journal of Scientific Research, provides a review of Intelligent Transport System for motorcycles safety and related issues with some existing or emerging ITS technologies to enhanced vehicles safety. The authors note that there are several ITS technologies in-vehicle systems to be introduced and adapted to motorcycles: advanced driver assistance system, intelligent speed adaptation, driver monitoring system, collision warning and avoidance system, lane keeping and lane-change warning system, visibility enhancing system, seat belt/helmet reminder system. However, 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. Motorcycle pose particular problem when it comes to the technical adaptation of certain ITS systems, particularly those that have not been custom-designed for motorcycle.

Table B-10. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
M. Bayly; S. Hosking; and M. Regan	Intelligent transport systems and motorcycle safety	20th International Technical Conference on the Enhanced Safety of Vehicles, 2007, Lyon, France	2007	https://trid.trb.org/view/1155103	This policy paper, presented in the 20th International Technical Conference on the Enhanced Safety of Vehicles (ESV), looked at how underrepresented motorcycles are in the ITS advancements. It looked at different safety topics that could be further investigated on motorcycles. The author determined that curve speed warning is one of several priority topics for further research. The paper concluded that it is important to promote more studies on these topics to deal with the important number of motorcycles crashes currently happening.
Choon Wah Yuen; Mohamed Rehan Karim; and Ahmad Saifizul	Investigation on motorcyclist riding behavior at curve entry using instrumented motorcycle	The Scientific World Journal (2014)	2014	https://www.mendeley.com/research/investigation-motorcyclist-riding-behaviour-curve-entry-using-instrumented-motorcycle/	This paper, published in the Scientific World Journal, focuses on the changes in riding behavior, such as changes in speed as well as the brake force and throttle force applied, when motorcyclists ride over a curve section road using an instrumented motorcycle. Four regression equations are formed to study the relationship between four dependent variables, which are speed, throttle force, front brake force, and rear brake force applied with the independent variables.

Table B-10. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Sadayuki Tsugawa	Issues and recent trends in vehicle safety communication systems	IATSS Research	2005	http://www.sciencedirect.com/science/article/pii/S0386111214601138	This paper was published in the IATSS Research Journal. The study surveys the research on the applications of inter-vehicle communications, the issues of the deployment and technology, and the current status of inter-vehicle communications projects in Europe, the United States, and Japan. Primarily, this paper talks about motorcycles in Japan, where three of the four ministries involved with ITS are active in inter-vehicle communications. The Ministry of Land, Infrastructure and Transport, in its active safety-focused ASV (Advanced Safety Vehicle) project, uses communications among heavy duty trucks, passenger cars, and motorcycles to provide notification of motorcycles ahead in blind curves or hidden from view on narrow roads and to assist with right turns (in Japan) by providing notification of motorcycles traveling straight in the opposing lane. The author concludes that although inter-vehicle communications involve many issues, such applications should be promoted because they will lead to safer and more efficient automobile traffic.
Benedikt Lattke; Frank Sperber; Tobias Müller; Hermann Winner; Richard Eberlein; and Rainer Hoffmann	MoLife—hazard detection in a cooperative assistance system for motorcycles	NRD-NHTSA	2011	http://www-nrd.nhtsa.dot.gov/Pdf/ESV/esv22/22ESV-000070.pdf	This paper, included in the Proceedings of the 22nd International Technical Conference on the Enhanced Safety of Vehicles, talks about a research project at Technische Universität Darmstadt, Institute of Automotive Engineering, where they are researching the fundamentals of communication-based warning systems for motorcycles. The system under study generates sensor-based or manually entered warning messages and sends these to other motorcyclists using wireless communication devices. Through this system, riders can receive early warnings of road hazards. The research team is developing a hazard detection method through test drives. In addition, the project includes the development of a methodology to design an appropriate HMI, based on user acceptance.

Table B-10. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
A. Thomas; W. Smart; M. de Roos; K. Webster; and C. Gibbs	Motorcycle safety route review: A case study	NSW Roads and Traffic Authority	2011	http://casr.adelaide.edu.au/rsr/RSR2011/2CPaper%20006%20Thomas.pdf	This paper was presented in the Australasian Road Safety Research, Policing and Education Conference, in 2011. This paper examines driving behavior, road use, and design elements on a highly-used freeway on Australia, particularly by motorcycles. Speed was identified as a major factor contributing to motorcycle casualty crashes. The researchers obtained approval to upgrade the existing signposting with fluoro background signage, particularly in locations with high crash rates. The fluoro signage provided curve warning and speed advisory information. The benefit of this signage was increased visibility in varying light conditions.
H. Slimi; H. Arioui; L. Nouveliere; and S. Mammar	Motorcycle speed profile in cornering situation	American Control Conference (ACC), 2010	2010	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5530994&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5530994	This paper was published in in the American Control Conference journal. The paper presents a new method for the computation of the maximal authorized motorcycle speed in curves. The three main factors—which were the vehicle, the driver, and the infrastructure—were taken into account. The vehicle dynamics were represented by a four degrees of freedom model which included the vehicle's longitudinal slip and sideslip angle. The driver behavior model considered the ability in deceleration maneuvers according to the mobilized friction. The infrastructure characteristics introduced a precise handling of the road geometry and of the maximal available friction.
Roberto Montanari; Andrea Spadoni; Evangelos Bekiaris; and Stella Nikolaou	Saferider: CAN-based architecture on 2-wheelers domain	Road safety on four continents: 15th international conference, Abu Dhabi, United Arab Emirates, 28-30 March 2010.	2010	https://trid.trb.org/view.aspx?id=968760	This paper was presented in the Road Safety on Four Continents 15th International Conference. The project aimed to improve the comfort and safety of riders in the 2-wheelers domain introducing new on-board functionalities. These functionalities were classified as OBIS (On-Board Information System) and ARAS (Advanced Riding Assistance System) and are supported by a multi-points high speed CAN installed in the vehicle.

Table B-10. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Zifeng Wu; Anuj Sharma; Fred L. Mannering; and Shefang Wang	Safety impacts of signal warning flashers and speed control at high-speed signalized intersections	Accident Analysis and Prevention	2013	http://www.sciencedirect.com/science/article/pii/S0001457513000298	This paper was published in Accident Analysis and Prevention. This paper uses 10-year crash data from 28 intersections in Nebraska (all with intersection approaches having signal-warning flashers; some with no speed-limit reduction, and the others with either 5 mi/h or 10 mi/h reduction in speed limit) to estimate a random parameters negative binomial model of crash frequency and a nested logit model of crash-injury severity. Based on this research, speed-limit reductions in conjunction with signal-warning flashers appear to be an effective safety countermeasure, but only clearly so if the speed-limit reduction is at least 10 mi/h.
Seyed Farzin Faezi; Hussain Hamid; and Seyed Rasool Davoodi	The effect of pavement marking on speed reduction in exclusive motorcycle lane in Malaysia	Contemporary Engineering Sciences	2010	http://www.researchgate.net/profile/Seyed_Davoodi/publication/228412017_The_effect_of_pavement_marking_on_speed_reduction_in_exclusive_motorcycle_lane_in_Malaysia/links/00b7d5245e0cc55ff5000000.pdf	This paper was published in Contemporary Engineering Sciences Journal. A major problem in Malaysia is the high number of motorcycle accidents. The high percentage of motorcycle accidents has proved that motorcycle is a dangerous, unfavorable means of transportation in Malaysia. For the purpose of this study, a pavement marking pattern was employed and traffic speeds were analyzed before and after installation of the pavement markings at four exits in exclusive motorcycle lane in Malaysia. This study concentrates on the effect of pavement marking on speed reduction on exit ways. Results demonstrated that markings were effective in reducing speeds of motorcyclist.
Darlene Gorrill	Transverse Rumble Strips	Minnesota Department of Transportation	2007	http://www.lrrb.org/media/reports/TRS0701.pdf	This article was presented in Transportation Research Synthesis. North Carolina experienced dramatic results in the installation of Transverse Rumble Strips (TRSs) at an intersection with a record of two fatal crashes. However, other treatments also were used. The report also emphasized the need for regular maintenance of TRSs. Maintenance is an ongoing cost of rumble strip installation, as are other non-financial factors, such as noise, and concerns for motorcyclists and bicyclists.

Table B-10. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
M. H. James	Where you look is where you go	Institute of Road Safety Officers	2006	https://trid.trb.org/view/804430	This article was published in INROADS, by the Institute of Road Safety Officers. The article looks at a fresh approach to warning motorcyclists about sharp bends to increase road safety for this group of road users. Motorcyclists should use the vanishing point of a road (the furthest unobstructed view of the road surface) to determine the correct speed and gear to use, but tend to focus on roadside features instead. Traditionally, hazard marker posts are placed to highlight the crown of a bend: the WYLIWYG (Where you look is where you go) principle moves the posts further round the bend and places them closer together to aid the rider in focusing on the vanishing point of the bend.

Electronic Stability Program

Also known as Dynamic Stability Control, this computerized technology improves a vehicle's stability by detecting and reducing loss of traction (skidding). When the program detects loss of steering control, it automatically applies the brakes to help steer the vehicle in the direction the driver intends to go. Some programs also reduce engine power until control is regained.

Table B-11. Search terms.

Search Terms
Electronic Stability Program
Electronic Stability Program Motorcycle
Dynamic Stability Control
Dynamic Stability Control Motorcycle
Traction Control
Electronic Stability Control

