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Road Speed: Health Impact and Counteractive Measures

Scientific Review

INSTITUT NATIONAL DE SANTÉ PUBLIQUE DU QUÉBEC

Québec

ROAD SPEED: HEALTH IMPACT AND COUNTERACTIVE MEASURES

SCIENTIFIC REVIEW

DIRECTION DÉVELOPPEMENT DES INDIVIDUS ET DES COMMUNAUTÉS

SEPTEMBER 2008

Institut national
de santé publique
Québec

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The translation of this report was made possible by the National Collaborating Centre for Healthy Public Policy.

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LEGAL DEPOSIT 3RD QUARTER 2008
BIBLIOTHÈQUE ET ARCHIVES NATIONALES DU QUÉBEC
LIBRARY AND ARCHIVES CANADA
ISBN: 2-550-46109-6 (FRENCH PRINTED VERSION)
ISBN: 2-550-46110-X (FRENCH PDF VERSION)
ISBN: 978-2-550-54077-9 (PRINT VERSION)
ISBN: 978-2-550-54078-6 (PDF)

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ACKNOWLEDGEMENTS

The writing of a summary, while it is a solitary undertaking, requires the collaboration of several people. I have benefited from these generous advisors, who have recommended studies, questioned interpretations, improved wordings and offered comments with their rigour and knowledge.

At the Institut national de santé publique, I would like to thank, in particular, Pierre Maurice, coordinator of the *Sécurité et prévention des traumatismes* unit in the *Direction du développement des individus et des communautés* for his constant support and valuable, judicious comments. Claude Bégin's contribution as a reader and advisor both for the writing part and for his expertise in scientific review has unquestionably enhanced the finished product, as have the continuous enlightening comments made by Michel Lavoie.

I would like to thank Claude Bégin from the *Direction de santé publique de Lanaudière*, Claude Dussault and Marie-Claude Joly from the *ministère de la Santé et des Services sociaux* for their advice on the report's table of contents.

The following individuals agreed to serve as readers for the external review committee: Maxime Brault from the *Société de l'assurance automobile du Québec* (SAAQ), Guy Paquette from Université Laval and Carl Bélanger from the *ministère des Transports du Québec* (MTQ). They were asked to validate the report's scientific dimension, but not to endorse its conclusions. I am grateful to them for their attentive examination, the stimulating discussions that ensued, and the comments submitted to me.

I am also grateful to collaborators who shared their knowledge or sent documents or references, including Jean-Luc Marret, François Tardif, Claude Dussault and Guy Paquette. My thanks, as well, go to Rob*ert Jacob and Geneviève Lapointe at the Institut national de santé publique du Québec* for their support in this application of section 54.

Linda Bairstow from the Direction de santé publique de la Montérégie and Manon Dussault from the Institut national de santé publique du Québec are responsible for the layout of the report.

SUMMARY

Speeding is a widespread phenomenon and is not confined solely to a small group of delinquent drivers: between 50% and 80% of Québec drivers exceed the legal speed limit. The problem is equally rampant in cities, on rural roads and highways. Excessive speed does not refer solely to driving well over the posted speed limit[1] or very fast[2], which are rather marginal phenomena. The problem's source is, by and large, from less extreme but more frequent excess speed.

Despite more frequent issuing of speeding tickets in Québec, drivers perceive the risk of being arrested as low. Little systematic, sustained intervention has been implemented to date to counteract speeding, as has been the case to counteract drinking and driving, a comparable problem.

Health issues

The international literature has thoroughly demonstrated the link between the speed of motor vehicles and the risk of collision and injury. Indeed, speed is a contributory factor in all cases of mortality and morbidity. A law of physics explains this situation: the transfer of energy absorbed by the body on impact is the sole cause of injuries. The amount of energy transferred increases exponentially with speed.

In Québec, the burden on victims of road collisions accounts on average for roughly 700 deaths and 6 000 hospitalizations a year. Speeding appears to directly cause between 30% and 50% of fatal collisions and 25% of collisions causing serious injury. In terms of mortality alone, speeding would create a deficit equivalent to the annual number of births in two cities such as Rimouski and Drummondville.

Speeding aggravates the adverse effects of pollutants in the environment generated by transportation. In the United States, airborne emissions of the main contaminants increased when driving speeds rose.

Similarly, because it generates insecurity, speeding curtails walking and cycling, which are acknowledged to protect individuals against certain chronic diseases.

