7

Mobility and Safety of Powered Two-Wheelers in OECD Countries

The objective of this chapter is the analysis of powered two-wheeler (PTW) mobility and safety in the OECD countries, and the presentation of measures for the improvement of PTW mobility and safety. This research work was carried out by a working group of the OECD International Transport Forum, composed of experts from several countries. PTW use, mobility and safety figures are examined in terms of their development over time and their distribution per road user and vehicle characteristics. Moreover, contributory factors of PTW road accidents and injury risks are discussed, as well as PTW accident patterns, on the basis of an exhaustive review of international literature. On the basis of the results, a number of measures are discussed, including licensing, training and education, enforcement, traffic and speed management, vehicles and ITS, infrastructure, protective devices and conspicuity. Most importantly, improving PTW safety is compatible and should be integrated with the development of a safe system approach, and requires a toolbox of measures, which includes the safer behavior of all road users, safer infrastructure and vehicles with enhanced safety features.

7.1. Introduction

Significant growth in motorcycling has occurred during recent decades in most parts of the world [HAW 12], resulting in the powered two-wheelers (PTW) gradually becoming a true mobility tool, attracting an increasingly vast and varied population. Some riders use PTWs as their primary form of transportation, others for recreation. For many it is the only affordable or practical means of individual motorized mobility. The use of PTWs continues to grow globally each year in

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conjunction with multiple economic and social factors contributing to their expansion worldwide, such as increased traffic congestion and inner-city parking problems, increases in gasoline prices, the development of leisure, changes in lifestyle, etc. [SHI 12].

The result is that in spite of a remarkable improvement in traffic safety for all road users (including motorcyclists) in OECD countries, motorcyclists have seen their exposure to road risk increase to the point that in some countries the number of motorcyclists who died in road crashes actually increased over the past two or three decades [SHI 12], while the mortality of other road users declined significantly.

PTW riders are at far more risk than car drivers per kilometer ridden in terms of fatalities and severe injuries entailing long-term disability. The share of PTW fatalities is often much higher than their share in the vehicle fleet, especially in low- and middle-income countries.

Regardless of the countries concerned, however, PTW users are confronted with an excessive risk on the road, which has been qualified as "unfair" by Elvik [ELV 09], insofar as for the same number of kilometers driven they have a much higher risk of being killed or severely injured than car occupants. They are clearly overrepresented among road traffic casualty figures, even when they are not overrepresented in crash occurrences.

In this context, the objectives of this chapter can be outlined as follows:

– to review and summarize the most recent knowledge dealing with motorcycling safety;

– to review and summarize the current understanding of motorcycle crash configurations and mechanisms;

– to provide recommendations on measures that can be implemented in the short and medium term to improve the safety of motorcyclists;

– to progress toward a safe system approach for PTWs.

This research was carried out by a working group of the OECD International Transport Forum, composed of experts from several countries. The chapter starts by presenting the basic trends and figures of PTW mobility, use and safety. Then, a comprehensive review of PTW crash contributory factors is presented (user-, vehicle- or infrastructure-related). Subsequently, the integration of PTW in the Safe Systems approach is discussed, with particular focus on the challenges and particularities involved. Finally, the most promising individual measures for the improvement of PTW mobility and safety are outlined.

7.2. Mobility and safety figures of PTWs

7.2.1. *PTW mobility and use*

It is estimated that there are 313 million PTWs in the world, with a relatively uneven distribution across regions: 77% are found in Asia, 5% in Latin America, 1% in Africa, 1% in the Middle East and 16% in North America and Europe [ROG 08]. This disparity is also characterized by the uses made of this mode. Primarily recreational in North America and Australia, the two-wheeler does have a much more mixed function, for example, in Europe it is increasingly used to escape the problems of urban traffic congestion; in other regions of the world it may have a mainly utilitarian use.

In most OECD countries, over the past decade (2001–2010), the motorcycle fleet has grown much more rapidly than the passenger car fleet (see Table 7.1).