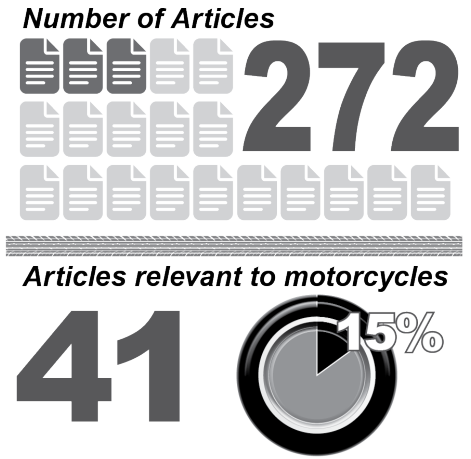


Table B-12. Literature Review

Authors	Title	Journal or Publisher	Year	Link	Summary
R. Willig and M. Lemejda	A new inertial sensor unit for dynamic stabilizing systems of powered two-wheelers	Forschungshefte Zweiradsicherheit	2012	https://trid.trb.org/view.aspx?id=1314982	This paper was presented and translated from the journal "Forschungshefte Zweiradsicherheit". This paper describes an inertial sensor unit that has been developed to support active driving systems in motorcycles, which provides data on vehicle accelerations, angular velocities, and inertial measurements.
J.D.G. Kooijman and A.L. Schwab	A review on bicycle and motorcycle rider control with a perspective on handling qualities	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2013	http://www.tandfonline.com/doi/full/10.1080/00423114.2013.824990#abstract	This paper, published in the Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, is a review study on handling and control of bicycles and motorcycles, the so-called single-track vehicles. The first part gives a brief overview on the modelling of the dynamics of single-track vehicles and the experimental validation. The second part focusses on a review of modelling and measuring human rider control. The third part deals with the concepts of handling and maneuverability and their experimental validation.
A. A. Popov; S. Rowell; and J. P. Meijaard	A review on motorcycle and rider modelling for steering control	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2010	http://www.tandfonline.com/doi/full/10.1080/00423110903033393#abstract	This paper was published in Vehicle Systems Dynamics: International Journal of Vehicle Mechanics and Mobility. It is a review of the state of knowledge of steering control in motorcycles and of the existing rider models. Since riders apply control based on available sensory information, predominantly from visual perception of a target path, the review also covers the state of knowledge of and research pertaining to road preview control. Here, some more emphasis is placed on recent applications of optimal control and model predictive control to the riding task and the motorcycle–rider interaction. The review concludes with key questions and a scope for further study.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Mat Oxley	An age of superheroes (a time before traction control)	Sparkford, Yeovil, Somerset, UK; Newbury Park, Calif.: Haynes	2010	http://melvyl.worldcat.org/title/age-of-superheroes-a-time-before-traction-control/oclc/620140322&referer=brief_results	This book summarizes six renowned motorcycle riders in the 1980s and 1990s. It is intended to be a nostalgic piece rather than an ITS document.
S. Rowell; A. A. Popov; and J. P. Meijaard	Application of predictive control strategies to the motorcycle riding task	Vehicle System Dynamics	2008	http://melvyl.worldcat.org/title/application-of-predictive-control-strategies-to-the-motorcycle-riding-task/oclc/1430361265869?referer=brief_results	Abstract not publically available.
Yoshitaka Marumo and Nozom Katagiri	Control effects of steer-by-wire system for motorcycles on lane-keeping performance	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2011	http://www.tandfonline.com/doi/full/10.1080/00423114.2010.515030#abstract	This paper, published in the Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, discusses the control effects of the steer-by-wire (SBW) system for motorcycles on the lane-keeping performance by examining computer simulation with a rider-vehicle system which consists of a simplified vehicle model, a rider control model and the controller of the SBW system.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
S. Kidane; R. Rajamani; L. Alexander; P. J. Starr; and M. Donath	Development and Experimental Evaluation of a Tilt Stability Control System for Narrow Commuter Vehicles	IEEE Transactions on Control Systems Technology	2010	http://melvyl.worldcat.org/title/development-and-experimental-evaluation-of-a-tilt-stability-control-system-for-narrow-commuter-vehicles/oclc/479886795 3&referer=brief_results	This paper, published in the IEEE Transactions on Control Systems Technology journal, concentrates on the development and experimental investigation of a compound control system designed for tilt stability of a narrow commuter vehicle. The control system is a combination of three different types of control schemes: Steering Tilt Control (STC) system, Direct Tilt Control (DTC) system and Tilt Brake system.
Lama Mourad; Fabien Claveau; and Philippe Chevrel	Direct and Steering Tilt Robust Control of Narrow Vehicles	IEEE Transactions on Intelligent Transportation Systems	2014	http://ieeexplore.ieee.org/document/6718083/	This paper was published in the IEEE Transactions on Control Systems Technology journal. The paper discusses tilting for Narrow tilting vehicles (NTVs), which are the convergence of a car and a motorcycle. Due to their height-to-breadth ratio, in order to maintain lateral stability, NTVs should tilt when cornering. Unlike the motorcycle, where the driver tilts the vehicle himself, the tilting of an NTV should be automatic. A three-degree-of-freedom (DoF) model of the vehicle is used, as well as a model of the steering signal, leading to a two-DoF low-order controller with an efficient feedforward anticipative part.
C. K. Huang and M. C. Shih	Dynamic analysis and control of an antilock brake system for a motorcycle with a camber angle	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2010	http://www.tandfonline.com/doi/full/10.1080/00423111003663568#abstract	This paper was published in the Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility. The paper analyses the dynamic response of a motorcycle with an antilock brake system (ABS) and camber or steering angle. Most studies have assumed that motorcycles brake in a straight line—that is, without a steering or camber angle. In this work, the performance of an ABS modulator is designed and analyzed at first. Then, a controller is designed for motorcycle turning.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Amrit Sharma and David J. N. Limebeer	Dynamic stability of an aerodynamically efficient motorcycle	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2012	http://www.tandfonline.com/doi/full/10.1080/00423114.2011.651147#abstract	This paper, published in the Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, discusses how motorcycles exhibit two potentially dangerous oscillatory modes known as 'wobble' and 'weave'. These unwanted dynamic features, which can occur when two-wheeled vehicles are operated at speed, have been studied extensively. The aim of this paper is to use mathematical analysis to identify important stability trends in the on-going design of a novel aerodynamically efficient motorcycle known as the ECOSSE Spirit ES1.
Jamie Mackenzie and Robert Anderson	Effects of electronic stability control interventions on rural road crashes in Australia	Department of Infrastructure, Transport, Regional Development and Local Government	2009	http://oskicat.berkeley.edu/record=b17695590~S1	This report was published by the Department of Infrastructure, Transport, Regional Development and Local Government, by the Australian Government. This report from Australia attempted to evaluate Electronic Stability Control in the context of rural crashes. For this, 20 crash scenarios were simulated based on actual road crashes obtained from a crash database. Of those, 12 were found to benefit from simulated ESC, with 10 of the 12 resulting in an entirely avoided collision, and 2 of the 12 resulting in a less severe collision. The discussion of motorcycles is limited to a statement that no known ESCs currently exist for motorcycles.
J. Edelmann and M. Plöchl	Electronic Stability Control of a Narrow Tilting Vehicle	SAE International	2011	http://papers.sae.org/2011-01-0976/	This paper, published by the SAE International Journal of Materials and Manufacturing, aims to contribute to the development of an electronic stability control for narrow, fully tiling vehicles with handling and stability characteristics similar to motorcycles, and to improve the understanding of the driver-vehicle interaction.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Pierpaolo De Filippi; Mara Tanelli; Matteo Corno; and Sergio M. Savaresi	Enhancing active safety of two-wheeled vehicles via electronic stability control	Preprints of the 18th IFAC World Congress	2011	http://www.nt.ntnu.no/users/skoge/prost/proceedings/ifac11-proceedings/data/html/papers/0697.pdf	This paper was published in the preprints of the 18th IFAC World Congress. The paper describes an innovative control architecture which allows enhancing the active safety while guaranteeing a good driving feeling. The proposed solutions are validated on a multibody motorcycle simulator on challenging maneuvers such as kick-back and strong braking while cornering at high speed.
Unspecified	Estimating Lives Saved by Electronic Stability Control, 2009-2011	National Highway Traffic Safety Administration	2013	https://trid.trb.org/view.aspx?id=1250024	This monograph was published by the National Highway Safety Administration. The document provides a summary of the safety benefits of ESC as quantified by an estimated number of lives saved between 2009 and 2011. Specifically, ESC was estimated to save 1,045 lives in 2011, 876 lives in 2010, and 705 lives in 2009. These estimates are based on vehicles that were known to have ESC available at the time of the crash, and therefore do not include any motorcycle data.
A. Doria; M. Formentini; and M. Tognazzo	Experimental and numerical analysis of rider motion in weave conditions	Vehicle System Dynamics	2012	https://trid.trb.org/view/1216837	This paper, published in Vehicle Systems Dynamics, focuses on motorcycle dynamics, which are characterized by the presence of modes of vibration that may become unstable and lead to dangerous conditions. In particular, the weave mode shows large yaw and roll oscillations of the rear frame and out of phase oscillations of the front frame about the steer axis. This paper deals with a research program aimed at measuring the oscillations of the rider's body on a running motorcycle in the presence of weave.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Vittore Cossalter; Alberto Doria; Matteo Formentini; and Martino Peretto	Experimental and numerical analysis of the influence of tyres' properties on the straight running stability of a sport-touring motorcycle	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2012	http://www.tandfonline.com/doi/full/10.1080/00423114.2011.587520#abstract	This paper was published in the Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility. The paper presents an experimental and numerical analysis dealing with the influence of tire properties on the stability of weave and wobble in straight running. The final goal was to find optimal sets of tire properties that improve the stability of a motorcycle. The investigation was based on road tests carried out on a sport-touring motorcycle equipped with sensors. Three sets of tires were tested at different speeds in the presence of weave and wobble.
Shintaroh Murakami; Hidekazu Nishimura; and Shaopeng Zhu	Front-Steering Assist Control System Design for a Motorcycle Stabilization during Braking	Journal of System Design and Dynamics	2012	https://www.jstage.jst.go.jp/article/jsdd/6/4/6_431/_article	This paper was published in the Journal of System Design and Dynamics. In braking situations, it is known that a motorcycle may become unstable. This paper documents the design of a front-steering assist control that has the ability to stabilize a motorcycle during braking. By carrying out simulations, the researchers demonstrated that the control system proposed can stabilize a motorcycle during braking when receiving a sudden disturbance from the front wheel. The paper then discusses the control system's applicable scope for several situations including different maneuvering of a rider.
P. Seiniger; H. Winner; and J. Gail	Future Vehicle Stability Control Systems for Motorcycles With Focus on Accident Prevention	ASME 2008 9th Biennial Conference on Engineering Systems Design and Analysis	2008	http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1636613	This paper was published as part of the ASME 2008 9th Biennial Conference on Engineering Systems Design and Analysis. Vehicle Stability Control systems for powered two-wheelers (especially motorcycles) so far include only antilock brakes and traction control systems, both systems are not designed to work in cornering. Further stability control systems are not known up to now. The objective of this paper is to assess the technical possibilities for future Vehicle Stability Control systems and the amount of accidents that could be prevented by those systems.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
J. Maddox	Government Status Report United States	Proceedings of the 21st (ESV) International Technical Conference on the Enhanced Safety of Vehicles, Held June 2009, Stuttgart, Germany	2009	https://trid.trb.org/view/1099924	This monograph, published as part of the proceedings of the 21st (ESV) International Technical Conference on the Enhanced Safety of Vehicles, addresses the status of current NHTSA Research Programs in the following areas: crashworthiness research; biomechanics; heavy vehicle research - NHTSA's heavy vehicle research program is directed toward improving the collision avoidance capabilities of these vehicles; intelligent technology research; human factors research; and tire safety.
Peter Henshaw	How your motorcycle works : your guide to the components & systems of modern motorcycles	Dorchester, Dorset, England : Veloce House Publishing	2012	http://melvyl.worldcat.org/title/how-your-motorcycle-works-your-guide-to-the-components-systems-of-modern-motorcycles/oclc/785068390&referer=brief_results	This book was printed by Veloce House Publishing. This print book explains how the modern motorcycle works, and is designed to be approachable to a non-technical audience. It covers the latest innovations, including traction control and pushbutton gear change, as well as long-established technologies, such as fuel injection and ABS.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Chuthamat Laksanakit	Impact of Motorcycle Defects on Motorcycle Safety in Thailand	Journal of Society for Transportation and Traffic Studies	2014	http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.672.2035&rep=rep1&type=pdf	This paper, presented in the Journal of Society for Transportation and Traffic Studies, gives a review of past research works that examined factors affecting motorcycle safety, focusing on: human errors, infrastructure defects, vehicle defects and their interaction which contribute to motorcycle crashes, with the aim of highlighting the need for more research on the effect of motorcycle defects on safety. Overview of the global motorcycle crash situation was conducted using data and various information sources, including the World Health Organization, Science Direct and Transportation Research Institute, the University of Michigan. Sources of motorcycle accident information in Thailand included those of the Royal Thai Police, Department of Land Transport, and Road Accident Victims Protection. The results show that human errors, speeding, alcohol impairment, disregard of traffic laws, and inexperience are the most common factors involved in a motorcycle crash. Although vehicle defects such as defective components, (e.g. head lamp, stop lamp, front brake, rear brake, improper tire pressure) played a relatively small part of all the factors affecting motorcycle crash, but the effect was significant and increasing.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Avesta Goodarzi and Alireza Armion	Integrated fuzzy-optimal motorcycle dynamic control	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2010	http://www.tandfonline.com/doi/full/10.1080/00423114.2010.502942#abstract	This paper was published in the Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility. Active safety is an interesting issue in the case of motorcycles. In this study, an intelligent integrated fuzzy/optimal controller is proposed to enhance motorcycle handling and safety. This controller consists of two layers. In the lower level, there are 13 individual LQR (Linear Quadratic Regulator) strategies which each one has been designed for a specific region of the performance motorcycle dynamics. In the upper layer, a fuzzy composer was used to manage the participation level of each of the LQR controllers in the final controller output. Numerous simulations were performed and their results show that the fuzzy/optimal controller improves the dynamic behaviour of the motorcycle.
M. Bayly; S. Hosking; and M. Regan	Intelligent transport systems and motorcycle safety	20th International Technical Conference on the Enhanced Safety of Vehicles, 2007, Lyon, France	2007	https://trid.trb.org/view/1155103	This paper, presented in the 20th International Technical Conference on the Enhanced Safety of Vehicles, is a policy paper looking at how underrepresented are motorcycles in the ITS advancements. It looks at different safety topics that could be further investigated on motorcycles. The author determines that ESC is one of several priority topics for further research. The paper concludes that it is important to promote more studies on these topics to deal with the important number of motorcycles crashes currently happening.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
G. Ferretti; S.M. Savaresi; F. Schiavo; and M. Tanelli	Modelling and simulation of motorcycle dynamics for active control systems prototyping	Proceedings of the 5th MATHMOD Conference, Vienna, Austria	2006	Not available online.	Abstract not publically available.
Said Mammar; Stephane Espie; and Christophe Honvo	Motorcycle modelling and roll motion stabilization by rider leaning and steering torque	Proceedings of the 2005 IEEE Conference on Control Applications	2005	http://aramis.iup.univ-evry.fr:8080/~smam/publications/publis2005/cca2005.pdf	This paper, published in the Proceedings of the 2005 IEEE Conference on Control Applications, discusses to the modelling and stabilization of the roll motion of a motorcycle. The proposed model processes a nonlinear tire-road interaction forces, and includes the rider leaning movement for stabilization. A prefilter was added in order to ensure reference model tracking. Simulation results showed the effectiveness of the approach.
R.S. Sharp	Motorcycle Steering Control by Road Preview	Journal of Dynamic Systems, Measurement, and Control	2007	http://www3.imperial.ac.uk/pls/portallive/docs/1/35349697.PDF	This article was published in the Journal of Dynamic Systems, Measurement, and Control. The main objectives of this paper were to devise an effective path-based motorcycle simulation capability and to further understand of how riders control motorcycles. The article concluded that a motorcycle rider model representing a useful combination of steering control capability and computational economy had been established. The model yielded new insights into motorcycle behavior.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
M. Massaro; R. Sartori; and R. Lot	Numerical investigation of engine-to-slip dynamics for motorcycle traction control applications	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2011	http://www.tandfonline.com/doi/full/10.1080/00423110903530992#abstract	This paper, published in the Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, discusses the motorcycle engine-to-slip dynamics, which are strictly related to the traction control design. A street motorcycle was analyzed by means of an advanced mathematical model which also includes the tire flexibility and the transmission compliance. Guidelines for increasing the maximum achievable closed-loop bandwidth were also presented.
Dalil Ichalal; Habib Dabladji; Hichem Arioui; Said Mammar; and Lamri Nehaoua	Observer Design for Motorcycle's Lean and Steering Dynamics Estimation: a Takagi-Sugeno Approach	Proceedings of the American Control Conference	2013	http://melvyl.worldcat.org/title/observer-design-for-motorcycles-lean-and-steering-dynamics-estimation-a-takagi-sugeno-approach/oclc/839302983&referer=brief_results	This paper was published in the Proceedings of the American Control Conference. In this paper, a nonlinear motorcycle model was considered in order to estimate both the lean and steering dynamics. The model was transformed into a Takagi-Sugeno (T-S) form using the well-known sector nonlinearity approach.
M. Massaro; R. Lot; and V. Cossalter	On Engine-to-Slip Modelling for Motorcycle Traction Control Design	Journal of Automobile Engineering	2011	http://pid.sagepub.com/content/225/1/15.short	This paper was published in the Journal of Automobile Engineering. The paper used three different physical models to describe the relationship between engine characteristics, tire characteristics, and engine-slip dynamics in motorcycles. The researchers asserted that this paper is a foundational piece for the development of a traction control system in a motorcycle.
Matteo Corno; Sergio Matteo Savaresi; Mara Tanelli; and Luca Fabbri	On optimal motorcycle braking	Control Engineering Practice	2007	http://www.sciencedirect.com/science/article/pii/S0967066107001384	This paper, published in Control Engineering Practice, discusses in detail the dynamic of motorcycle braking, particularly optimal braking strategy in a high-performance motorbike. The paper also presents a possible policy for semi-active suspension control during braking.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
R. S. Sharp	Optimal linear time-invariant preview steering control for motorcycles	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2006	http://www.tandfonline.com/doi/full/10.1080/00423110600871509#abstract	This paper, published in the Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, builds upon prior research on linear preview control theory to the steering of a car, but focuses only on motorcycles. This research replaced the simple car model employed previously with a much more elaborate motorcycle model, and changed the control mode from a fixed control for the car to a free control for the motorcycle. The new model yielded insights into motorcycle behavior.
Patrick Seiniger; Kai Schroter; and Gail Jost	Perspectives for motorcycle stability control systems	Accident Analysis and Prevention	2010	http://www.sciencedirect.com/science/article/pii/S0001457510003623	This paper, published in Accident Analysis and Prevention, describes the potential of stability control systems to help save motorcyclists' lives. It summarizes safety research conducted and commissioned by the Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt) during the last twenty-five years, with particular focus on the authors' own work in the last five years, and the state of the art in motorcycle control systems.
Giovanni Savino; Federico Giovannini; Niccolò Baldanzini; and Marco Pierini	Real-time estimation of road-tyre adherence for motorcycles	Vehicle System Dynamics	2013	http://www.researchgate.net/profile/Giovanni_Savino/publication/257606111_Real-time_estimation_of_road_tyre_adherence_for_motorcycles/links/547506160cf245eb4370b5c3.pdf	This paper was published in Vehicle System Dynamics. The study used simulation and naturalistic driving data to validate a method for estimating the maximum available adherence during braking. The proposed approach was positively validated through multi-body simulations and experimental data acquired in naturalistic riding conditions.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
I. Boniolo; S.M. Savaresi; and M. Tanelli	Roll angle estimation in two-wheeled vehicles	IET Control Theory & Applications	2009	http://digital-library.theiet.org/content/journals/10.1049/iet-cta_20080052	This paper was published in IET Control, Theory & Applications. In support of traction control and electronic stability control for motorcycles, this paper explores a method for estimating roll angle (which influences the tire-road contact forces) for motorcycles in real time. The method proposed is based on a low-cost sensor configuration, suitable for industrial purposes. The validity of the proposed approach is assessed in a multi-body motorcycle simulator environment and also on an instrumented test vehicle.
Yoshihiro Masuda and Yoshimoto Matsuda	Stability Control of Motorcycle	SAE International	2011	http://papers.sae.org/2011-32-0558/	This paper was published by SAE International. The authors developed an active control more suitable for sports riding than the previous electronic stability control system.
Chihiro Nakagawa; Kimihiko Nakano; Yoshihiro Suda; and Ryuzo Hayashi	Stability of the Dynamically Stabilized Two-Wheeled Vehicle Traveling on a Rough Road	Journal of Mechanical Systems for Transportation and Logistics	2009	https://trid.trb.org/view/913033	This paper was published in the Journal of Mechanical Systems for Transportation and Logistics. The authors investigated the responses of an inverted pendulum, which was stabilized by an optimal controller, to vertical vibrations. With theoretical analysis, numerical simulations and experiments using a large scale vibration exciter were examined. The results showed that the system dynamics are governed by the Mathieu equation, thus the amplitude ratio reaches its peak when the frequency of the forced vibration is twice the natural frequency of the controlled inverted pendulum system.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Y. Marumo and M. Nagai	Steering control of motorcycles using steer-by-wire system	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2007	http://www.tandfonline.com/doi/full/10.1080/00423110701200194#abstract	This paper was published in the Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility. This study proposed a steering control method to improve motorcycle handling and stability. Steer-by-wire (SBW) technology was applied to the motorcycle's steering system to remove characteristic difficulties of vehicle maneuvers. By examining computer simulation using a simplified motorcycle model, the actual rolling angle of the SBW motorcycle was controlled to follow the desired rolling angle intended by the rider.
Vittore Cossalter; Alberto Doria; Matteo Formentini; and Martino Peretto	The effect of rider's passive steering impedance on motorcycle stability: Identification and analysis	Meccanica	2011	https://www.mendeley.com/catalog/effect-riders-passive-steering-impedance-motorcycle-stability-identification-analysis/	This paper was published in Meccanica. Many scientific papers deal with motorcycle stability (weave and wobble modes) but very seldom do they take into account the passive response of the rider's body. This paper studied the interaction of the rider's arms and torso with the handlebar and the frame.
Pascal Cardinale; Camillo D'Angelo; and Massimo Conti	Traction Control System for Motorcycles	EURASIP Journal on Embedded Systems	2009	http://jes.eurasipjournals.com/content/2009/1/161373	This paper, published in the EURASIP Journal on Embedded Systems, presents an algorithm and a low-cost real-time hardware implementation of a traction control system for motorcycles. A prototype was developed, applied on a commercial motorcycle, and tested in a real track. The traction controller proposed can be applied to any existing motorcycle.

Table B-12. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Matteo Corno; Giulio Panzani; and Sergio M. Savaresi	Traction-Control-Oriented State Estimation for Motorcycles	IEEE Transactions on Control Systems Technology	2013	https://www.infona.pl/resource/bwmeta1.element.ieee-art-000006422362/tab/summary	This paper, published in the IEEE Transactions on Control Systems Technology journal, addresses two problems relevant to traction control for motorcycles: vehicle velocity estimation and wheelie (i.e., front wheel lifting off the ground during acceleration) detection. Two methods to estimate velocity were compared and evaluated, and a wheelie detection algorithm was developed that can detect wheelies in 70 ms. Both methods were deemed computationally efficient and industrially viable. Track tests on an instrumented sport motorcycle were employed to illustrate and validate the methods.
Jingang Yi; Dezhen Song; A. Levandowski; and S. Jayasuriya	Trajectory tracking and balance stabilization control of autonomous motorcycles	Robotics and Automation	2006	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=1642091&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D1642091	This paper was part of the Proceedings of the 2006 IEEE International Conference on Robotics and Automation. The paper presents a new trajectory tracking and balancing control algorithm for an autonomous motorcycle. This research built on the existing modeling work of a bicycle; the new dynamic model of the autonomous motorcycle considers the bicycle caster angle and captures the steering effect on the vehicle tracking and balancing.

Helmet-Mounted Displays and Visibility Improving Helmet

System that projects alerts, warnings, and possibly other information such as speed onto a helmet visor or as audible speech into the helmet. Sensors in a helmet that sense light conditions, adjust the darkness of the visor, and provide night vision capabilities in very dark conditions.

Table B-13. Search terms.

Search Terms
Helmet-Mounted Displays
Helmet Display
Helmet Alerts
Motorcycle Head-Mounted Display
Visibility Improving Helmet
Helmet Sensors
Motorcycle Head-Mounted Sensor
Helmet Night Vision

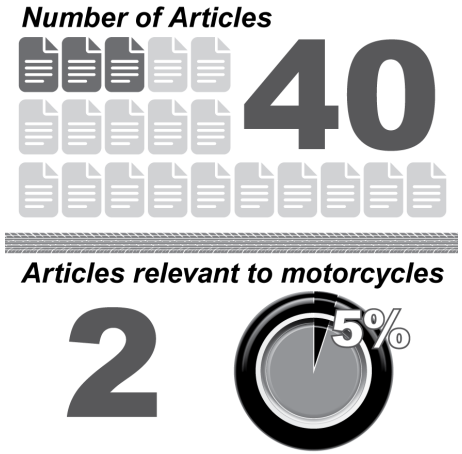


Table B-14. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
T.M. Pickrell and T.J. Ye	Motorcycle Helmet Use in 2009: Overall Results	National Highway Traffic Safety Administration	2009	http://www-nrd.nhtsa.dot.gov/Pubs/811254.PDF	This article was published by the National Highway Traffic Safety Administration. In the past five years, motorcycle helmet use has been increasing slowly but steadily—increasing from 48 percent in 2005 to 67 percent in 2009. A 2009 survey found the following: helmet use in states that require all motorcyclists to wear helmets significantly increased from 78 percent in 2008 to 86 percent in 2009. Helmet use in these States continued to be higher than in states without universal helmet use laws. Helmet use in the northeast U.S. increased by 16 percent to 61 percent in 2009. In 2009, helmet use in rural areas increased to 75 percent while urban areas saw a 15-percentage point drop to 57 percent.
J.V. Ouellet and V. Kasantikul	Motorcycle Helmet Effect on a Per-Crash Basis in Thailand and the United States.	Traffic Injury Prevention	2006	http://www.ncbi.nlm.nih.gov/pubmed/16484033	The objective of this paper, published in Traffic Injury Prevention, was to compare the effectiveness of motorcycle helmets seen in on-the-street motorcycle accident investigations. The data were drawn from two detailed, in-depth studies of motorcycle accidents, in which trained investigators collected extensive accident evidence on-scene immediately after the crash. This paper compared helmeted and un-helmeted motorcycle riders on a per-accident basis for fatality rates, the rate of serious brain injuries among survivors, or an outcome that involved either of the two. Helmets were extremely effective in preventing brain injury and death in 97% of the accident population in less-than-extreme crashes. The researchers stressed that helmet use cannot prevent all fatalities because many of those killed succumb to below-the-neck injuries that a helmet cannot prevent.