The choice of speed is a shared responsibility

Vehicles, road environments and legislation are factors that influence the speeds that drivers choose. Automobile manufacturers are allowed to produce, advertise and sell vehicles that can reach speeds well above speed limits. The construction of wide, straight, unencumbered roads encourages speeding. Less stringent legislation and less systematic enforcement of the law in terms of speeding compared to drinking and driving weaken the message that "*Speed kills*". With so many incentives to break the law, the decision is left to drivers to

1 ≥ 15 km/h above the legal speed limit.

2 ≥ 130 km/h in a 100-km/h zone.

comply with the speed limit, under threat of penalty. The speeds that drivers adopt stem from shared responsibility between the state, which adopts laws and regulations, the industry, and users.

Counteractive measures

Under the injury prevention approach, priority measures rely on the effectiveness of interventions in preventing, limiting or mitigating the accumulation and transfer of energy. Because they are all geared to this objective, it is passive technical enhancements such as airbags, seatbelts, and bicycle and motorcycle helmets that have contributed the most to reducing the number of victims, according to the European Council for Transportation Safety[3].

An examination of measures aimed at reducing speed and injuries leads us to the same conclusion regarding passive technical enhancements.

The speed limiter[4] is regarded as the most promising technology to reduce speed and the number of injuries once a sufficient number of vehicles are equipped with the device. Indeed, it would make other measures obsolete. However, as is true of any innovation, this innovation must be implemented gradually. It is anticipated that it could become compulsory in 10 to 15 years in England and Sweden.

Its optimal effectiveness is due to its ability to reduce speed on the entire road network at all times once the device is installed on vehicles. The speed limiter is also credited with having a positive environmental impact through the anticipated reduction in gas consumption and pollutant emissions.

Traffic calming measures, which are favourable to pedestrians and cyclists, encourage or compel drivers by means of physical obstacles or specific layouts to slow down. Such measures are widespread in Europe. The approach has had a less conclusive but positive impact on safety and speed reduction, when applied in urban areas. Traffic circles and speed bumps appear to be among the most effective targeted measures. Once installed, they require no reinforcement; that is, they are passive.

Most importantly, however, all measures depend upon the speeds chosen as legal limits. Research in the United States and Europe has shown that increases in speed limits influence actual driving speeds and the toll of victims. Conversely, lowering legal speed limits has a positive effect on actual driving speeds and the number and rate of lives saved. Credible speed limits strongly encourage drivers to comply with them and, to this end, speed limits must be adapted to the environment and to all road users.

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3 This agency estimates that such devices account for 15% of the reduction in the number of victims, as against 11% for measures aimed at drinking and driving, and 6.5% for measures focusing on infrastructure.

4 The adaptive speed limiter slows down vehicles that exceed the speed limit by means of a control mechanism external to the driver. The device does not restrain in any way those who stay within the legal speed limit.

Moreover, measures aimed at modifying behaviour have had limited impact. Promotional and awareness campaigns have a short-term effect when conducted in isolation. They neither broaden compliance with speed limits nor reduce the number of victims.

For a long time, strong empirical evidence has shown the worrisome effects of driving courses and driver education programs among novice drivers. By encouraging young people to obtain their driver's licences sooner, courses and programs increase their exposure and therefore, their rate of involvement in collisions and their likelihood of being injured as a result. These measures must be excluded from a preventive strategy.

As for the effectiveness of control measures such as police or automated surveillance, it is based on the perception of the risk of arrest. To modify driving speed and injuries, there must be sustained and intensive surveillance operations. Such programs are costly and their impact is limited over time and confined to the control sites.

Photoradar heightens the perception of the risk of arrest because it detects numerous offenders around the clock. To be effective, the sites must be selected based on the danger associated with driving speeds. Otherwise, the measure is discredited because it is perceived as a tax designed to enrich the state. In any case, once the measure has been fully implemented, financial benefits lessen over time.

Beyond measures: government determination

Beyond specific measures for which conclusive data exists, a more general observation prevails: the countries that have achieved the greatest success in reducing the number of victims are those that give speeding the same priority as drinking and driving. Great Britain, Sweden, the Netherlands, Australia and other countries have adopted government safety policies that have reduced preventable mortality thresholds to the lowest levels. The policies promote technology as a means of achieving ambitious, realistic objectives. They also strike a new balance between safety and the imperatives of mobility.

The human, social and economic costs of road injuries justify the choice of the measures most likely to reduce the number of victims and injuries linked to speeding. This is also the focal point of the *Programme national de santé publique*.

To date, the *Politique québécoise de sécurité dans les transports 2001-2005* (Québec transportation safety policy, 2001-2005) has included measures that target, above all:

- behavioural change (police surveillance, photoradar, awareness campaigns, penalties and advertising);
- the definition of road development standards, and;
- the establishment of criteria governing the determination of speed limits on the road network.