	Passenger cars	Mopeds	Motorcycles
Australia	25%	–	88%
Czech Republic	29%	10%	35%
France	11%	−22%	48%
Great Britain	13%	−27%	28%
Greece	52%	−14%	76%
Japan	11%	−20%	14%
Spain	22%	27%	82%
Sweden	8%	84%	91%
United States (excl. SUVs)	5%	–	67%

Table 7.1. *Evolution (%) in the PTW and passenger car fleets for a selection of OECD countries 2001–2010 (source: IRTAD)*

PTWs are becoming an important component of the transport system and represent in some cities up to 30% of the motor vehicle fleet [ACE 13]. They present both assets for mobility, and also challenges in terms of traffic management and safety. However, only a few countries have in place a national transport strategy for PTWs (e.g. [DFT 05, VIC 08]), though several measures may be taken at the local level.

7.2.2. *Safety development over time*

While there has been significant progress in most OECD countries in improving road safety and reducing road mortalities, PTW riders have not benefited at the same pace as car occupants from safety improvements over the last decade (see Figure 7.1).

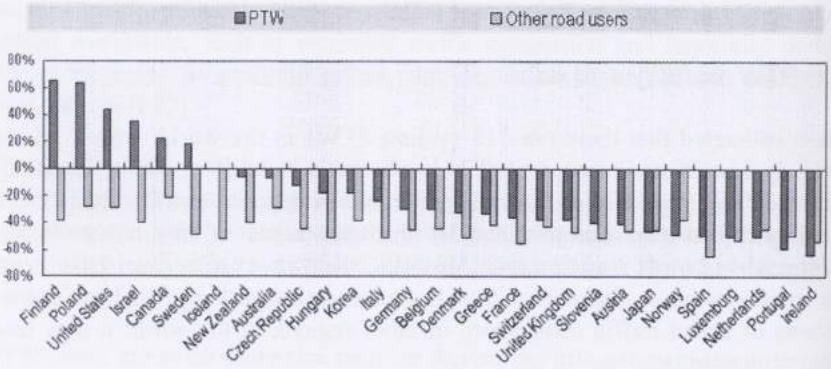

Figure 7.1. *Evolution in fatalities among PTW and other road users, OECD countries, 2001–2011 (source: IRTAD, 2001–2010 data for Canada)*

In fact, the situation of motorcyclists has deteriorated in the past decade if one compares with the significant progress with other road users. PTW trends are not following the overall fatalities decrease in the OECD countries; this may be explained by the high increase in PTW fleet and respective mobility, as PTWs have been steadily gaining in popularity in recent years, with large gains seen in PTW ownership and ridership. PTW is the only mode of transport for which the number of fatalities has increased, significantly in some countries, over the last decade, which stresses the importance of taking immediate appropriate counter measures.

7.2.3. *Crash characteristics and scenarios*

When related to the number of kilometers travelled, a motorcyclist is, depending on the country, between 9 and 30 times more likely to be killed in a traffic crash than a car driver (see Table 7.2).

On average, in OECD countries, PTW riders and passengers count for 16.5% of all road fatalities, while only representing 8% of the fleet. PTWs are clearly overrepresented in road traffic casualties. The situation in developing countries is drastically worse. In total, 90% of global deaths occur in low- and middle-income countries.

In many countries, the average age of motorcyclists killed has increased. In Europe, the number of motorcyclists killed in the 40–60 years age group has doubled in 10 years [YAN 10, NHT 12]. The fatality rates for moped riders aged 15–19 and motorcycle riders aged 20–30 are notably high. It appears that being

young, male and lacking experience is associated with increased PTW fatality risk [YAN 05, LAR 05, REE 95].