Inter-Vehicle Communication System and Motorcycle Detection Systems

Inter-Vehicle Communications Systems are vehicle-based systems that facilitate communications between vehicles (e.g., car-to-car or motorcycle-to-car communications). Motorcycle Detection Systems are vehicle-based systems that use inter-vehicle communications to recognize other nearby vehicles and, perhaps more importantly, be recognized by other vehicles (i.e., motorcycle in a truck's blind spot).

Table B-15. Search terms.

Search Terms
Inter-Vehicle Communication System
Motorcycle V2V
Motorcycle Communications
Motorcycle Detection System
V2V Detection
Connected Vehicle Motorcycle Detection

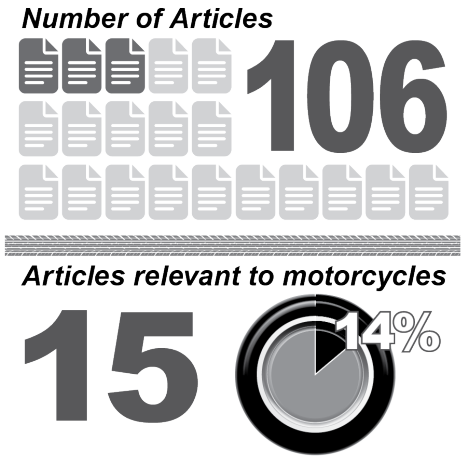


Table B-16. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
Vincenzo Manzoni; Andrea Corti; Cristiano Spelta; and Sergio M. Savaresi	A Driver-to-Infrastructure Interaction System for Motorcycles Based on Smartphone	13th International IEEE Conference	2010	https://trid.trb.org/view.aspx?id=1096437	This paper was presented in the 13th International IEEE Conference on Intelligent Transportation Systems. The paper concerns the definition and implementation of an add-on interaction system for motorcycles. The researchers analyzed a vehicle-to-driver communication system and a driver-to-infrastructure communication system, based on a smartphone core and a wireless Bluetooth medium. The paper gives the general hardware and software architecture, and some specific Web-oriented implementation, of these systems.
Sophia University; Panasonic Corporation; and Panasonic Mobile Communications R&D Lab., Co. Ltd.	A Proposal of Detection Method to Avoid Collision between Vehicle and Motorcycle in an Intersection	15th World Congress on Intelligent Transport Systems	2008	https://trid.trb.org/view/909026	This project, presented in the 15th World Congress on Intelligent Transportation Systems, details a detection method to avoid collision between a vehicle and a motorcycle in a road intersection using radio wave DOA estimation by ESPRIT. The system is based on distributed system and requires no infrastructures on the road side. The authors installed the transmitter in the motorcycle and the receiver in the vehicle. The vehicle receives radio waves arriving from different directions due to reflections from buildings and diffraction around the corner of building. The results made possible the calculation of whether the motorcycle is in Line of Sight (LOS) or Non Line of Sight (NLOS), and right or left of the vehicle.
Takeshi Chiba; Yuriko Ino; Toru Saito; and Tokujiro Kizaki	Advanced Design of Motorcycle Approaching Indication	Proceedings of 20th ITS World Congress	2013	https://trid.trb.org/view.aspx?id=1322084	This paper was included in the 20th ITS World Congress Proceedings. The paper focuses on the Motorcycle Approaching Indication (MAI) using a Vehicle-to-Vehicle Communication Systems (V2V), whose basic function Honda also reported in the ITS World Congress 2012. The authors emphasized that MAI still needs to define the motorcycle detection area around the subject vehicle. The paper described the issues, suggested an improved algorithm, and tested results of MAI in the public road environment.

Table B-16. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Vicente Milanésa; Enrique Onieva; Joshué Pérez; Javier Simó; Carlos González; and Teresa de Pedra	Detecting Motorcyclists and Bicyclists at Intersections	Public Roads	2010	http://www.fhwa.dot.gov/publications/publicroads/10mayjun/06.cfm	This study, published in the Federal Highway Administration magazine, Public Roads, reports on a multiphase research project to develop a system to detect and classify two- and three-wheeled vehicles more effectively. During phase I, the researchers collected a total of 45 vehicle samples and found the performance of the multisensor motorcycle classifier promising, even though it misclassified vehicles on several occasions.
Yuriko Ino; Takeshi Chiba; and Tokujiro Kizaki	Evaluation of Effective Notification for Various Target Vehicle Types on V2V Collision Prevention Support	20th ITS World Congress	2013	http://trid.trb.org/view.aspx?id=1320533	This paper, included in the 20th ITS World Congress Proceedings, discusses the analysis made for the DRIVE C2X project, which focused on the reduction of motorcycle traffic accidents and developed a driver support application named Motorcycle Approaching Indication (MAI). By evaluating the application's ability to prevent collisions in crossings using a driving simulator, the researchers confirmed that increasing the informational content of notifications about motorcycles increases effectiveness. The authors also confirmed user acceptability by varying and evaluating the informational content of notifications.

Table B-16. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Arno Hinsberger; Horst Wieker; Michael Ortgiese; and Alexandra Roos	Extending the Scope of Vehicular Ad-Hoc Networks in Order to Protect Vulnerable Road Users	15th World Congress on Intelligent Transport Systems	2008	https://trid.trb.org/view/902214	This paper, presented in the 15th World Congress on Intelligent Transport Systems and ITS America 2008 Annual Meeting, reports on a strategy to extend the scope of vehicular ad-hoc communication networks in order to protect vulnerable road users, notably motorcyclists and pedestrians. While motorcycles will use primarily the same technology as other vehicles, there are so far few considerations about how to include pedestrians and cyclists in the vehicular communication scenario. The authors propose a self-contained, communication-based system for the protection of vulnerable road users. In urban scenarios with crowded pavements there is a high probability that several devices will evaluate such increased risk at the same time. The paper also defines specific algorithms for the protection of cyclists and pedestrians. The authors stress that, in order to ensure compatibility with future vehicular ad-hoc networks the system has to reflect the specifications and recommendations of the C2C-CC, which aims to globally harmonize related standards.
J. Chiverton	Helmet presence classification with motorcycle detection and tracking	Intelligent Transport Systems	2012	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6279626&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6279626	This paper was published in IET Intelligent Transport Systems. Helmets are essential for the safety of a motorcycle rider, however, the enforcement of helmet wearing is a time-consuming, labor-intensive task. A system for the automatic classification and tracking of motorcycle riders with and without helmets is therefore described and tested in this paper. The system uses support vector machines trained on histograms derived from head region image data of motorcycle riders using both static photographs and individual image frames from video data. Tests showed that the classifier is able to accurately classify whether riders are wearing helmets or not on static photographs. Tests on the tracking system also demonstrated the validity and usefulness of the classification approach.

Table B-16. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Bo Ling; David R. P. Gibson; and Dan Middleton	Motorcycle detection and counting using stereo camera, IR camera, and microphone array	SPIE, Video Surveillance and Transportation Imaging Applications	2013	http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1669939	This paper was included in the Proceedings of SPIE. Working with FHWA, the authors developed a hybrid motorcycle detection and counting system using a suite of sensors including stereo camera, thermal IR camera, and unidirectional microphone array. Field test results showed that this hybrid motorcycle detection and counting system has an excellent performance.
Chung-Cheng Chiu; Min-Yu Ku; and Hung-Tsung Chen	Motorcycle Detection and Tracking System with Occlusion Segmentation	Image Analysis for Multimedia Interactive Services	2007	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4279140&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4279140	This paper, presented in the 8th International Workshop on Image Analysis for Multimedia Interactive Services, proposes an occlusion detection and segmentation method. The method uses the visual length, visual width, and Pixel Ratio to detect the classes of the motorcycle occlusions and segment the motorcycle from each occlusive class. Experiments obtained by using complex road scenes are reported, which demonstrate the validity of the method in terms of robustness, accuracy, and time responses.
S.A. Rajab; A.S. Othman; and H.H. Refai	Novel vehicle and motorcycle classification using single element piezoelectric sensor	15th International IEEE Conference on Intelligent Transportation Systems	2012	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6338778&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6338778	This paper, presented in the 15th International IEEE Conference on Intelligent Transport Systems, presents a novel vehicle classification setup that uses a single piezoelectric sensor placed diagonally across the traffic lane to accurately identify motorcycles from among other vehicles by detecting the number of vehicle tires.

Table B-16. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
William Belisle	Ranges of Safety Provided by Safety Technologies Used for Reducing Motorcycle Crashes, Fatalities, Injuries and Loss	Collision. The International Compendium for Crash Research	2009	http://trid.trb.org/view.aspx?id=903167	This article, published in the International Compendium for Crash Research Collision, evaluated the range of protection provided by motorcycle safety technologies. Technologies evaluated include helmets, clothing, eye and foot protection, vests, reflective materials, seatbelts/fall-bars/enclosure scooters, and airbags and enclosures. Evaluative methods included descriptive statistics and compiling lists and categories of motorcycle safety technologies; identifying and estimating safety and protection provided for the motorcycle or rider; and assessing the potential for the technology to reduce crashes, injuries, fatalities and costs. The results of the study suggested the greatest degree of safety and protection, and hence cost reduction, is provided by the motorcycle airbag equipped enclosure.
Bobo Duan; Shenyang; Wei Liu; Pengyu Fu; and Chunyang Yang	Real-time on-road vehicle and motorcycle detection using a single camera	IEEE International Conference on Industrial Technology	2009	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4939585&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4939585	This paper, presented in the IEEE International Conference on Industrial Technology, documents a real-time monocular vision based rear vehicle and motorcycle detection and tracking approach for lane change assistant (LCA). The test results under various traffic scenes illustrated the accuracy, robustness, and real-time ability of this application.
K. Maruyama; Y. Tsutsumiq; and Y. Murata	Study of FACE Design, Lighting System Design for Enhanced Detection Rate of Motorcycles	Proceedings of the International Technical Conference on Enhanced Safety Vehicles	2008	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv21/09-0406.pdf	This paper was included in the Proceedings of the 21st (ESV) International Technical Conference on the Enhanced Safety of Vehicles. Under the limited scope of study reported here, it was shown that the FACE (Facial Attention for Conspicuity Enhancement) design using three lights and inverted triangle arrangement (which was considered a simple figure reminiscent of a face) could enhance the detection rate of motorcycles from the point of view of a car driver.

Table B-16. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Kazuyuki Maruyama; Takeshi Chiba; Tokujiro Kizaki; and Amira Horozovic	Vehicle-To-X Functions For Improved Motorcycle Safety	Auto Tech Review: The language of technology	2014	http://melvyl.worldcat.org/title/vehicle-to-x-functions-for-improved-motorcycle-safety/oclc/33135690434931?referer=brief_results	Abstract not available online.
M. Y. Ku; C. C. Chiu; H. T. Chen; and S. H. Hong	Visual motorcycle detection and tracking algorithms	WSEAS Transaction on electronics	2008	http://www.wseas.us/e-library/transactions/electronics/2008/30-863.pdf	This paper, published in the WSEAS Transactions on Electronics Journal, describes a real-time vision-based motorcycle monitoring system that can be used to detect and track motorcycles in a sequence of images. Experimental results obtained with complex road images revealed that the proposed system could successfully segment and detect various occlusions.

Lane Keeping and Departure Warning Systems

Vehicle-based system that detects when the vehicle is crossing a lane line without using the turn signal and alerts the driver (lane departure warning); the system also may nudge the vehicle back into the proper lane (lane keeping).

Table B-17. Search terms.

Search Terms
Lane Keeping Assist
Lane Keeping Assist Motorcycle
Lane Departure Warning
Lane Departure Warning Motorcycle
Roadway Departure Warning
Roadway Departure Warning Motorcycle

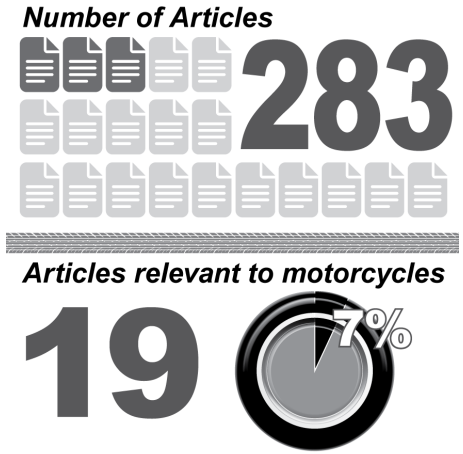


Table B-18. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
A. A. Popov; S. Rowell; and J. P. Meijaard	A review on motorcycle and rider modeling for steering control	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2010	http://www.tandfonline.com/doi/full/10.1080/00423110903033393#abstract	This paper, published in Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, is a review of the state of knowledge and understanding of steering control in motorcycles and of the existing rider models. The review also covers the knowledge and research-to-date on road preview control. Additional emphasis is placed on recent applications of optimal control and model predictive control to the riding task and the motorcycle–rider interaction. The review concludes with some open questions and presents a scope for further study.
Dominique Lord; Marcus A. Brewer; Kay Fitzpatrick; Srinivas R. Geedipally; and Yichuan Peng	Analysis of roadway departure crashes on two-lane rural roads in Texas	Texas Transportation Institute	2011	http://ntl.bts.gov/lib/44000/44000/44098/0-6031-1.pdf	This paper was published by the Texas Transportation Institute, in cooperation with Texas Department of Transportation, and the Federal Highway Administration. The research team reviewed Texas Peace Officer's Accident Reports for 394 single-vehicle runoff-road KABC crashes for 31 sites in four TxDOT districts. These crashes occurred between 2003 and 2008. Key factors were the presence of horizontal curves, nighttime conditions, unsafe/illegal speeds, motorcycles, and/or drivers who were distracted, fatigued, asleep, or impaired. To help reduce the number and severity of roadway departures, the research team proposed several medium-to-low-cost countermeasures that can realistically be implemented by TxDOT. These countermeasures were grouped into three categories: targeted for horizontal curves, general applications, and new and innovative treatments. For each treatment, the information focused on the general characteristics, key design features, safety effectiveness, cost (when available), and additional resources where the reader can find more detailed information about the treatment. More than 25 treatments were described for reducing roadway departure crashes.

Table B-18. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
José Manuel Barrios; Andrés Aparicio; Saadet Dündar; and Dimitrios Schoinas	Common database of existing safety functions and corresponding system platforms	Traffic Accident Causation in Europe	2007	http://www.trace-project.org/publication/archives/trace-wp6-d6-1.pdf	This report was published by Traffic Accident Causation in Europe (TRACE). TRACE Work Package 6 was tasked with investigating the safety functions incorporated into motor vehicles and roadways. The report suggested that a further evaluation be carried out for "other road users" to determine if some systems being developed for passenger cars can successfully be installed into HGVs and motorcycles to establish what necessary modifications might be required.
Véronique Huth; Francesco Biral; Óscar Martín; and Roberto Lot	Comparison of two warning concepts of an intelligent Curve Warning system for motorcyclists in a simulator study	Accident Analysis and Prevention	2011	http://www.sciencedirect.com/science/article/pii/S0001457511001047	This paper was published in Accident Analysis & Prevention. An Intelligent Curve Warning system was designed that gives the riders support when negotiating a curve. The system was tested in a simulator study carried out with 20 test riders. The subjects performed three rides: one without the system (baseline) and two experimental rides using a version of the Curve Warning system, one providing the warnings by a force feedback throttle and one by a haptic glove. The effects of the two system versions were evaluated both in terms of the simulated riding performance and the subjective assessment by the riders. A descriptive analysis of the riders' reactions to the warnings shows that the warnings provided by both system versions provoke an earlier and stronger adaptation of the motorcycle dynamics to the curve than when the riders do not use the system. The comparison of the riders' opinions about the system reveals a preference of the Curve Warning system with the haptic glove. The better acceptance of this system version suggests a higher potential in the enhancement of riding safety.

Table B-18. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Yoshitaka Marumo and Nozomi Katagiri	Control effects of steer-by-wire system for motorcycles on lane-keeping performance	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2011	http://www.tandfonline.com/doi/full/10.1080/00423114.2010.515030#	This paper, published in Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, discusses the control effects of the steer-by-wire (SBW) system for motorcycles on the lane-keeping performance by examining computer simulation with a rider-vehicle system which consists of a simplified vehicle model, a rider control model and the controller of the SBW system. The lane-keeping assistance (LKA) system was applied to the SBW system and the cooperativeness of the SBW and the LKA systems was examined. The LKA system improved the lane-keeping performance of the SBW system under not only the steering torque disturbance but also the lateral force disturbance.
N. Katagiri; Y. Marumo; and H. Tsunashima	Design and Evaluation of Lane-Keeping-Assistance System for Motorcycles	AVEC 2008	2008	https://trid.trb.org/view/912981	Abstract not available online.
N. Katagiri; Y. Marumo; and H. Tsunashima	Design of lane tracking controller for motorcycles	SICE Annual Conference 2007	2007	http://melvyl.worldcat.org/title/design-of-lane-tracking-controller-for-motorcycles/oclc/481476207&referer=brief_results	This paper, included in the proceedings of the SICE 2007 Annual Conference, examined a lane tracking control system for motorcycles and developed a lane keeping assistance system. The authors applied the optimal control theory based on a model-based control to the controller to follow a desired lane. By examining computer simulation using a simplified vehicle model, a good lane tracking performance was developed by evaluating the lateral displacement of gravity in the cost function of the optimal control. Furthermore, evaluating the lateral displacement at the virtual point ahead of the vehicle, which is defined by synthesizing the lateral displacement of the vehicle gravity and the yawing angle, copes with both lane tracking performance and convergence with suppressing undesirable yawing motion.

Table B-18. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Vittore Cossalter and James Sadauckas	Elaboration and quantitative assessment of maneuverability for motorcycle lane change	Vehicle System Dynamics (2006)	2006	https://www.mendeley.com/catalog/elaboration-quantitative-assessment-manoeuvrability-motorcycle-lane-change/	This article was published in Vehicle Systems Dynamics. The article describes the development of a new metric applied to lane change (LC) tests and coined 'LC roll index'. This metric takes into account the peak-to-peak values of the rider-input steering torque divided by the peak-to-peak roll rate response of the vehicle and normalizes this quantity by the forward velocity. In addition to this new metric, an analytical expression was developed, which in many cases summarizes a motorcycle's LC performance in a single, terse, analytical term. Simulation results highlighted the correlation between the proposed indices and handling.
N. Katagiri; Y. Marumo; and H. Tsunashima	Evaluating Lane-Keeping-Assistance System for Motorcycles by Using Rider-Control Model	SAE International	2008	http://papers.sae.org/2008-32-0056/	This paper, published by SAE International, presented a design for a lane-keeping controller for motorcycles, and evaluated it through computer simulation with a rider-control model. By examining the computer simulation with the rider-in-the-loop system consisting of the motorcycle, the controller, and the rider-control model, good lane-following performance was achieved without interference between the control input and the rider's input. Additionally, the lane-following performance was improved by using a virtual-point regulator.

Table B-18. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Kamarudin Ambak; Riza Atiq; and Rozmi Ismail	Intelligent Transport System for Motorcycle Safety and Issues	European Journal of Scientific Research	2009	http://www.researchgate.net/profile/Kamarudin_Ambak/publication/241917211_Intelligent_Transport_System_for_Motorcycle_Safety_and_Issues/links/00b7d53c62d7ec4ceee000000.pdf	This paper, published by the European Journal of Scientific Research, provides a review of Intelligent Transport System for motorcycles safety and related issues with some existing or emerging ITS technologies to enhanced vehicles safety. The authors state that there are several ITS technologies in-vehicle system to be introduced and adapted to motorcycles, including: advanced driver assistance system, intelligent speed adaptation, driver monitoring system, collision warning and avoidance system, lane keeping and lane-change warning system, visibility enhancing system, seat belt/helmet reminder system. However, 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. The paper emphasizes that motorcycles pose problems when it comes to the technical adaptation of certain ITS systems, particularly those that have not been custom-designed for motorcycle.
M. Bayly; S. Hosking; and M. Regan	Intelligent transport systems and motorcycle safety	20th International Technical Conference on the Enhanced Safety of Vehicles, 2007, Lyon, France	2007	https://trid.trb.org/view/1155103	This paper was presented in the 20th International Technical Conference on the Enhanced Safety of Vehicles. This is a policy paper looking at how underrepresented motorcycles are in terms of ITS advancements. It looks at different safety topics that could be further investigated on motorcycles. The author determines that Lane Keep Assistance and Departure Warning Systems is one of several priority topics for further research. The paper concludes that it is important to promote more studies on these topics to deal with the important number of motorcycles crashes currently happening.

Table B-18. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Kuo-Yu Chiu and Sheng-Fuu Lin	Lane detection using color-based segmentation	IEEE Publications Database	2005	http://melvyl.worldcat.org/title/lane-detection-using-color-based-segmentation/oclc/481002439&referer=brief_results	This paper, included in the Proceedings of the 2005 IEEE Intelligent Vehicles Symposium, proposes a new method for lane boundary detection, based on color information, and this method is applicable in complex environments. The system first chooses a region of interest to find out a threshold using statistical method in a color image. This system demands low computational power and memory requirements, and is robust in the presence of noise, shadows, pavement, and obstacles such like cars, motorcycles and pedestrians conditions. The result images can be used as pre-processed images for lane tracking, road following or obstacle detection.
A. P. Teerhuis and S. T. H. Jansen	Motorcycle state estimation for lateral dynamics	Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility	2012	http://www.tandfonline.com/doi/full/10.1080/00423114.2012.656655#	This paper, published in Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, investigates the feasibility of such a motorcycle state estimator (MCSE). A simplified analytic model of a motorcycle was developed by comparison to an extended multi-body model of the motorcycle, designed in Matlab/SimMechanics. The analytic model was used inside an extended Kalman filter. Experimental results of an instrumented Yamaha FJR1300 motorcycle showed that the MCSE is a feasible concept for obtaining signals related to the lateral dynamics of the motorcycle.

Table B-18. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Arno Eichberger; Rüdiger Rohm; Wolfgang Hirschberg; Ernst Tomasch; and Hermann Steffan	RCS-TUG Study: Benefit Potential Investigation of Traffic Safety Systems With Respect to Different Vehicle Categories	NRD-NHTSA	2008	http://www-nrd.nhtsa.dot.gov/Pdf/ESV/esv22/22ESV-000155.pdf	This paper was presented in the Proceedings of the 22th International Conference on the Enhanced Safety of Vehicles (ESV). This study, called RCSTUG study (Retrospective Case Study of the Graz University of Technology), exhibited the advantage from many different systems were analyzed in detail using the same sample with a comparatively high case number. This led to improved comparableness. The present study continued the analysis of the RCS-TUG study. The new analysis differentiated between the vehicle categories such as motorized two-wheelers, light trucks, passenger cars, trucks and busses with respect to the ego-vehicle. Additionally, the database was checked for errors. The limitations of the study were the restriction to fatal accidents in the area of Austria. Additionally some systems were evaluated by subjective judgment of the authors.
Bobo Duan; Wei Liu; Pengyu Fu; Chunyang Yang; Xuezhi Wen; and Huai Yuan	Real-time on-road vehicle and motorcycle detection using a single camera	2009 IEEE International Conference on Industrial Technology	2009	http://melvyl.worldcat.org/title/real-time-on-road-vehicle-and-motorcycle-detection-using-a-single-camera/oclc/480129787 5&referer=brief_results	This paper was presented in the IEEE International Conference on Industrial Technology. A real-time monocular vision based rear vehicle and motorcycle detection and tracking approach was presented for lane change assistant (LCA). To achieve robustness and accuracy, this work detected and tracked multiple vehicles and motorcycles on road by combining multiple cues. To achieve real-time multi-resolution results, technology was used to reduce computing complexity, and all algorithms were implemented on an IMAP (integrated memory array processor) parallel vision board. The test results under various traffic scenes illustrated accuracy, robustness and real-time of this work.

Table B-18. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Melisa D. Finley; Dillon S. Funkhouser; and Marcus A. Brewer	Studies to determine the operational effects of shoulder and centerline rumble strips on two-lane undivided roadways	Texas Transportation Institute	2009	http://ntl.bts.gov/lib/31000/31100/31124/0-5577-1.pdf	This paper was published by the Texas Transportation Institute, in cooperation with Texas Department of Transportation, and the Federal Highway Administration. This report describes the methodology and results of analyses performed to evaluate the impact of shoulder rumble strips (SRS) and centerline rumble strips (CRS) on the placement of vehicles in the travel lane of two-lane, undivided roadways, and determine the minimum shoulder width required for drivers to correct errant vehicle trajectories once alerted by passing over SRS. The installation of SRS and CRS on undivided, two-lane roads may be perceived by some users to adversely affect certain types of vehicles. To date, one of the biggest concerns regarding SRS has been bicycles. However, motorcycles, wide loads, vehicles with trailers, and mail carriers may also be adversely impacted.
C. Visvikis; T. L. Smith; M. Pitcher; and R. Smith	Study on lane departure warning and lane change assistant systems	Transport Research Laboratory	2008	http://www.trl.co.uk/umbraco/custom/report_files/PPR374.pdf	This report was published by Transport Research Laboratory. The study considers the potential casualty savings to occupants of both the vehicle to which the equipment is fitted as well as occupants of other vehicles. The potential benefits for vulnerable road users (pedestrian, cyclists, and motorcyclists) were also considered. The report states that the standard ISO 17387 does not consider motorcycles.

Table B-18. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
M. Fujito; K. Sakai; and Y. Harazono	Support Effects of the Haptic Throttle Grip by the Friction Circle on the Driving Wheel	SAE International	2013	http://papers.sae.org/2013-01-0084/	This paper was published by SAE International. For a motorcycle, it is generally suitable to use a haptic display for rider assistance, since there are many disturbances in open-air situation such as sunshine and surrounding noise. Therefore, this research developed a test vehicle based on a large motorcycle equipped with the haptic throttle grip that is connected to a motor by gear, an original ECU to control the motor, and a lean angle sensor to calculate the lateral force of the motorcycle. As the result of riding tests, all of the riders were able to recognize the signal and understood the request from the motorcycle. It became clear that this system was able to offer the information of surplus driving force warning, and to support the throttle grip operation.
Eui Yoon Chung; Ho Choul Jung; E. Chang; and In Sik Lee	Vision-Based for Lane-Change Decision Aid System	The 1st International Forum on Strategic Technology	2006	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4107297&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4107297	This paper was presented in the 1st International Forum on Strategic Technology. The authors developed a lane change decision aid system (LCDAS), which detects vehicles and motorcycles behind in adjacent lanes with a single camera and informs the driver of dangerous situations during lane change maneuvers. The experiments showed that the LCDAS can be utilized as a device which assists safety driving by detecting rear side vehicles under weather and environmental change.

Road Surface Condition Monitoring and Warning

Sensor systems that collect information on road surface conditions and communicate that information to the driver via V2I and V2V systems. Road conditions reported may include weather (wet or icy), uneven pavement, grooved pavement, work zones and work zone metal plates, and bridge open gratings.

Table B-19. Search terms.

Search Terms
Road Surface Warning
Road Ice Monitoring
Road Icy Warning
Slippery Road Conditions Monitoring
Road Friction Estimate

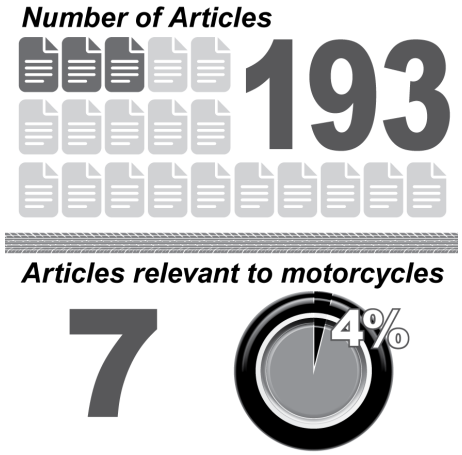


Table B-20. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
Zac Doerzaph	Connected Motorcycle System Performance	Final Report to Research and Innovative Technology Administration	2013	https://trid.trb.org/view.aspx?id=1402933	This project was conducted by Research and Innovative Technology Administration. The project considers the relevance of many common connected vehicle applications to motorcycles, including monitoring of roadway surface conditions. The paper indicates that surface monitoring and driver warnings for slippery pavement could reduce the occurrence of roadway departure incidents.
M. Bayly; M. Regan; and S. Hosking	Intelligent Transportation Systems and Motorcycle Safety	Report 260, Monash University Accident Research Center, Victoria, Australia	2006	http://www-nrd.nhtsa.dot.gov/Pdf/ESV/esv20/07-0301-O.pdf	This paper, published by Monash University Accident Research Center, examines the extent to which ITS have been applied to motorcycles (including both existing and emerging technologies) and discusses these ITS according to their likely safety benefits to motorcycle safety. According to the paper, road surface conditions are rarely cited as key factors in motorcycle crashes.
S. Fujii; S. Shiozawa; A. Shinagawa; and T. Kishi	Investigation of Steady-State Cornering Characteristics of Motorcycles Based on Tire Slip Angle Measurement	SAE Technical Paper	2010	http://papers.sae.org/2010-32-0105/	This paper, published by SAE International, examines the tire slip behaviors of motorcycles during cornering maneuvers. The focus of the work was to examine the tire slip angle and its relationship to motorcycle dynamics/characteristics. Results from simulation were compared to results from real-world measurements.
Hamid Slimi; Hichem Arioui; Lydie Nouveliere; and Sa'I Mammar	Preventive Safety: Warning System for Control Loss of Two-Wheeled Vehicle	2nd Mediterranean Conference on Intelligent Systems and Automation	2009	https://hal.archives-ouvertes.fr/hal-00420877/	This paper, published by 2nd Mediterranean Conference on Intelligent Systems and Automation, identifies existing and emerging Intelligent Transport System (ITS) that have the possibility to enhance the safety of motorcycle rider. The focus is on developing a warning system for the motorcycle operator in the event of an imminent crash. Although the article discusses road friction coefficients, it does not explore how these coefficients may be estimated in real-time.

Table B-20. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Giovanni Savino; Federico Giovannini; Niccolò Baldanzini; and Marco Pierini	Real-time estimation of road-tire adherence for motorcycles	Vehicle System Dynamics	2013	http://www.researchgate.net/profile/Giovanni_Savino/publication/257606111_Real-time_estimation_of_road_tyre_adherence_for_motorcycles/links/547506160cf245eb4370b5c3.pdf	This paper, published in Vehicle Systems Dynamics, uses simulation and naturalistic driving data to validate a method for estimating the maximum available adherence during braking.
Mats Andersson; Fredrik Bruzelius; and Johan G Casselgren	Road friction estimation	Saab Automobile AB, Trollh'a	2007	http://publications.lib.chalmers.se/publication/101026-road-friction-estimation	This paper was published by Chalmers Publication Library. This project was part of the Swedish IVSS program. The aim of this project was to investigate the possibilities to estimate the tire to road friction. The scope was limited to friction coefficient estimation from throttling action of a two-wheeled driven car at close to straight-line driving. Preliminary results indicated that the proposed methods can be used to detect changes in road conditions with very little throttling (which is used as input data).
J. Svendenius	Tire Modeling and Friction Estimation	Department of Automatic Control, Lund University, Sweden	2007	http://www.control.lth.se/documents/2007/jsvenPDH.pdf	This is thesis from the Department of Automatic Control, at the Lund University. This thesis proposes a new "brush model" type of friction-estimator using local measurements from the vehicle. The paper briefly discusses the differences in tire tilting angle (called the camber angle) for motorcycles and other types of vehicles, as they factor into the modeling of tire dynamics. The model was tested on snow, ice, and normal asphalt surfaces. The friction estimator developed in this thesis was restricted to acceleration conditions of two-wheel driven vehicles, since the model fails if there are any un-driven wheel rotations.

Automated Crash Notification Systems

Note that literature is filed in multiple categories. We need to note that these databases are dynamic, and results that show up earlier one day may not show up as early the next day (this means new papers may pop up in the earlier search results before termination criteria are met—papers that were not originally found using our approach). Automatic crash notification (ACN) systems detect the occurrence of a crash through vehicle speed, tilt, and deceleration sensors, and automatically notify emergency services. [Intelligent transport systems and motorcycle safety].

Table B-21. Search terms.

Search Terms
Automated Crash Notification
Automatic Crash Notification
Automated Collision Notification
Automatic Collision Notification
Intelligent Transportation Next Generation 9-1-1

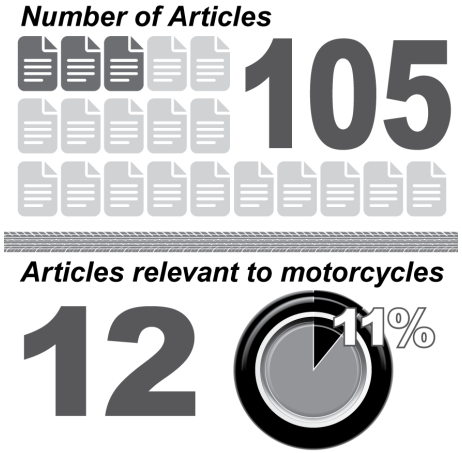


Table B-22. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
Patricia Turner; Laura Higgins; and Srinivas Geedipally	Development of a statewide motorcycle safety plan for Texas: technical report	Texas Department of Transportation. Research and Technology Implementation Office	2013	https://trid.trb.org/view.aspx?id=1253546	This document was published by Texas A&M Transportation Institute, in collaboration with Texas Department of Transportation and the Federal Highway. The project included a review of published literature on current and proposed countermeasures for reducing the incidence and/or severity of motorcycle-involved crashes and related injuries, a review of existing and emerging Intelligent Transportation System (ITS) and other advanced technologies for motorcycles and other vehicles, an analysis of Texas motorcycle crash and injury data, and a statewide survey of Texas motorcycle riders that explored the demographics, riding histories, training and licensing status, use of protective gear, crash involvement, and attitudes toward various motorcycle safety countermeasures. These data collection activities culminated in a list of potential motorcycle crash and injury countermeasures; these countermeasures were then evaluated and prioritized in a workshop attended by motorcycle safety experts and advocates.
Li, Ming-Der and Doong; Ji-Liang and Chang; Kai-Kuo and Lu; Tsung-Hsueh and Jeng; and Ming-Chang	Differences in urban and rural accident characteristics and medical service utilization for traffic fatalities in less motorized societies	Journal of safety research	2008	http://www.sciencedirect.com/science/article/pii/S0022437508001450X	This paper was published in the Journal of Safety Research. This paper from Taiwan explores the differences in fatality rates for collisions in urban and rural environments, finding a higher fatality occurrence in rural environments. This was attributed to lower use of restraints (i.e., helmets or seat belts), lower percentage of motorcyclists, and more highway accidents. Automated collision notification systems would be one strategy for addressing this issue.