	Car occupant	Motorcyclists	Mopeds (when distinction is made in statistics)	Relative risk of motorcyclists vs. car occupants
Australia	5.2	71.8		14
Austria (2010)	4.7	59.7	56.1	13 for motorcyclists
				12 for mopeds
Belgium (2010)	5.9	76.9		13
Canada (2010)	4.9	62.9		13
Czech Republic (2010)	10.5	252.6		24
Denmark	4.2	49.5		12
France	4.9	72.4	64.7	15 for motorcyclists
				13 for mopeds
Germany	3.3	59.5	14.6	18 for motorcyclists
				4 for moped
Ireland	2.5	60.8		24
Israel (2010)	5.1	45.7	26.8	9 for motorcyclists
				5 for mopeds
Netherlands (2004–08)	3.0	64	63	21
Slovenia	4.3	112.5		26
Sweden (2010)	2.2	43.9		20
Switzerland	2.3	39.2	29.6	17 for motorcyclists
				12 for mopeds
United States	5.0	150.6		30

Table 7.2. *Deaths per billion veh-km in 2011 for motorcyclists and car occupants (source: IRTAD)*

A large majority of PTW crashes are single vehicle crashes occurring on rural roads; 25% of all PTW crashes in Italy, 38% in Greece and 44% in Finland and Sweden [2BE 10]. Almost one-third of all PTW fatalities occur at junctions – a proportion notably higher compared to other road users (ACEM 2006, [YAN 10]). This stresses the importance of taking specific counter measures for junction safety improvement for PTWs.

7.3. Contributory factors of PTW crashes

The level of risk for PTW is influenced by many factors. A first general factor is the intrinsic difficulty of driving a PTW, due to the necessity to control the balance, its lower friction capacity and its greater sensitivity to environmental perturbations (wind, gravel, any change in road surface, etc.) which may destabilize the vehicle. PTW riders also have a higher risk of injury due to their greater vulnerability, resulting from a lack of protection compared to passenger cars.

Elvik [ELV 04a] has defined some basic factors which influence the level of risk of road accidents. Among these risk factors some are considered to affect PTWs more specifically, such as low friction (as mentioned above), but also lack of visibility, road-user rationality, road-user vulnerability and system forgiveness.

Moreover, by its very nature, driving a PTW may induce a specific behavior pattern on the road which is different from the drivers of four-wheeled vehicles. Such behavior is not necessarily "deviant" according to the law, but may surprise other road users. Even "normal" behavior, i.e. common to PTW riders, may be atypical for other vehicle operators (e.g. overtaking within a small space, overtaking on the right, filtering, positioning on one side of the road, intense acceleration, etc.), disturbing their normally efficient information-seeking routines. Atypical behavior also refers to "deviant" behavior, including speeding, slaloms, stunts, wheeling, etc.

Generally speaking, driver- and rider-related behavior factors are much more prevalent in PTW crashes, compared to vehicle and road infrastructure/environment factors. Speeding is a bigger problem for PTW crashes, compared to other modes. On average, motorcyclists ride at higher speeds than cars and PTW crashes usually occur at higher speeds compared with cars [HOR 05]. Similarly, consumption of alcohol is associated with an increased risk of fatal crashes among PTWs [KAS 05]. Moreover, for the same BAC, the severity of the crashes is higher for the PTW than for the other road users [MCL 93, SOD 95]. Operating a PTW requires more co-ordination and balance than operating a car, which explains that impaired riding (e.g. by alcohol or drugs) or inappropriate behavior (e.g. speeding) is even more problematic for PTW riders.

Vehicle technical failures are only a minor proportion of PTW road crash contributory factors. On the other hand, for PTWs, road design and road environment factors have a significant influence on the crash severity (e.g. roadside obstacles and barriers, speed reduction installations) even more than on crash occurrence [ACE 06]. However, PTWs are specifically sensitive to infrastructure design (e.g. alignment, curves, intersections, etc.) and maintenance (holes, gravels, vegetation, etc.). Due to this sensitivity, defects on the layout are likely to create more difficulties on PTW riders than on operators of other motorized vehicles.

A large number of crashes involve a problem of perception/appraisal by the other vehicle operator. This overrepresentation of inappropriate perception in PTW crashes suggests a specific problem of detectability (conspicuity) for these road users [PRE 95, YUA 00]. The problem of perception is complex and cannot be reduced to the simple fact that PTWs are physically less visible than other vehicles. There are many causes behind the poor detectability of PTWs and these are often connected to each other and with the general parameters of the driving context. Indeed, this problem can be explained both by the visual characteristics of PTWs, by the sensory capabilities of the human perceptual system, by the atypical behavior of PTWs and by the expectations that road users develop.