Table B-22. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
J. Abele; C. Kerlen; S. Krueger; H. Baum; T. Geifller; S. Grawenhoff; J. Schneider; and W.H. Schulz	Exploratory study on the potential socioeconomic impact of the introduction of intelligent safety systems in road vehicles	VDI/VDE Innovation	2005	http://www.transport-research.info/Upload/Documents/201012/20101208_184626_84759_SEISS%20final_2005.pdf	This report, published by VDI/VDE Innovation, examined the expected costs, benefits, and congestion savings resulting from ACN. The report estimated that, with ACN, motorcycle fatalities and severe injuries can both be reduced by an average of between 5% and 10%.
P. Cairney and A. Ritzinger	Industry and rider views of ITS for safer motorcycling	23rd ARRB Conference, 2008, Adelaide, South Australia, Australia	2008	http://trid.trb.org/view.aspx?id=885929	This paper was presented in the 23rd ARRB Conference. It has a different title, but it is the same paper as "Motorcyclists' view of advanced technology for motorcycle safety," which is also included in this table (Table B.23), below.
Kamarudin Ambak; Riza Atiq; and Rozmi Ismail	Intelligent transport system for motorcycle safety and issues	European Journal of Scientific Research	2009	http://www.researchgate.net/profile/Kamarudin_Ambak/publication/241917211_Intelligent_Transport_System_for_Motorcycle_Safety_and_Issues/links/00b7d53c62d7ec4cee000000.pdf	This paper, published in the European Journal of Scientific Research, provides an overview of Intelligent Transportation Systems (ITS) for motorcycles safety. ITS technologies have significant potential to enhance traffic safety but very few have been developed especially for motorcycles. This research identified several priority ITS technologies to be adapted and developed for motorcycles, including advanced driver assistance systems, intelligent speed adaptation, driver monitoring systems, collision warning and avoidance systems, lane keeping and lane-change warning systems, visibility enhancing systems, and seat belt/helmet reminder systems. References to Automated Crash Notification Systems, however, were limited to the paper's literature review section.

Table B-22. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Megan Bayly; Michael A. Regan; and Simon G. Hosking	Intelligent transport systems and motorcycle safety	Monash University Accident Research Centre	2006	http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/ESV/esv20/07-0301-O.pdf	This paper, published by the Monash University Accident Research Centre, examines the extent to which ITS have been applied to motorcycles (including both existing and emerging technologies) and discusses these ITS according to their likely safety benefits to motorcycle safety. According to the paper, 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%.
Patricia A. Turner and Laura Higgins	Intelligent Transportation System (ITS) Technologies for Motorcycle Crash Prevention and Injury Mitigation	Unspecified	Unspecified	http://www.msf-usa.org/downloads/imsc2013/Oct16_Session1-Turner-Incorporating_ITS_Technologies_for_Motorcycle_Crash_Prevention_PAPER.pdf	While the publishers of this paper is unspecified, the authors are related to Texas A&M University. This paper presents the results of a broad literature review focused on ITS applications, with particular emphasis on motorcycle safety. It only briefly discusses ACN, and only on a conceptual level.
P. Cairney and A. Ritzinger	Motorcyclists' view of advanced technology for motorcycle safety	Australasian Road Safety Research Policing Education Conference, 2008, Adelaide, South Australia, Australia	2008	https://trid.trb.org/view.aspx?id=891848	This paper, presented in the Australasian Road Safety Research Policing Education Conference, studied the feasibility and acceptance of automatic collision notification (ACN) systems among motorcycle operators. Interviews with safety experts indicated that the ACN systems were expected to have positive impacts on motorcycle safety; focus groups of motorcycle riders revealed their expectations that ACN would indeed have safety benefits, but for a small number of riders.

Table B-22. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
W. Belisle	Ranges of Safety Provided by Safety Technologies Used for Reducing Motorcycle Crashes, Fatalities, Injuries and Loss	Collision, The International Compendium for Crash Research	2009	Not available online.	Not available online.
Texas A&M Transportation Institute	Texas strategic action plan for motorcycles: 2013-2018.	Texas Department of Transportation	2013	http://ntl.bts.gov/lib/47000/47700/47733/0-6712-P2.pdf	This report was published by Texas Department of Transportation. This five-year plan for Texas identified actions and implementable strategies for enhancing safety for motorcycle users. Several activities were completed during the course of this project, culminating in a list of potential motorcycle crash and injury countermeasures that were evaluated and prioritized in a workshop attended by motorcycle safety experts and advocates. There, participants rated automated crash notification systems as one of the most promising technologies in terms of anticipated effectiveness.
Natthapol Watthanawisuth; Anurat Wisitsoraat; Tanom Lomas; and Adisorn Tuantranont	Wireless Black Box for Real Time Accidental Monitoring of Vehicle	17th ITS World Congress	2010	https://trid.trb.org/view.aspx?id=1089534	This study was presented on the 17th ITS World Congress. This work considers a small add-on device for motorcycles that uses an accelerometer and a GPS device to automatically detect falls or collisions involving the vehicle, and subsequently send a text message to EMS or family members. The test results showed that it can detect linear fall, non-linear fall and normal ride with high accuracy.

Table B-22. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
L. Longthorne; C. Varghese; and U. Shankar	Fatal Two-Vehicle Motorcycle Crashes	NHTSA	2007	http://www-nrd.nhtsa.dot.gov/Pubs/810834.pdf	This study was published by the National Highway Traffic Safety Administration. In 2005 there were 4,553 motorcycle rider fatalities, of which 2,021 (44%) were from single-vehicle crashes and 2,532 (56%) were from multivehicle motorcycle crashes. Of the 2,532 fatalities from multivehicle motorcycle crashes, 2,260 (89%) were from two-vehicle motorcycle crashes. More than 85 percent of the 2,260 motorcycle riders killed in two-vehicle crashes were in crashes involving passenger vehicles. Among the fatalities in two-vehicle crashes involving motorcycles and passenger vehicles, 98 percent of the fatalities were motorcycle riders and only 2 percent of the fatalities were passenger vehicle occupants. With such a high proportion of motorcycle rider fatalities in two-vehicle motorcycle crashes, this report was written to provide insight into the possible factors in these crashes. The analysis is based on 2001-2005 data from the Fatality Analysis Reporting System (FARS).

Precrash Systems and External Airbags

Precrash systems combine the active and passive collision avoidance technologies described above (CAPS systems). For example, potential collisions activate the precrash system that in turn primes other vehicle systems, such as advanced braking systems or passive ITS in order to minimize the effects of the crash [Intelligent Transport Systems and Motorcycle Safety]. External airbags on a vehicle act to disperse the force of the crash more slowly; rather than directly protecting the occupant, they prevent collision force from ever reaching the car.

Table B-23. Search terms.

Search Terms
Precrash System
Precrash Braking
External Airbags
Collision Mitigation System

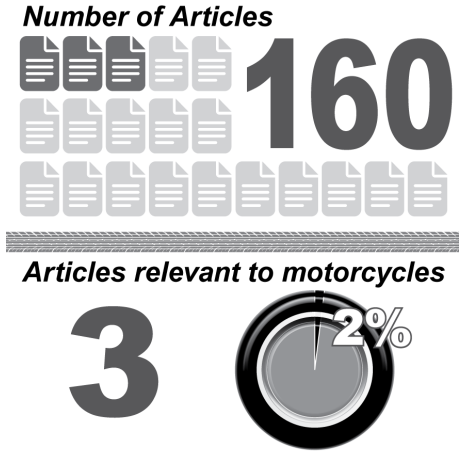


Table B-24. Literature review.

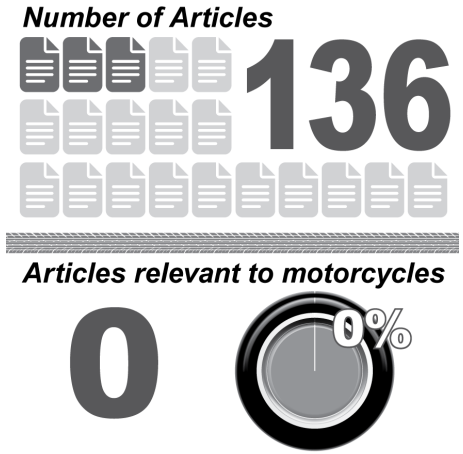
Authors	Title	Journal or Publisher	Year	Link	Summary
Marco Pieve; Francesco Tesauri; and Andrea Spadoni	Mitigation accident risk in powered two-wheelers domain: improving effectiveness of human machine interface collision avoidance system in two-wheelers	2nd Conference on Human System Interactions, 2009. HSI '09	2009	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5091046&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5091046	This paper was presented in the 2nd Conference on Human System Interaction. This paper focused on interfaces and methods for providing warnings and alerts to operators of motorcycles. No specific information about precrash systems was provided in the abstract, and the full paper was unavailable.
Andreas Georgi; Marc Zimmermann; Thomas Lich; Lisa Blank; Nils Kickler; and Reiner Marchthaler	New approach of accident benefit analysis for rear end collision avoidance and mitigation systems	21st International Technical Conference on the Enhanced Safety of Vehicles	2009	https://trid.trb.org/view.aspx?id=1100049	This paper was included in the proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles. This paper explored the benefit of precrash warnings and autonomous emergency braking systems for motor vehicles. It estimated that 38% of rear-end collisions could be avoided with predictive collision warnings, and that 72% could be avoided with automatic emergency braking. Furthermore, it estimated that the emergency brake system could reduce collision speed in unavoidable collisions by between 25% and 55%. Although the article mentioned motorcycles, it does so only tangentially, as part of a description of the crash data used for the analysis.
Marc-Michael Meinecke; Marian Andrzej; and T'o Obojski	SAVE-U: First experiences with a precrash system for enhancing pedestrian safety	Proceedings of the ITS	2005	https://www.researchgate.net/publication/228880997_SAVE-U_First_experiences_with_a_pre-crash_system_for_enhancing_pedestrian_safety	This paper, presented in the 5th European Congress and Exhibition on Intelligent Transportation Systems and Services, presents the results from a program designed to protect vulnerable road users (e.g., pedestrians), using radar sensors to apply brakes automatically and decrease vehicle speed in the event of an expected/anticipated collision. Motorcycles are only mentioned in a figure describing trends in road user fatalities.

Variable Message Signs

Electronic signs along a highway (freeway or arterial). These signs may provide information needed by motorcyclists such as weather conditions, work zones, or congestion ahead.

Table B-25. Search terms.

Search Terms
Variable Message Signs
Dynamic Message Signs
Variable Message Display
Motorcycle Dynamic Message Signs
Message Sign Weather
Message Sign Road Work
Message Sign Traffic Congestion



Strategic Planning

Table B-26. Search terms.

Search Terms
General Overall Search

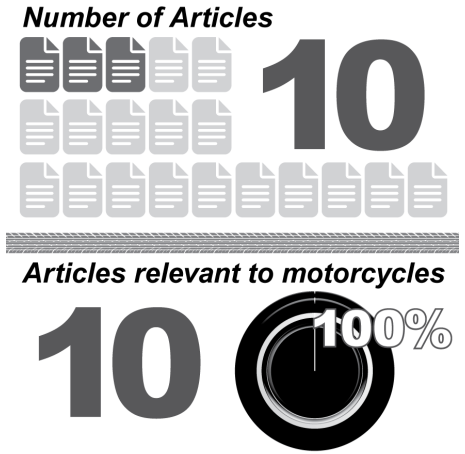


Table B-27. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
National Highway Traffic Safety Administration Office	The Effects of Entry-Level Motorcycle Rider Training on Motorcycle Crashes	National Highway Traffic Safety Administration Office	2015	Not available online.	This study investigates the effectiveness of driver training for reducing motorcycle crashes, by comparing the driving behavior of two groups of entry-level riders: one that received safe rider training, and one that did not. A third group of experienced riders was also included in the comparison. Using video data and statistical analyses, the researchers found that there were significant differences between the groups with respect to basic riding skills, safe riding characteristics, and the use of safety equipment. The findings suggest tangible benefits to rider training for novice riders.
City of Sydney	Motorcycle And Scooter Strategy And Action Plan	Public Draft Strategy Document	2011	http://www.amc.asn.au/web/sites/default/files/sydcty_draftstrategy.pdf	This planning and policy document from the City of Sydney, Australia looks at increased ridership of motorcycles and scooters in the city and addresses parking, sustainability (emissions), safety, and security issues. This effort included outreach to the rider community. No technology aspects were addressed.
Dutch Ministry of Infrastructure and the Environment	Action plan for improving road safety for motorcyclists—Strategic approach (Netherlands)	Dutch Ministry of Infrastructure and the Environment	2011	http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiKloLZ8_LJAhVLIIMKHf0LBa4QFggdMAA&url=http%3A%2F%2Fwww.loot.nl%2FDownload%2FMin-IenM_AVVM_Engels.pdf&usg=AFQjCNH7feVcxMIOZtmyc_sBrlqk3tLvGA&sig2=cI5NVUe04LGYnZ-tRaydqQ	This strategic plan for the Netherlands examines motorcycle safety issues and defines measures to address them. The technology discussion focused on motorcycle braking and stability technologies, including ABS. The plan also indicated that human error was a significant contributing factor, contributing to approximately 90 percent of crashes, and that 40 percent of crashes were single vehicle motorcycle crashes resulting in a fatality.

Table B-27. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Road Safety Authority	National Motorcycle Safety Action Plan 2010-2014 (Ireland)	Road Safety Authority	2010	http://www.rsa.ie/Documents/Road%20Safety/Motorcycles/National_Motorcycle_Action_Plan.pdf	This report outlines a Motorcycle Road Safety Action Plan for Ireland, including safety issues and infrastructure needs. The technology section addresses vehicle design and testing, protective clothing, running lights, and fuel spillages. The document also addressed enforcement, education and monitoring specific to motorcycles. The report ends with the establishment of performance measure targets.
U.S. DOT	U.S. Department of Transportation Action Plan to Reduce Motorcycle Fatalities	U.S. DOT	2007	http://www.nhtsa.gov/DOT/NHTSA/Communication%20&%20Consumer%20Information/Articles/Associated%20Files/4640-report2.pdf	This 2007 Action Plan, from the U.S. DOT, is a comprehensive study of motorcycle safety. It identified areas of need for new data sources and new data collection technologies.
Transport for London/Mayor of London	London Motorcycle Safety Action Plan (England)	Transport for London/ Mayor of London	2013	https://tfl.gov.uk/cdn/static/cms/documents/motorcycle-safety-action-plan.pdf	The Motorcycle Safety Action Plan (MSAP), from Transport for London, focuses on understanding the risks and challenges faced by motorcyclists while riding on London's roads and identifies ways to improve the safety of motorcycle riders and passengers. The main focus of the plan is on safety with minor discussion of the need for new technologies and research related to technologies.
GTSAC (Governor's Traffic Safety Advisory Commission)	Michigan Motorcycle Safety Action Plan 2009-2012	GTSAC (Governor's Traffic Safety Advisory Commission)	2009	http://michigan.gov/documents/FinalMotorcycleActionPlan_162717_7.pdf	This Safety Action Plan, commissioned by GTSAC, identifies safety and education issues related to motorcycles and the motorcycling community in the State of Michigan.

Table B-27. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Evangelos Bekiaris	SAFERIDER: Advanced Telematics for Enhancing the Safety and Comfort of Motorcycle Riders: Project Presentation	Centre for Research & Technology Hellas (CERTH), Hellenic Institute of Transport (HIT), Thessaloniki, Greece	2008	http://www.saferider-eu.org/assets/docs/deliverables/SAFERIDER_D10_1_Project_Presentation.pdf	The SAFERIDER project was an investigation of suitable interfaces for advanced driver assistance systems and in-vehicle information systems, in the context of motorcycles. This document includes a discussion of: how SAFERIDER project was positioned to address motorcycle accidents based on crash data; the technical approaches that the project planned to use, and what the anticipated outcomes from the project were. Final reports were not yet completed at the time this document was published.
M A Elliott, C J Baughan, J Broughton, B Chinn, G B Grayson, J Knowles, L R Smith, and H Simpson	Motorcycle Safety: A Scoping Study	Department of Transport, Road Safety Division, Great Britain (TRL Report TRL581)	2003	http://motorcycleminds.org/virtuallibrary/ridersafety/TRL581.pdf	The objectives of this safety study were to review the relevant literature and research, to identify existing gaps in knowledge and to make recommendations for further research. The study reviewed national accident figures, which showed that motorcyclists are a particularly vulnerable group of road users.
VicRoads and Monash University Accident Research Centre	Monash University Accident Research Centre (MUARC) Motorcycle Study	State Government Victoria, Australia	2014	https://www.vicroads.vic.gov.au/safety-and-road-rules/motorcyclist-safety/muarc-motorcycle-study	The study aimed to better understand factors that contribute to motorcycle crashes, to provide evidence-based information to riders and the wider community, and to better inform road safety organizations in their decision-making. The study focused on two main issues: motorcycle travel speed and the key factors that determine the choice of speed; and the role of the physical environment in causing a crash. Results were expected at the end of 2014, but were not yet released at the time this literature review was compiled.

Behavior

Table B-28. Search terms.

Search Terms
None

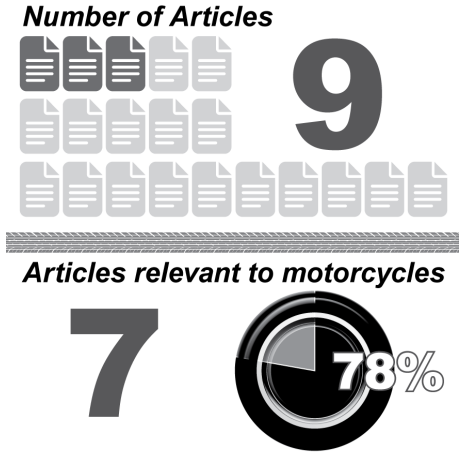


Table B-29. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
J.F. Lenkeit; B.K. Hagoski; and A.I. Bakker	A Study of Motorcycle Rider Braking Control Behavior	NHTSA	2011	http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811448.pdf	This document reports a study wherein a motorcycle riding simulator was used to study how non expert motorcycle riders use conventional brakes in emergency braking situations. Sixty-eight rider-subjects were exposed to traffic situations requiring a range of braking from normal slowing to emergency braking. The authors investigated possible relationships between rider characteristics, braking behavior, and event outcome. However, linear and logistic regression analyses produced generally poor correlation between individual rider factors and braking behavior or event outcome.
Patricia S. Bramati, MD; Lynn F. Heinert; Lindsey B. Narloch, MS; Jeff Hostetter, MD; and Javier D. Finkielman, MD	Animal-Related Motorcycle Collisions in North Dakota	Wilderness and Environmental Medicine	2012	http://www.wemjournal.org/article/S1080-6032%2811%2900243-2/pdf	This paper examined motorcycle collisions with animals, using data from North Dakota between 2007 and 2009. This corresponded to a data set of 766 crash records, of which 6.3 percent involved collisions with animals. The analysis revealed that helmets were worn by only 32 percent of drivers and 12 percent of passengers. These crashes, though only a small subset of all crash records, exhibited a high mortality rate. The authors suggested that this problem might be addressed by increasing awareness of these crash risks among motorcycle riders and by encouraging further helmet usage.
Marc Green	Is The Moth Effect Real?	Visualexpert.com news article	2013	http://www.visualexpert.com/Resources/motheffect.html	This article discusses what motorists and motorcyclists refer to as “target fixation.” The author describes the moth effect (staring at a roadway obstacle you are trying to avoid is associated with striking the obstacle) is “in one sense and reality in another.” The author explains that “drivers may steer off the road when they fixate flashing lights is likely correct, but they are not drawn to the lights like moths to a flame.”

Table B-29. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Russ Rader	Motorcycle ABS Benefits Both High-Risk and Low-Risk Riders	Insurance Institute for Highway Safety	2014	http://www.iihs.org/iihs/sr/statusreport/article/49/10/3	This news article discussed results from a new HLDI study about the benefits of ABS for motorcyclists. Using insurance claims history as a proxy for how risky a driver behaves, the researchers found that the presence of ABS resulted in a decrease in claim frequency of 24 percent to 29 percent across all four risk classes of drivers. Thus, the researchers concluded that the degree of benefits afforded by ABS were not dependent on the risk-taking characteristics of the drivers.
Motorcycle Safety Foundation	Motorcycle Safety Foundation (MSF) 100 Motorcyclists Naturalistic Study to Improve Countermeasures Data Acquisition Phase Complete, Preliminary Results Being Published	Online News Article	2014	http://www.msf-usa.org/news.aspx#/details/26	This article covers the announcement of results from the MSF 100 Motorcyclists Naturalistic Study. The study utilized a naturalistic methodology that provided researchers with information captured by instruments installed on 100 motorcycles ridden for a combined 9,000+ hours by real riders in real riding conditions. At the time this article was published, all 100 riders on their equipped motorcycles had completed the data acquisition phase of the study, and the analysis phase was beginning to yield preliminary results. However, a copy of the results was not found online.

Table B-29. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Randa Radwan Samaha; Kazuyoshi Kuroki; and Kennerly H. Digges	Opportunities for Safety Improvements in Motorcycle Crashes in the United States	Motorcycle Accident Analysis	Unspecified	https://trid.trb.org/view.aspx?id=926090	This paper provides a descriptive analysis of motorcycle crashes on U.S. roads to gain insight into causal factors and to investigate opportunities for improving rider safety. Using data between 1992 and 2004, the authors found that, in addition to the increase in crash risk due to exposure, motorcycle crashes are becoming more deadly. Overall, as compared to all crashes, a rider was about two times more likely to be killed in a road departure. In addition, riders under age 30 were most vulnerable followed by riders over 50 in all motorcycle crashes. Findings support opportunities in safety strategies such as rider education, grouped by age, relative to speeding, helmet use, and alcohol consumption. Findings also support opportunities in countermeasures such as improved visibility, including enhanced lighting, for the motorcycle and/or roadway, and improved performance of larger motorcycles in frontal crashes.
D.J.N. Limebeer; R.S. Sharp; and S. Evangelou	The Stability of Motorcycles Under Acceleration and Braking	Proceedings of the Institution of Mechanical Engineers	2001	http://www3.imperial.ac.uk/pls/portallive/docs/1/35343697.PDF	This report documents a comprehensive study of the effects of acceleration and braking on motorcycles. The results showed that motorcycle acceleration and braking stability (motorcycle "wobble") decreased when the machine was descending an incline or braking on a level surface. Conversely, the vehicle's stability increased when the machine was ascending an incline at constant speed, or accelerating on a level surface. Except at very low speeds, inclines, acceleration, and deceleration appeared to have little effect on the "weave" behavior of the motorcycle.

Technology

Table B-30. Search terms.