It is also noted that a more frequent combination of road crash contributory factors is found in PTW crashes, compared to other road users' crashes, which results in the multiplication of the relative risk. For example, it has been found that those without a valid license have a higher probability of not wearing a helmet, driving above the speed limit, driving under the influence of alcohol and without daytime running lights and so on ([PEE 96, REE 96].

Although human behavior and characteristics are the most frequently represented contributing factors in crashes, this does not mean that the solution to improve safety conditions for PTWs must only focus on behaviors. A safe system approach is required; it can be more efficient to change behavior by acting on a range of levels, including the infrastructure, the vehicle and the system as a whole. However, the integration of PTWs in a safe systems approach may be challenging in several ways; these are discussed in the next section.

7.4. Toward an integrated road safety strategy for PTW

7.4.1. *The safe systems approach*

The safe system is variously described in a number of jurisdictions but has a single core principle: a recognition that road users will make mistakes, or inappropriate decisions, and that the system, while also minimizing errors, should accommodate these errors so that no individual road user is exposed to crash forces likely to result in death or serious injury. The system then manages their safety by providing them with vehicles, road and roadside infrastructure and travel speeds that combine to ensure that any crashes that do eventuate result in crash forces that are below the level of human tolerance to physical harm.

Another characteristic of safe system approaches is consideration of the interactions between the different elements of the system and between the effects of different interventions. Some aspects of this are well recognized, for example, the

influence of road design on chosen travel speeds. The challenge is to optimize the protection by combining the components of the road traffic system.

According to the recommended approach of the OECD's Towards Zero – Ambitious Road Safety Targets and the Safe System Approach [OEC 08], a strategic planning process on the basis of the Safe Systems approach principles can be outlined as follows:

– situational analysis: conduct sufficient data collection and analysis to understand crash risks and current performance;

– define strategic objectives: adopt a highly ambitious vision for road safety, set interim targets to move systematically toward the vision, develop a Safe System approach, essential for achieving ambitious targets;

– determine strategies and actions: exploit proven interventions for early gains, invest in road safety;

– establish supporting arrangements: strengthen the road safety management system, accelerate knowledge transfer, foster commitment at the highest levels of government.

7.4.2. *PTWs in the safe system*

Growing PTW traffic makes it imperative to adopt safety interventions targeting this mode of transport, while integrating it into a safe system approach. According to the above, improving the safety of PTWs should be a shared responsibility. All relevant stakeholders need to be actively involved in the process of drawing up and implementing a shared road safety strategy which includes safer behavior of all road users, safer infrastructure and vehicles with enhanced safety features.

A strategic approach should consider the most effective combination or measures according to the specific needs of individual jurisdictions. Several OECD countries do have strategic plans for PTW safety, although not always involving specific strategic objectives, quantitative targets, specific evidence-based measures to achieve the targets etc. (e.g. [DFT 05, DGT 07, RIJ 11, TRA 10, VIC 08])

The inclusion of motorcyclists into the Safe System yields two challenges. The first is the technical problem of providing protection from physical harm at the speeds at which collisions with other vehicles or fixed objects are likely. While this could be solved by ensuring travel speeds by, and in the vicinity of, motorcyclists are much lower, this then amplifies the second challenge. This is to ensure that any measures taken to improve motorcycle safety are supported both by the broader community and by motorcyclists in particular.

This leads to consideration of whether the conventional Safe System approach should be modified by recognizing that, in the short to medium term, motorcycling will remain an inherently risky activity and that measures should be taken to reduce risk. This may result in, for example, strategies that focus more on avoiding crashes, rather than mitigating their effects.

A toolbox of measures is required to improve the safety of PTW riders within the traffic system. These measures must take into account the specific challenges of PTW traffic, and also consider the variety of PTW users, insofar as some segments may be addressed with particular measures.

7.5. Measures for PTW safety improvement

The Safe System approach assumes that road users will enter the system competent and will take measures to ensure that they remain compliant and alert. Licensing, training, education, enforcement and communication campaigns are essential tools for improving riding safety. It is also important, in a complementarily way, to enhance the road environment and the vehicles toward this safety objective.

7.5.1. *Licensing, training and education*

Access to PTWs should be gradual, with a licensing system aiming at managing novice rider risks while riders are gaining experience and maturity [REE 95].

Novice riders of every kind of PTW should be trained. Training should not only focus on basic maneuvering skills and mastering traffic situations, but also address attitudes toward safety, putting a special emphasis on hazard perception and defensive riding [KAR 10].

Other road users should also be made aware of the specific risks associated with PTW vulnerability and crash patterns. Communication campaigns addressing required behavior change should be targeted at key groups of drivers and riders.

7.5.2. *Enforcement and communication*

Enforcement of traffic rules is an indispensable ally of other safety measures [ELV 04b] to promote homogeneous and safe traffic behavior between all road users. PTW operators, as other operators of motorized vehicles, must comply with traffic rules and typical enforcement activities, to control speeding, drinking and driving, non-respect of traffic rules, etc.

Traffic rules apply equally to operators of two- and four-wheeled vehicles and should be equally enforced. As for other motorized vehicle users, enforcement is needed to improve compliance with key safety rules like speed, drinking and driving, helmet use, proper licenses and a vehicle that meets safety standards. High-visibility enforcement accompanied by other measures, such as communication and publicity has proven to have a strong deterrent effect. Speed enforcement is key to reducing the speed and associated crash risk. Automated speed enforcement has proven its effectiveness for cars, but further adjustments are needed to make it as effective for PTWs.

The combination of enforcement-communication campaigns (on speeding, riding without a helmet and other risky behavior) has proven its effectiveness in many countries [HEN 08]. The success of enforcement and communication strategy depends on the involvement of motorcyclists themselves and motorcyclists associations have an important role to play in the diffusion of communication messages, informing riders about the rules and making enforcement acceptable.

7.5.3. *Infrastructure and traffic management*

Road and traffic management have traditionally been designed for four-wheeled vehicles. In some cases, these are not properly adapted for PTWs. Much could be done to facilitate the mobility and safety of PTWs, without compromising the mobility of other motorized vehicles.

Infrastructure should be improved with the development of self-explaining roads to guide drivers and riders to adopt appropriate speeds, traffic calming measures and PTW friendly equipment (forgiving roads), targeted at areas of highest PTW risk [ACE 06].

Engineers, road designers, road safety auditors and inspectors should be trained to consider PTWs in the design, maintenance and operation of roads, and be provided with the necessary risk assessment tools to make the right decisions. Local authorities' staff should be trained and informed on the infrastructure requirements for PTWs to compensate for the safety problems to which they are specifically subject.

Traffic management measures can have a dual purpose: facilitating PTW traffic and increasing safety. Further research is needed on the safety impact of measures such as advanced stop lines and traffic filtering. When implementing any new measure in favor of PTW mobility, caution must be paid that no new risk is induced for themselves or for any other road users.

7.5.4. *Vehicles, ITS and protective devices*

There are a number of developments within the motorcycle industry to improve the passive and active safety of motorcycles.

The anti-lock braking system (ABS) is a well proven technology which can significantly improve the safety of PTWs in certain situations [RIZ 09]. While it is currently offered as an option on new high-end bikes of major PTW manufacturers, with a slow penetration rate in most OECD countries, it can certainly benefit all powered two-wheelers and should become a standard. Cost is however an issue, and industry and government should work together to facilitate a quicker penetration of these technologies, which anyway will become mandatory in some regions in the coming years (expected in EU for the years 2016–2017). Other advanced braking systems may also help in reducing injury risk, but the priority today is to keep ensuring the penetration of ABS in the fleet.