Search Terms
None

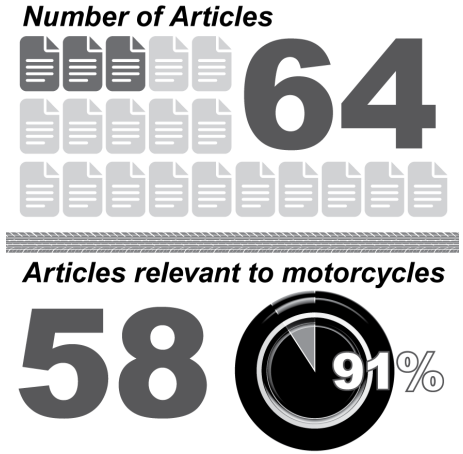


Table B-31. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
Beth Stebner	'Guardian' motorcycle helmet offers riders augmented reality, safety features from NJ entrepreneur	New York Daily News	2014	http://www.nydailynews.com/life-style/guardian-helmet-takes-augmented-reality-spin-article-1.1818690	This article describes the features of a 'Guardian' motorcycle helmet that, at the time this article was published, was planned to be released to the public in 2015.
Donovan Green	A Comparison of Stopping Distance Performance for Motorcycles Equipped with ABS, CBS, and Conventional Hydraulic Brake Systems	National Highway Traffic Safety Administration, International Motorcycle Safety Conference	2006	http://www.msf-usa.org/downloads/imsc2006/Green-Comparison_of_Stopping_Distance-Paper.pdf	In 2003, the U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA), in cooperation with Transport Canada (TC), conducted a motorcycle brake research project. The objective of this testing program was to assess the effectiveness of antilock braking systems (ABS) and combined brake systems (CBS) on motorcycles using various braking maneuvers and loading conditions. The results indicate that ABS generally improved stopping distance performance under most test conditions, and CBS improved braking performance when only the rear (foot) pedal was applied.
Airbag Jacket	Airbag Jacket	Airbag Jacket Web site	N/A	http://www.airbagjacket.eu/airbag_jacket.html	This Web site describes the history and emerging technologies related to airbag jackets.
E. Beukes and M. Vanderschuren	An Evaluation of the Benefits of Intelligent Speed Adaptation	Proceedings of the 26th Southern African Transport Conference	2007	http://repository.up.ac.za/bitstream/handle/2263/6005/083.pdf?sequence=1	The aim of this study was to find, list, and quantify all of the benefits that Intelligent Speed Adaptation (ISA) might hold for South Africa. In addition, an attempt was made to provide an initial estimate of the cost savings that ISA could offer the country if it is implemented in full. The study took the form of a review of local and international studies to determine the various effects of excessive speed. Research into the effects of ISA and the application of ISA technologies was then applied to the findings regarding the effects of speed, and the results were used to determine what the potential benefits of ISA are for South Africa.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Vicki Williams; Shane McLaughlin; and Sherry Williams	An Exploratory Analysis of Motorcyclist Apparel Using Naturalistic Riding Data	Motorcycle Safety Foundation	2014	http://msf-usa.org/downloads/imsc2013/Oct17_Session2-McLaughlin-An_Exploratory_Analysis_of_Motorcyclist_Apparel_Using_Naturalisti_Riding_Data_PAPER.pdf	Many studies have investigated protective clothing in terms of injury prevention and mitigation, conspicuity, and comfort. However, most studies have involved accident data review, literature review, simulation studies, or self-reported data. All of these clothing-related issues are very complex subjects that warrant additional study, particularly under actual riding situations. This paper contains a descriptive summary of clothing worn in a sample of trips, and results provide support for more detailed future analyses of clothing-related safety issues after the conclusion of the MSF 100 Motorcyclists Naturalistic Study.
Josh Max	Antilock brakes, controversial among motorcycle riders, reduce accidents, says study	New York Daily News	2012	http://www.nydailynews.com/autos/antilock-brakes-controversial-motorcycle-riders-reduce-accidents-study-article-1.1114107	This article describes how existing antilock braking systems reduce motorcycle accidents.
Insurance Institute for Highway Safety and Highway Loss Data Institute	Antilock braking systems make riding safer.	Insurance Institute for Highway Safety/Highway Loss Data Institute	N/A	http://www.iihs.org/iihs/brochures/motorcycle-abs-why-you-want-to-ride-with-it	This article lists the benefits, workings, and availability of ABS in motorcycles by make and model.
Insurance Institute for Highway Safety and Highway Loss Data Institute	Antilocks slash claims for newly insured riders	Highway Loss Data Institute	2012	http://www.iihs.org/iihs/news/desktopnews/antilocks-slash-claims-for-newly-insured-riders	The article discusses how antilock brakes cut crashes for motorcyclists of all abilities, and the benefit is especially large for those new to riding or to a particular bike.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Shoji Kanbe; Motoaki Deguchi; and Yousei Hannya	Basic Research for a New Airbag System for Motorcycle	NRD-NHTSA	2005	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv20/07-0095-O.pdf	This article discusses viability of motorcycle and scooter airbags. The paper concludes that tests have shown that this air bag system is promising, but there are remaining technical issues that need to be resolved before it can be put to practical use.
Henrik Liers	Benefit Estimation of Secondary Measures in Real-World Pedestrian Accidents	Verkehrsunfallfor-schung an der TU Dresden GmbH (VUFO)	2011	http://www-esv.nhtsa.dot.gov/Proceedings/22/files/22ESV-000300.pdf	The paper presents a methodology for the benefit estimation of several secondary safety systems for pedestrians, using the exceptional data depth of German In Depth Accident Study (GIDAS).
Green Car Congress	Cohda, BMW and Honda in V2V motorcycle study as part of DOT Safety Pilot Model Deployment	Green Car Congress	2013	http://www.greencarcongress.com/2013/06/cohda-20130604.html	This article discusses a motorcycle study to determine how cars, trucks, buses, and motorcycles interact using V2V (Vehicle-to-Vehicle) communications technology.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
David R. Thom	Comparison Tests of Motorcycle Helmets Qualified to International Standards	Collision and Injury Dynamics	N/A	http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwj8kM2Y8_LJAhUNm4MKHWP4B8UQFggdMAA&url=http%3A%2F%2Fwww.msf-usa.org%2Fdownloads%2Fimsc2006%2FThom-Comparison_Tests_of_Motorcycle_Helmets-Paper.pdf&usg=AFQjCNESfTNvbqqt7bHJDKTmjjL5OWckIQ&sig2=RO9Am52ME7VoXejsbNNX4g	This article describes impact analyses of existing motorcycle helmets. Thirty-two contemporary full-facial coverage motorcycle helmets consisting of 16 different models, two samples each, were destructively tested. Two anvil configurations were used: flat pavement and a narrow metal edge. These tests were designed to compare the helmets' relative performance under identical, realistic test conditions rather than to determine compliance with any particular standard.
Visordown News	Could external airbags save riders' lives?	Visordown News	2012	http://www.visordown.com/motorcycle-news-videos/could-external-airbags-save-riders-lives/20707.html	This article discusses the success of external airbags implemented on Volvo's V40 model.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Wen-Jing Huang	Development of the Intelligent Motorcycle Transportation Systems in Urban Areas; Development of the Intelligent Motorcycle Transportation Systems in Urban Areas	ITS America 9th Annual Meeting and Exposition: New Thinking in Transportation	1999	http://trid.trb.org/view.aspx?id=675655	The concept of the Intelligent Motorcycle Transportation Systems (IMTS) was developed to provide smart transportation solutions for the motorcycle operations, especially for countries with a large amount of motorcycles in their traffic flow. This paper on IMTS discusses the increasing usage of motorcycles as well as motorcycle characteristics, including safety and operational restraints. Also, the paper discusses motorcycle policies along with the major ITS user services and compares automobile and the motorcycle user services. The significant differences found between the two modes were: safety, information gathering mechanisms, different traffic control strategies, parking management, and incident management. For the safety aspect, the motorcyclists were found to be more likely to be injured compared with automobile users. The paper concluded that, by developing smarter motorcycles with multiple safety functions such as obstacle warning and smart braking system, motorcyclists could avoid certain fatal accidents.
American Motorcycle Association	Drivers Privacy Act Now Includes Motorcycles	American Motorcyclist Association News Article	2014	http://www.motorcycle-usa.com/2/18279/Motorcycle-Article/Drivers-Privacy-Act-Now-Includes-Motorcycles.aspx	This article describes legislation related to data and motorcyclists privacy rights.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
G. Mavros	Enhanced motorcycle roll stability by use of a reaction wheel actuator	Loughborough University/Society of Automotive Engineers of Japan (JSAE)	2010	https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/14744/3/George_Mavros_extra_final_AVEC10_paper.pdf	The paper presents a preliminary study on the use of the reaction wheel for improving the roll stability of motorcycles. The development of the controller in this paper was based on the dynamics of the reaction wheel pendulum. A feedback linearization approach was employed for the control of the reaction wheel pendulum and the resulting controller was subsequently implemented in a 12 degrees of freedom nonlinear motorcycle model. Simulations revealed the effectiveness of the controller, as well as some problems related to unrealistic power requirements and gyroscopic effects of the reaction wheel during cornering. The latter were treated by introduction of a moving roll-angle reference, while some proposals for reducing the required power to realistic levels also were discussed.
Insurance Institute for Highway Safety and Highway Loss Data Institute	Evaluation of motorcycle antilock braking systems, alone and in conjunction with combined control braking systems	Highway Loss Data Institute	2013	http://www.iihs.org/media/d9b615d8-7720-4428-84d0-f43de70974ed/1175364287/HLDI%20Research/Bulletins/hldi_bulletin_30.10.pdf	This article evaluates existing antilock braking systems used in conjunction with control braking systems.
Takeshi Kuroe; Hideo Namiki; and Satoshi Iijima	Exploratory Study of an Airbag Concept for a Large Touring Motorcycle: Further Research Second Report	NRD-NHTSA	2005	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv19/05-0316-O.pdf	This article describes the feasibility of implementing airbags for large touring motorcycles. Results revealed that an airbag system for a large touring motorcycle is feasible.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Virginia Tech Transportation Institute's Center for Advanced Automotive Research	Graduate student exploring ways to make riding a motorcycle safer using connected driving data	Virginia Tech Transportation Institute's Center for Advanced Automotive Research	2014	http://www.vtnews.vt.edu/articles/2014/11/110514-gradschool-motorcycleresearch.html	This article discusses the use of connected vehicle technology and naturalistic driving research to improve transportation safety and reduce crashes.
Rodger Charlton and Gary Smith	How to Reduce the Toll of Road Traffic Accidents	Journal of the Royal Society of Medicine	2003	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC544624/	This article discusses efforts to reduce road traffic accidents.
Insurance Institute for Highway Safety and Highway Loss Data Institute	IIHS, HLDI petition Federal government to require ABS on all motorcycles	Highway Loss Data Institute	2013	http://www.iihs.org/media/ddcf0bce-ca7a-47f2-90a6-f2226d7316c8/-1693001650/Petitions/petition_2013-05-30.pdf	This article discusses the need to require ABS on all motorcycles, driven by data from the Insurance Institute for Highway Safety (IIHS) and Highway Loss Data Institute (HLDI).
Akio Takahashi and Nobuyoshi Asanuma	Improvement of Visibility for Vulnerable Parties in Traffic Accidents	NRD-NHTSA	2001	http://www-nrd.nhtsa.dot.gov/pdf/ESV/esv17/Proceed/00142.pdf	The objectives of this paper was to improve visibility for vulnerable road users. At the time this paper was published, more than half of fatalities in traffic accidents in Japan were the vulnerable parties in such accidents (pedestrians, motorcycles, or bicycles). In most of these accidents, the cause was collision involving automobiles. The results from research on these systems showed that their use can be expected to have a positive effect in reducing the occurrence of accidents.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Bob Simpkin; Frank Lai; Kathryn Chorlton; and Mark Fowkes	Intelligent Speed Adaptation—Results of Motorcycle Trial	The University of Leeds and MIRA Ltd	2007	http://www.righttoride.co.uk/virtuallibrary/warningcontrolsystems/motorcycletrial.pdf	This document describes the implementation and assessment of an Intelligent Speed Adaptation (ISA) system for motorcycles.
Oliver Carsten; Mark Fowkes, Frank Lai; Kathryn Chorlton; Samantha Jamson; Fergus Tate; and Bob Simpkin	Intelligent Speed Adaptation (ISA)—Final Report	The University of Leeds and MIRA Ltd	2008	http://www.righttoride.eu/virtuallibrary/warningcontrolsystems/isareportjune2008.pdf	The main tasks of this project were to investigate car driver behavior with ISA by means of set of field trials with a voluntary ISA, study overtaking behavior with ISA in a driving simulator, prepare an ISA design for motorcycles and large trucks, build a demonstrator of each, and investigate the costs and benefits of ISA.
Federation of European Motorcyclists' Associations (FEMA)	Intelligent Transport Systems (ITS)—FEMA Position Paper	Federation of European Motorcyclists' Associations (FEMA)	2011	http://www.fema-online.eu/uploads/documents/ITS/20110110_FEMA_ITS_position.pdf	This paper explains FEMA's position on Intelligent Transport Systems. In principle, FEMA supports the implementation of ITS technology that has the potential to provide added safety, comfort, and economy to road users provided that: their use is not mandatory, and does not exclude unequipped vehicles from the road; they take into account the needs, characteristics, and limitations of powered two-wheeler users and their vehicles; and they do not create any additional hazards to any category of road users. In order to guarantee that current deployment and future developments comply with the above principles, all research and development should be conducted on the basis that: ITS functions developed for powered two-wheelers should be adapted to their needs and capabilities, and ITS in infrastructure and other vehicles must integrate the existence of motorcyclists; impact assessments must fully study the direct and indirect consequences of their use for motorcyclists, cyclists, and pedestrians.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Patricia A. Turner and Laura Higgins	Intelligent Transportation System (ITS) Technologies for Motorcycle Crash Prevention and Injury Mitigation	Texas A&M Transportation Institute	2013	www.msf-usa.org/downloads/imsc2013/Oct16_Session1-Turner-Incorporating_ITS_Technologies_for_Motorcycle_Crash_Prevention_PAPER.pdf	This paper presents findings from research conducted to identify existing and emerging Intelligent Transportation Systems (ITS) technologies for all vehicle types, including motorcycles, and examine the potential application of these technologies to improve motorcycle safety. Findings are based on a review of the existing literature, including published studies and industry-produced reports, and compiled according to the potential of the technology to: 1) prevent motorcycle crashes (crash prevention); and 2) reduce motorcyclists' injuries incurred in a crash (injury mitigation).
Art Friedman	Lane-change-warning technology could protect motorcyclists	Motorcyclists Online	2009	http://www.motorcyclistonline.com/lane-change-warning-technology-could-protect-motorcyclists	This article discusses a Lane Departure Warning System (LDWS) developed by Iteris.
National Cooperative Highway Research Program	Leading Practices for Motorcyclist Safety	NCHRP Project 20 68A, Scan 09 04	2011	http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_09-04.pdf	In March and April 2011, a team of transportation professionals with expertise in highway design, maintenance, data collection and analysis, and motorcyclist safety issues, held discussions with representatives from five States, four motorcycle rider advocacy groups, and one manufacturer on infrastructure issues relating to enhancing motorcyclist safety. The scan team focused on infrastructure, event management and travel planning, data collection and analysis, and communication and coordination as topics for discussion. The scan team chose specific States and organizations because of their innovative approaches to enhancing motorcyclist safety and their unique circumstances in hosting major riding events. The team invited motorcycle rider advocacy groups to participate because of their unique interests in promoting rider safety.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Yojiro Tsutsumi and Kazuyuki Maruyama	Long Lighting System for Enhanced Conspicuity of Motorcycles	NRD-NHTSA	2007	https://trid.trb.org/view.aspx?id=1367061	The LONG (Longitudinal-Oriented Normative Time Gap Compensation) concept describes a lighting system that enhances the conspicuity of motorcycles by enhancing the ability of oncoming drivers to evaluate the distance and speed of a motorcycle equipped with lighting in the LONG configuration. It is based on the hypothesis that a motorcycle observed at the same distance and speed as an automobile may be perceived farther away and traveling more slowly than the automobile, because of the motorcycle's higher lamp location and narrower lighting layout compared with that of an automobile. To address this the LONG configured are spread farther apart along a vertical axis compared to the relatively tightly grouped lighting layout found on a typical motorcycle. Knowledge of cognitive psychology is applied to the LONG system. To test the hypotheses behind the LONG concept, this research evaluated the LONG concept by measuring critical time gap in right-turn across path scenario (in left traffic right-of-way countries). The results demonstrated that motorcycles with the system have conspicuity on a level comparable to automobiles by measuring critical time gaps of about 20 experimental subjects. The effects of both the layout of the lighting and luminous intensity dependence also were reported.
Benedikt Lattke; Frank Sperber; Tobias Müller; Hermann Winner; Richard Eberlein; and Rainer Hoffmann	MoLife—Hazard Detection in a Cooperative Assistance System for Motorcycles	NRD-NHTSA	2011	http://www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000070.pdf	This paper discusses new methods of developing vehicle dynamics sensors (e.g., wheel speed sensors, gyro sensors) that deliver information about the current driving state variables. The paper discusses situations that could be avoided using these sensors. These include: Roadway damages, e.g., unevenness, ground waves, transversal ruts, and pot holes; obstacles on the road, such as broken-down vehicles behind a curve; excessive speed in curves, especially in irregular road conditions; and friction steps caused by oil, gravel, and sand.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
James W. Jenness; Richard W. Huey; Shawn McCloskey; Jeremiah Singer; Jeremy Walrath; Elisha Lubar; and Neil D. Lerner	Motorcycle Conspicuity and the Effect of Auxiliary Forward Lighting	NHTSA	2011	http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811507.pdf	A field experiment was conducted with 32 participants to determine whether the conspicuity of approaching motorcycles viewed in daylight may be improved by various forward lighting treatments. The treatments tested included pairs of low-mounted auxiliary lamps (LA), high-mounted auxiliary lamps (HA), both high- and low-mounted auxiliary lamps (LHA), low-mounted LED lamps (LED), and a modulated high-beam headlamp (MHB). These results should be interpreted cautiously in light of differences that were observed between participants who reported using a landmark-based strategy to judge when it was no longer safe to turn in front of approaching vehicles and participants who used other strategies. Overall, the results suggest that enhancing the frontal conspicuity of motorcycles with lighting treatments beyond an illuminated low-beam headlamp may be an effective countermeasure for daytime crashes involving right-of-way violations.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Lorenzo I. Torrez	Motorcycle Conspicuity: The Effects of Age and Vehicular Daytime Running Lights (DRL)	University of Central Florida	2008	http://etd.fcla.edu/CF/CFE0002016/Torrez_Lorenzo_I_200805_PhD.pdf?origin=publicationDetail	Research has shown that riding a motorcycle can potentially be much more dangerous than operating a conventional vehicle. There are factors inherent in driving or riding a small two-wheeled vehicle, such as a motorcycle, moped, or even bicycle that can potentially decrease their ability to be seen or noticed by other drivers. This disadvantage is reflected in the disproportionate overrepresentation of injuries and/or fatalities incurred by this particular driving group. This creates a significant problem, which deserves dedicated evaluation as to causative factors and/or influential variables. This study was conducted with intentions to investigate the topic of motorcycle conspicuity to further explain the variables, which positively contribute to a motorcycle being seen, and to supplement the body of knowledge that currently exists on this topic. This study specifically evaluated the influence of sex, age, motorcycle lighting conditions, and vehicular daytime running lights upon one's ability to effectively detect a motorcycle within a "high-fidelity" simulated environment. This research additionally sought to examine the feasibility and validity of using a novel fixed-base "high-fidelity" simulator for the evaluation of motorcycle conspicuity. The results from this research clearly indicate a link between vehicular DRLs and the effective detection of motorcycles and also support previous research as to the effectiveness of motorcycle DRLs. Additionally, these results suggest that as one ages, certain degradations in vision, cognition, and physiology occur which decrease one's performance in detecting and responding to a motorcycle. These findings additionally provide support for the use of a "high-definition" fixed-base simulator as a valid technology for the evaluation of motorcycle conspicuity.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
NHTSA	Motorcycle Factors: Braking	NHTSA	N/A	http://www.nhtsa.gov/people/injury/pedbimot/motorcycle/00-nht-212-motorcycle/motorcycle45-46.html	This article aims to improve motorcyclist awareness of existing antilock braking systems and proper braking techniques.
Riders Magazine Staff	Motorcycle Industry Council Gives Support to Vehicle-to-Vehicle Communication Research	Rider Magazine	2013	http://ridermagazine.com/2013/07/10/motorcycle-industry-council-gives-support-to-vehicle-to-vehicle-communication-research/	This article describes an event sponsored by the Motorcycle Safety Foundation, to promote emerging vehicle-to-vehicle communication technologies, and research related to these technologies. The event was held on May 23, 2013, at the Rose Bowl Stadium in Pasadena, California.
Liz de Rome and Guy Stanford	Motorcycle Protective Clothing: Fashion or Function?	The 2006 International Motorcycle Safety Conference (IMSC)	2006	http://www.msf-usa.org/downloads/imsc2006/de_Rome-protective_Clothing_Function_or_Fashion-Paper.pdf	This report identifies the features of effective motorcycle protective clothing and develops a process to ensure riders are able to make informed purchasing choices. While clothing cannot prevent serious high-impact injuries, there is evidence that perhaps half of all motorcycle injuries could have been reduced or prevented by the use of effective protective clothing. This research endeavored to encourage the local Australian motorcycle industry to develop a product safety assurance system for motorcycle clothing in order to remain competitive with European imports. The aim was to achieve a higher standard of protective clothing, consumer confidence, and hence increased usage by riders who can be assured it is fit for the purpose.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Zachary R. Doerzaph	Motorcycle Research of the U.S. DOT Affiliated, Virginia Connected Corridor for Researching Vehicles, Technology, Humans, and Infrastructure Interactions	2015 Annual Meeting Transportation Research Board (P15-6573). Reginald Viray, Virginia Tech Transportation Institute	2015	http://www.rita.dot.gov/sites/default/files/pdf/tis_2015_03_18a.pdf	This report by the Virginia Tech Transportation Institute (VTTI) provides an overview of the connected vehicle concept and how CV may increase motorcycle safety. Motorcycle safety can be increased through greater awareness and various advisory and warning systems (crash imminent, safety advisories, forward collision, blind spot, intersection, gap, and back up). At the time this report was published, VTTI was currently conducting testing on various systems in Virginia (Virginia Connected Corridors).
Linda Dodge and Michael Halladay	Motorcycle Safety and Intelligent Transportation Systems	FHWA	2008	Not available online.	This paper argues that technologies from Intelligent Transportation Systems (ITS) have the potential to reduce the risk of motorcycle riding and help reverse the recent rising trends in motorcyclist fatalities. ITS countermeasures have not yet been fully realized for motorcycles, but they show promise for improving safety. To maximize the potential of ITS contributions, the paper emphasizes that it is critical to recognize the unique characteristics of motorcycles as a vehicle class in terms of ITS system architectures and implementation. This paper also showcases key opportunities for the adaptation of ITS technologies for making motorcycle driving safer.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
American Motorcycle Association	Motorcycle Safety Foundation iTunes U courses offer riding strategies, advice, and more to motorcyclists of all skill levels	American Motorcycle Association	2014	http://www.motorcycledaily.com/2014/03/motorcycle-safety-foundation-itunes-u-courses-offer-riding-strategies-advice-and-more-to-motorcyclists-of-all-skill-levels/	The Motorcycle Safety Foundation posted four free courses on Apple's iTunes U that provide motorcycle tips and strategies to help motorcyclists sharpen their skills, make wise choices on the road and become riders of good riding character. The course "An Adventure in Motorcycle Physics" provides explanations of the dynamics of motorcycle handling, braking, tire grip and traction distribution, while the course "Dr. Ray's Street Strategies," adapted from advice MSF provides to readers of American Motorcyclist magazine, incorporates practical lessons covering various aspects of motorcycle ownership, from riding techniques to handling hazardous traffic situations and more. The course "Dr. Ray's Guide to Group Riding" focuses on the strategies and added responsibility of riding with others, while "Dr. Ray's Seasoned Rider" course is designed to help motorcyclists remain safe on the road through all phases of their lives.
Mark Jackman	Motorcycle safety through smart technology	Journal of the Australasian College of Road Safety	2014	http://acrs.org.au/wp-content/uploads/ACRSJournalVol25No2May14WEB.pdf	This article discusses the motorcycle safety risk reductions that can be achieved through the intelligent selection of the bike's safety features (such as Antilock Braking Systems (ABS)).
Anthony Effinger	Motorcycles at 150 mi/h Made Less Risky With Air Bag Suits	Bloomberg News	2014	http://www.bloomberg.com/news/2014-03-18/motorcycles-at-150-mph-made-less-risky-with-air-bag-suits.html	This article describes various airbag technologies for motorcyclists.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Steve Farrell	Motorcycles to get speed limiters	Motorcycle News Article	2008	http://www.motorcyclenews.com/news/2008/september/sep1908-speed-limiters-for-motorcycles/	This article discusses the state of the practice on intelligent speed adaptation as well as barriers to full implementation of the technology.
Peter Cairney and Adam Ritzinger	Motorcyclists' view of advanced technology for motorcycle safety	Australasian College of Road Safety	2008	http://acrs.org.au/files/arsrpe/RS080191.pdf	This article discusses the motorcycle safety benefits of Intelligent Speed Adaptation (ISA), Automatic Crash Notification (ACN) and Advanced Braking Systems, which include antilock braking systems (ABS), linked braking systems, and emergency brake assist (EBA). VicRoads engaged ARRB Group to investigate the feasibility of these technologies in the near future and the likelihood that these technologies would be accepted within the motorcycling community. Interviews were conducted with nine individuals who were expert in motorcycling safety or vehicle systems. Discussions were conducted with eight rider focus groups which attracted riders of different ages and motorcycling expertise and who rode different types of machines. All ITS systems investigated were expected to have positive impacts on motorcycle safety by a group of experts interviewed separately from the motorcyclists. Riders were generally more skeptical. While they recognized that ACN would have safety benefits for a small number of riders, they were not convinced that ISA would have safety benefits and were divided over whether advanced braking systems would have safety benefits or not. Rider opinion about advanced braking systems was not based on practical experience since very few riders had ridden motorcycles with these features. Barriers to the uptake of ITS safety technologies, and actions to advance the case for safety-related ITS, are discussed.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
James Holter	Myths Busted: Antilock Braking Systems (ABS): ABS Is Becoming More Common. Here's Where The Tech Stands Today	American Motorcyclist	2013	https://issuu.com/americanmotorcyclist/docs/09_2012_web/48	This article discusses the state of the practice of antilock braking system technology.
Vision Zero International	Nine Lives of ABS	Vision Zero International	2014	http://viewer.zmags.com/publication/6fa299ac#/6fa299ac/12	This article describes the evolution of Bosch ABS and EU legislation requiring antilock brakes.
Promocycle Foundation	Performance Evaluation for Various Braking Systems of Street Motorcycles	Promocycle Foundation	2003	http://www.msf-usa.org/downloads/imsc2006/Belmonte-Task_Analysis_of_Intensive_Braking_of_Motorcycles-Paper.pdf	This report covers a series of motorcycle braking tests aimed at measuring the performance of the front brake and of the rear brake compared with using the two brakes simultaneously during intensive braking in a straight line. This report also describes braking tests performed on motorcycles equipped with antilock braking systems (ABS). In addition, it covers the efficiency of certain variants with a shared (integrated) braking system, as well as summarizing the influence of a wet surface and of the addition of a passenger on the global braking properties of a motorcycle.
Stéphane Espié and Niccolò Baldanzini	Powered Two-Wheelers and Intelligent Transport Systems	Motorcycle Riders Foundation	2012	http://www.itsinternational.com/sections/associations/news/powered-two-wheelers-and-its/	This article discusses the weakness of dedicated fatality and injury reduction research targeting vulnerable road users (VRU) compared to the plethora of fatality and injury reduction research targeting car drivers. VRUs in this article include pedestrians, cyclists, and powered two-wheelers. The author notes several research programs related to VRU technology design and/or improvement, but mentions few programs focus on VRU behavior, training, and retraining issues. Behavior, training, and retraining research is imperative to reduce fatalities and serious injuries for VRUs.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
NHTSA	Prioritized Recommendations of the National Agenda for Motorcycle Safety. Final Report	National Highway Traffic Safety Administration	2013	http://www.nhtsa.gov/staticfiles/nti/pdf/811789.pdf	The National Agenda for Motorcycle Safety (NAMS) is a comprehensive plan to improve United States motorcycle safety in the 21st century. The NAMS was developed by a technical working group of experts representing all constituencies involved in motorcycle safety, led by the National Highway Traffic Safety Administration and the Motorcycle Safety Foundation (MSF), and published in November 2000. The 82 individual NAMS recommendations address the full range of topics and strategies relevant to motorcycle safety: human, vehicle, environmental, and social factors to prevent crashes; reduce injuries in crashes; and care for people injured in crashes. The technical working group prioritized the 82 recommendations into three groups: urgent (4 recommendations), essential (56), and necessary (22).
Tien-Pen Hsu	Proposed ITS Issues on Motorcycle Traffic	National Taiwan University, ITS World meeting in Berlin, Germany	1997	http://trid.trb.org/view.aspx?id=541641	Motorcycles are an important mode in some countries and should not be ignored in developing ITS systems. In Taiwan, there are about 10 million motorcycles in an overall population of 21 million. This paper discusses motorcycle traffic issues associated with the development and application of ITS. In this paper, a comprehensive development concept of motorcycle ITS is proposed based on the experience in solving motorcycle traffic problem as well as in the research on the motorcycle traffic theory in Taiwan. The research can inform the concepts to develop the ITS system especially for motorcycle or a passive concept to enhance the existing ITS system to consider the motorcycle traffic into the ITS system.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Loz Blain	Review: BikeHUD by BikeSystems, the first motorcycle heads-up display	Gizmag	2014	http://www.gizmag.com/bikehud-motorcycle-hud-heads-up-display-review/33884/	The article summarizes motorcycle heads-up displays by various manufacturers.
Niccolò Baldanzini	RIDERSCAN ITS Survey: Preliminary Results	European Motorcyclists' Forum Brussels Presentation	2014	http://www.fema-online.eu/uploads/EMF/EMF2014/II_3NiccoloBaldanzini.pdf	This presentation discusses a variety of motorcycle safety technologies and ranks the technologies from best to worst.
David L. Hough	Road Science. Braking: Part 4	Sound Rider	Not given	http://www.soundrider.com/archive/safety-skills/RS-braking4.aspx	This report describes the variety of braking technologies for motorcycles.
Patricia Turner; Laura Higgins; and Marcelina Perez	Texas Motorcycle Crash Countermeasure Workshop	Texas A&M Transportation Institute	2013	http://ntl.bts.gov/lib/47000/47700/47732/0-6712-P1_all.pdf	The materials associated with this workshop summarize the literature on countermeasures to improve motorcycle safety. The materials were provided as background information for a workshop that would discuss a new strategic direction for the use of motorcycles and the safety of motorcycles over a five-year period in Texas.
Elizabeth Kreft	The Awesome Piece of Motorcycle Technology That Could Save Riders' Lives	The Blaze News	2014	http://www.theblaze.com/stories/2014/03/25/crash-this-motorcycle-and-it-will-wirelessly-inflate-the-airbag-in-your-jacket/	This article describes a new wireless airbag system that became available in Europe in 2014.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Consumer Reports News	The most-valuable motorcycle feature: antilock brakes	Consumer Reports	2012	http://www.consumerreports.org/cro/news/2012/04/the-most-valuable-motorcycle-feature-antilock-brakes/index.htm	This article argues that existing antilock braking systems are the most important feature in motorcycles.
Oliver Hoffmann; Alfred Eckert; James Remfrey; and Jürgen Woywod	The Motorcycle Integral Brake System MIB: An Advanced Brake Solution for High-Performance Motorcycles	Continental Automotive Systems	2006	https://trid.trb.org/view.aspx?id=1367067	This paper describes the Motorcycle Integral Brake system, its operating principles compared with other brake systems, and its various hydraulic and functional possibilities.
European Association of Motorcycle Industries	The safe ride to the future—The motorcycle industry's commitment to road safety	European Association of Motorcycle Manufacturers (ACEM)	2014	http://www.raivereniging.nl/ecm/?id=workspace://SpacesStore/b78e686c-1d7f-4c5f-89ce-ce159072a011	This report provides an overview of the most significant industry-led initiatives in the field of road safety (e.g., key safety technology developments, advocacy actions, and accident research). It also delves into the future of motorcycling, touching upon the industry's vision of intelligent transport systems. The report explains why there is an urgent need for tailored policy interventions at the national level and outlines upcoming industry initiatives in this area. The report explains the German Road Safety Council Quality Seal for certifying the quality of practical driving training courses in detail as well. Overall, the report provides concrete policy recommendations to national and European decision-makers, with the aim of improving the road safety outcomes for motorcycle users.

Table B-31. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Virginia Tech Transportation Institute's Center for Advanced Automotive Research	Transportation Institute Uses Connected Technology to Improve Motorcycle Safety	Virginia Tech Transportation Institute's Center for Advanced Automotive Research	2013	Not available online.	This article discusses results from a connected vehicle test that put 43 connected roadside units near Fairfax, Virginia, along Interstate 66, and another 12 along the Smart Road test track in Blacksburg, Virginia. Wireless infrastructure devices were installed near the road to send and receive information from test vehicles, including motorcycles. Vehicles involved in the test were able to send and receive data wirelessly from roadside equipment that could inform transportation officials about crashes, congestion, and other issues. Additionally, drivers could receive information from the roadside that enables numerous applications targeted at improving safety, mobility, and the environment. Vehicles also could share information directly with each other, providing 360-degree awareness about their position, likely trajectory, and speed, which gives drivers warnings about possible crash scenarios. The article discusses that the tested technology was, at the time this article was published, years away from reality for motorcycles.
Shane McLaughlin	Virginia Tech Transportation Institute's (VTTI) Motorcycle Research Group	VTTI	2014	http://www.motorcycle.vtti.vt.edu/	This entry in the literature review covers the ongoing work of VTTI's Motorcycle Research Group, which was founded in 2007 with the objective of applying the multidisciplinary research capabilities at VTTI to real-world motorcycle riding. The group was born out of a history in transportation research, concern over increasing numbers of motorcyclist fatalities and injuries, and the excitement of a surprisingly large number of VTTI engineers, staff, researchers, and family who are riders. The Motorcycle Research Group focuses on the rider and his or her machine, while considering other factors in the surrounding system. VTTI performs research for both public and private clients and currently are conducting our third large-scale study since 2007. With the help of study participants VTTI has collected hundreds of thousands of real-world miles in approximately half the States in the U.S. Study results are posted on the VVTI Web site.

Manufacturing

Table B-32. Search terms.

Search Terms
None

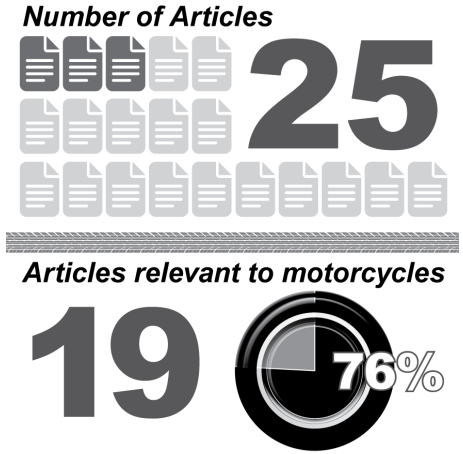


Table B-33. Literature review.

Authors	Title	Journal or Publisher	Year	Link	Summary
BMW Web site	Adaptive Headlight technology—lighting the way	BMW Web site	2011	http://www.bmw-motorrad.com/se/sv/bikes/tour/k1600gt/media/Adaptive_Headlight_technology.pdf	This article from the BMW Web site, discusses how the BMW K 1600 models feature ride height sensors in the front and rear axles that provide data for permanent headlamp levelling, regardless of riding and load conditions, but the optional adaptive headlight actually tilts the headlight according to lean angle, allowing riders to see around a corner as they turn, instead of having to ride into darkness.
BMW Web site	ASC (Automatic Stability Control)	BMW Web site	2015	http://www.bmw-motorrad.com/com/en/index.html?content=http://www.bmw-motorrad.com/com/en/technology_new/item_asc.html&notrack=1	This new item from the BMW Web site provides a manufacturer technology description of automatic stability control (ASC). This technology has been available since 2007. The rider assistance system acts as a traction slip regulator. When required, it effectively reduces uncontrolled spin of the rear wheel. Web site includes video graphic of how ASC works.
WebBikeWorld	BMW Announces Motorcycle Automatic Stability Control System	Web Bike World News	2013	http://www.webbikeworld.com/BMW-motorcycles/stability-control/	This news article describes the release of new technology, specifically automatic stability control, by BMW.
Loz Blain	BMW's Advanced Safety Concept: Moving Towards A Safer Motorcycle	Gizmag	2011	http://www.gizmag.com/bmw-advanced-safety-concept-motorcycle/19119/	This article highlights research efforts on technologies for BMW motorcycles, which may or may not make it to the production line. These technologies include daytime riding light rings, automatic collision notification system, camera-based rider information and assistance system, "connected ride" a V2V application, traffic light phase assistance, bad weather warning, obstacle warning system, emergency vehicle warning system, electronic brake light system, left turn assist, and overtaking assistance.

Table B-33. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Loz Blain	BMW's Advanced Safety Concept: moving towards a safer motorcycle	Gizmag	2011	http://www.gizmag.com/bmw-advanced-safety-concept-motorcycle/19119/	This article, from Gizmag, gives an overview of the Advanced Safety Concept (ASC) that BMW developed in 2011 for its next generation of motorcycles and technologies. The ASC included daytime riding light rings, eCall automatic collision notification, a camera-based rider information and assistance system, and ConnectedRide intelligent assistance systems.
Bosch Rider News	Bosch Introduces Motorcycle Stability Control	Sport Rider Magazine	2013	http://www.sportrider.com/sportbike-news/bosch-introduces-motorcycle-stability-control	This article describes the release of new technology, particularly motorcycle stability control, by Bosch.
News Release	Bosch unveils new safety system for motorcycles	Power Sports Business	2014	http://www.powersportsbusiness.com/news/2014/10/22/bosch-unveils-new-safety-system-for-motorcycles/	This article from industry magazine, Power Sports Business, discusses Bosch's development of Motorcycle Stability Control (MSC) as an all-in-one safety system for motorcycles. Bocsh's MSC was designed to measure key motorcycle data and intervene in critical situations, resulting in improved rider safety.
Texa	Diagnostic Products	Texa Web site	N/A	http://www.texa.com/solutions/bike	This material from the Texa Web site describes diagnostic products (i.e., portable, wireless and Bluetooth technology). These products are available to diagnose different types of motorcycle malfunction.

Table B-33. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Klaus Kompass	Driving Forces	Vision Zero International Magazine	2013	http://viewer.zmags.com/publication/95778ceb#/95778ceb/28	This article from Vision Zero International Magazine describes BMW's motorcycle ABS and head protection airbags. It also provides motorcycle graphics on how ABS is structured on a motorcycle noting that BMW Motorrad was the first motorcycle manufacturer to offer ABS as standard equipment. Klaus Kompass, Vice President of Safety at BMW, is quoted as saying: "From both statistical analysis and my personal experience, I judge… (ABS)… to be one of the best innovations of the past decade."
AFP	Europe's Major Motorbike Firms Go High-Tech to Cut Accidents	Hindustan Times	2014	Not available online.	This article discusses the "Safe Ride to the Future" initiative, announced by the European Association of Motorcycle Manufactures (ACEM) at the 10th International Motorcycle Conference in Cologne, Germany. This initiative details a holistic approach to reducing the number of bike-related accidents via a combination of technology, training, education, and infrastructure investment. By enabling vehicles to communicate with each other, either via the Wi-Fi spectrum or a 3G or 4G cellular connection, collisions can be avoided or warnings about adverse local conditions can be shared automatically. The technology also enables elements of infrastructure, such as traffic lights, to interact with vehicles to reduce congestion and boost fuel economy.

Table B-33. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Honda	Honda Demonstrates Advanced Vehicle-to-Pedestrian and Vehicle-to-Motorcycle Safety Technologies	Honda News	2013	http://news.honda.com/newsandviews/article.aspx?id=7352-en	This article discusses two experimental safety technologies developed by Honda that are aimed at reducing the potential for collisions between automobiles and pedestrians and between automobiles and motorcycles. These advanced Vehicle-to-Pedestrian (V2P) and Vehicle-to-Motorcycle (V2M) technologies, while still in the research and testing phase at the time this article was released, demonstrate Honda's vision to advance safety for all road users, including pedestrians and motorcycle riders, as well as automobile occupants. These new technologies are part of a comprehensive effort undertaken by Honda to develop leading-edge safety and driver assistive systems that can help predict and avoid traffic accidents through advanced sensing and communications technologies.
Honda	Honda's Approach to ITS	Handouts from the ITS World Congress in Detroit, Michigan	2014	Not available online.	These advertising materials from Honda, distributed at the ITS World Congress in Detroit, Michigan, describe Honda's ITS research projects. Projects include Vehicle-to-Motorcycle cooperative safety applications (in conjunction with UMTRI). A demo in the exhibit hall highlighted a fully equipped motorcycle with DSRC wireless communication abilities.
Dräger	Ignition Interlock Devices (IID) and Services from Dräger	Dräger Web site	N/A	http://www.dsdi4life.com/interlock-xt/participants/	This material from the Dräger Web site states that ignition interlock devices (IID) can help motorcyclists by supporting sober driving. There were, at the time these materials were released, various Dräger interlock models. Dräger made this technology available for motorcycles, automobiles, boats, and other modes.

Table B-33. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Honda	Motorcycle Airbag System	Honda Web site	N/A	http://world.honda.com/MotorcycleAirbag/introduction/index.html	This material from the Honda Web site gives a manufacturer description, development progress, and crash test results of Honda's Motorcycle Airbag System. Honda designed passive safety measures (such as airbags and body protectors) to help protect riders in the event of an accident, as part of Honda's ongoing safety research and development efforts.
Bosch	Motorcycle stability control	Bosch—Technology for two-wheelers	N/A	http://www.bosch-motorcycle.com/en/de/fahrsicherheit_fuer_zweiraeder/sicherheitssysteme_fuer_zweiraeder/motorrad_stabilitaetskontrolle/motorcycle_stability_control.html	This material from Bosch describes Bosch's motorcycle stability control system, which constantly measures all key motorcycle data: wheel speed, lean angle, pitch angle, acceleration, braking pressure, and more. This data allows for the recognition of and intervention in critical situations, thereby preventing motorcycle wheels from locking when braking, stopping the wheels from spinning out, mitigating damage from the rear wheel lifting, and making sure that the front wheel stays on the ground. The system also ensures that braking force is distributed optimally over both wheels.
Continental Automotive Group	Optimized Curve Braking—New Function by Continental Provides Motorcycles with More Stability	Continental Automotive Group	2014	http://www.continental-corporation.com/www/pressportal_com_en/themes/press_releases/3_automotive_group/chassis_safety/press_releases/pr_2014_11_13_optimiertes_kurvenbremsen_en.html	This is a press release from the manufacturer Continental, detailing its Motorcycle Integral Brake (MIB) system, which was enhanced in 2014 by the addition of a new function: the optimized curve braking—for safer braking in curves. The function went into series production in the new BMW S 1000 XR motorcycle in early summer of 2015.

Table B-33. Literature review (continuation).

Authors	Title	Journal or Publisher	Year	Link	Summary
Morgan Peck	Skully Motorcycle Helmet Has Heads-Up Display and Rearview Camera	IEEE Spectrum	2014	http://spectrum.ieee.org/tech-talk/transportation/safety/skully-motorcycle-helmet	This article details the motorcycle helmet known as the Skully AR 1 helmet—which the company called "the world's smartest motorcycle helmet." The design of this helmet provides all the information a rider needs in a heads-up display in the visor.
Honda Motorcycles	The World's First Production Motorcycle Airbag System, Designed to Help Lessen the Severity of Injuries to the Rider in a Frontal Collision	Honda Web site	N/A	http://world.honda.com/motorcycle-picturebook/Airbag	This article discusses Honda's motorcycle airbag system. This system employs tether straps that anchor the airbag to the motorcycle frame for support. This results in the development of an oversized, V-shaped airbag that offers increased stability as the rider encounters it. Honda unveiled its production motorcycle airbag technology in 2005, followed by the release in 2006 of the Gold Wing Airbag, a production bike equipped with the world's first motorcycle airbag.
Press Release	Volvo Cars and POC to demonstrate life-saving wearable cycling tech concept at International CES 2015	Volvo Web site	2014	https://www.media.volvocars.com/us/en-us/media/pressreleases/155565/volvo-cars-and-poc-to-demonstrate-life-saving-wearable-cycling-tech-concept-at-international-ces-201	This press release from Volvo describes a new car/bike connected technology. The technology consists of a connected car and helmet prototype that establishes two-way communication offering proximity alerts to Volvo drivers and cyclists to avoid accidents.

Appendix C. Practitioner Interview Questions and Discussion Guide

The practitioner interviews were guided by a preformed set of questions tailored to each practitioner group: Manufacturers; State DOTs and Public Safety Agencies; Academia; and Industry Associations and Research Organizations. The preformed set of questions for each practitioner group are included in this appendix, below. The interviews, however, did not strictly follow the guiding questions and allowed the interviewees to freely discuss their perspective of the categories of investigation and other technology and safety issues related to motorcycles at any point during the interview.

Manufacturers

Do you have a division that specifically looks at motorcycle technology as it may relate to communicating with roadside infrastructure (V2I), or interface with DOT systems? How do you engage with public agencies (i.e., DOT) to inform your research?

Do you have a division that researches technology for motorcycles to communicate with other vehicles, either motorcycles or vehicles (V2V)? How do you engage other manufactures to inform your research?

What safety systems have been most successful in terms of buyer awareness?

What information technology systems have been most successful in terms of buyer awareness?

Is there a research agenda for motorcycle technology separate from other vehicle technology?

What research is needed to address specific motorcycle safety and technology?

We sent you a list of forty “categories of investigation” that are foundational to our research. Of these categories, which are, in your opinion, specific to manufacturers:

- Which topical areas are flourishing in the manufacturing world?
- Which topical areas are interesting, but not currently in the purview of manufacturers?
- Which are the lowest priority areas on this list? (i.e. irrelevant in the next 20 years)

What are the current motorcycle ITS trends, and what trends do you anticipate might be right around the corner?

Are there other stakeholders we should be talking to?

What bottlenecks exist in advancing the research?

State Department of Transportations and Public Safety Agencies

Does your DOT have a division that specifically addresses motorcycle travel on the roadways, as it relates to safety and technology? Separating the pure "safety" programs that exist within the DOT for motorcycles, are there any research efforts looking at technology systems unique to motorcycles? For the research that occurs in the traditional Intelligent Transportation Systems/ Connected Corridors program, are there any focus areas unique to motorcycling? Are motorcycles considered as part of the larger picture?

As Vehicle-to-Infrastructure (V2I) advance within the DOT landscape, what roadway design elements would most apply to motorcycles?

What research is needed to address specific motorcycle issues within a DOT?

Do you see any trends in the DOT for motorcycle ITS?

What research is needed to address motorcycle issues from a public safety perspective (specific to technologies, i.e. not driving under the influence or without licenses/training)?

We sent you a list of forty "categories of investigation" that are foundational to our research. Of these categories, which are, in your opinion, specific to the DOT:

- What topic areas hold the most promise for improving motorcycle safety?
- Of these areas which have an established progression for adoption, which are on the horizon, which need more attention?
- What motorcycle ITS research is needed in the industry/community?

Are you aware of any other State DOTs leading the charge for ITS deployments that have motorcycle ITS specific elements?

Are there other stakeholders we should be talking to?

What bottlenecks exist in advancing the research?

Academia

What transportation research areas hold the most promise for improving motorcycle safety?

- Of these areas which have an established progression for adoption, which are on the horizon, which need more attention?

What motorcycle ITS research is needed in the industry/community?
What topical areas –related to transportation, motorcycles, ITS, and technology - are flourishing in the research world?

Besides your university, what other research entities are out there doing important research in this area?

What are the important issues, ITS solutions, and potential implications for improving safety in the motorcycling industry/community?

We sent you a list of forty "categories of investigation" that are foundational to our research. Of these categories, in your opinion which topic areas reside in the university research space?

What hinders this general area from being researched at the university level?

Are there other stakeholders we should be talking to?

What bottlenecks exist in advancing the research?

Industry Associations and Research Organizations

We sent you a list of forty "categories of investigation" that are foundational to our research. Of these categories, in your opinion which topic areas reside in the industry association research space?

- What topic areas hold the most promise for improving motorcycle safety?
- Of these areas, which have an established progression for adoption, which are on the horizon, which need more attention?
- What motorcycle ITS research is needed in the industry/community?
- What topical areas are flourishing in the research world?

What industry trends do you see (or hear about from your members) specific to motorcycles and ITS?

What are the hot topics of interest—for instance, topics that your members might see in a research program, but not on the market yet?

Who do you look to learn about current research in advancing motorcycle safety and technology?

Are there other stakeholders we should be talking to?

What bottlenecks exist in advancing the research?

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