There has been little advancement of intelligent transportation systems research dedicated to motorcycle safety. Motorcycle ADAS (Advanced Driver Assistance Systems) could improve the safety of the rider as well. There is however a number of obstacles that will likely lead to a slower uptake compared to passenger cars, including the challenges posed by the Human Machine Interface requirements, costs and the required support from the motorcyclists community. In spite of these obstacles, ITS has a role to play to increase motorcycle safety in the future. e-Call, blind spot detection, curve and collision warning systems are suitable applications for the motorcycle – once sufficiently developed for them.

While research into the benefits of protective clothing is unequivocal [DER 11, ACE 06], there are rider willingness-to-pay issues with mandatory requirements for protective clothing. Further research and development into clothing and equipment with lower weight and improved ventilation should be encouraged.

The helmet is the most important source of protection against severe injuries for both motorcyclists and moped riders [LIU 07]. The use of helmets and other protective equipment with adequate safety standards should be promoted and regulated where required.

7.6. Key messages and recommendations

The OECD/ITF group on PTW mobility and safety proposed a number of key messages and recommendations, which are summarized in Table 7.3, and analyzed below.

Key messages and recommendations	
1)	The powered two-wheeler population increases and plays a significant role in mobility
2)	PTW riders are at far more risk than car drivers
3)	PTW crashes are mainly due to perception and control failures
4)	A safe system approach is required to improve the safety of PTWs
5)	A toolbox of measures is required to improve the safety of PTW riders
6)	Promoting appropriate behaviors of road users is a prerequisite
7)	Self-explaining and forgiving roads contribute to lower crash risk
8)	Protective equipment and vehicles with enhanced safety features save lives
9)	It is essential to extend the knowledge on PTW mobility and crash mechanisms

Table 7.3. *Key messages and recommendations on PTW mobility and safety*

Motorcycling has become an integrated part of the traffic system offering certain benefits over other modes of transport; consequently, they need to be properly integrated into mobility plans and safety strategies. As the economic costs associated with PTW crashes are significant, investing in PTW safety can bring important societal and economic benefits.

However, PTW safety figures have not followed the impressive improvement trends of the last decade that other users' safety figures demonstrate. Moreover, per kilometer driven, PTW riders have a much higher risk of being killed than car occupants, between 9 and 30 times higher. PTW riders are also more likely to be very seriously injured in a road crash with long term disabilities than other motorized road users. They are also more vulnerable to impairment by e.g. alcohol.

Young, inexperienced and male riders are over represented in crashes. The most frequent PTW fatal crashes are single-vehicle crashes, partly due to intrinsic difficulties of riding a PTW (e.g. necessity to keep the balance) and to the higher sensitivity of riders to external perturbations (e.g. wind or poor pavement condition). The other most frequent crash type occurs at intersections with other traffic, involving, for a large number of crashes, a problem of perception and appraisal by the driver and/or the rider.

A safe system approach is proposed for improving PTW mobility and safety in OECD countries; it can be more efficient to change crash and injury outcomes by implementing a range of interventions, including road users, infrastructure, the vehicle and the system as a whole, i.e. their interactions. The implementation of this approach involves dealing with a number of challenges in balancing the different

objectives of the safe system design with the PTW particularities and needs. In each case, a selection of specific measures for implementing the strategy will be required.

Priorities in individual measures may include:

– promoting appropriate behaviors of road users (licensing, training and education, enforcement of traffic rules, communication campaigns addressing required behavior);

– self-explanatory and forgiving roads (roads to guide drivers and riders to adopt appropriate speeds, traffic calming measures and PTW friendly equipment, training of engineers and local authorities etc.);

– protective equipment and vehicles with enhanced safety features (use of helmets and other protective equipment with adequate safety standards, enhanced safety features in vehicles, notably with the general introduction of advanced braking systems, etc.).

Additional research is needed to better understand current challenges related to PTW mobility and safety problems. This involves a need to develop and apply relevant methods, tools and indicators to measure PTWs in traffic flows and analyze their mobility and behavior (exposure data). More in-depth investigations will allow a better understanding of fatal and serious injury crash patterns and causes. Conspicuity and other perception problems deserve further study in order to identify key contributing factors and effective countermeasures.

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