To protect the public at the lowest cost and on the basis of effectiveness, any close examination of the literature should target measures that apply to all vehicles at all times, i.e. passive measures. Physical traffic calming measures can be introduced in the medium term on an experimental basis. The introduction of speed limiters, which solve the problem at the source, can be considered in the medium and long term. In the short term, solutions aimed at motorists' behaviour must be adapted according to criteria that are acknowledged to enhance their effectiveness.

The orientations that result from present knowledge are sufficiently clear to facilitate the best choices. Only a comprehensive perspective allows integration of public health objectives, sustainable development and safety for all users of the road network.

This platform can serve as a basis for discussion between interveners who share responsibility for the problem and solutions for it.

One second is the minimum time for a vigilant driver to react to an obstacle. **Seventy-six metres** is the total distance that a vehicle covers before stopping when the driver is travelling at 100 km/h on a dry road, and 165 m when the vehicle is going 130 km/h. **Zero** is the probability of survival when a pedestrian is struck by a vehicle travelling at 80 km/h. Every year, **708** deaths, on average, occur on Québec roads, equivalent to the passenger loads of two Boeing 747 aircraft or the total number of births recorded each year in Rimouski and Drummondville. The average annual number of days of hospitalization attributable to road collisions stands at **6 167**. Speeding accounts for **30% to 50%** of fatal collisions according to a number of experts in the world, which makes it as important a factor as drinking and driving, all the more so as most drivers exceed the speed limit. In Québec in 2001, **596 649** speeding tickets were issued, three-quarters of all infractions issued by the police. **One driver in two** or even two drivers out of three or three out of four fail to comply with the posted speed limit, depending on the type of road, in Québec. Some **95%** of drivers deem their driving speeds to be safe. The perception among Québec drivers of the risk of being arrested for speeding is **low**. Over 50% of the vehicles manufactured and sold today can reach a maximum speed of **200 km/h**. The laws of physics show that the transfer of **energy** sustained by the body in a collision is the sole cause of death and injury, and risk increases exponentially with speed. To demand that drivers alone curb the power of their vehicles without the help of technical devices such as the speed limiter to reduce preventable deaths would be equivalent to renouncing the use of a vaccine to combat an epidemic. This scourge afflicts both adults and youth in Québec society.

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The automobile has truly revolutionized the transportation of passengers and goods in a rapidly expanding economy. It has also influenced our values and ways of life. Indeed, it has gradually allowed us to widen the distance between residences and workplaces and to move schools and services outside residential neighbourhoods. These conditions have increased the reliance on the automobile, thus reducing the number of utilitarian trips on foot of less than one or two kilometres, while lengthening daily travelling time. Changing motor vehicle technologies have led to the manufacture of more powerful[5] and comfortable vehicles, and to better soundproofing that mitigates to some extent the inconvenience of traffic. Some of the consequences of our growing reliance on the automobile adversely affect health and the quality of life. In particular, we face the serious public health problem of road injuries. We also face the motor vehicle's effects on the environment and on participation in healthy activities such as walking or cycling.

Under the circumstances, it is of no surprise to observe that speeding, which is deemed to rank second only to drinking and driving as a cause of collisions[6], is a widespread problem among all road users and not just a small group of delinquent drivers. Indeed, depending on speed zones, between 50% and 80% of Québec drivers do not comply with the legal speed limit.

Addressing the issue of speeding is one of the key policy directions in overall road safety policies adopted in a few countries, including Sweden, Australia, France, Great Britain and the Netherlands.

The objective of reducing speed should not be confined to large discrepancies (≥ 15 km/h[7] over the legal speed limit) or to very high speed (≥ 130 km/h in a 100-km/h zone) but should also include speeds unsuited to the environment, increasing risks to users.

The mission of the Institut national de santé publique du Québec is to inform the *ministère de la Santé et des Services sociaux* (Ministry of Health and Social Services) of the impact of public policy on the health of the population through this report. It is intended to support the Minister in fulfilling the role of advisor to the government, as indicated in the new *Public Health Act,* to promote the adoption of heathy public policies.

When the government is setting priority objectives, choosing measures based on rigorous and convincing data, and influencing the adoption of policies or the administration of legislation, the roles and legal mandates of the public health sector are clearly in line with

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5 Unless indicated otherwise, the term "vehicle" refers to a motor vehicle.

6 This term has been chosen instead of "accident" and includes any event involving one or more vehicles that collide with a stationary object, another vehicle, a pedestrian, or "without collision" as WHO proposes.

7 Fifteen km/h over the speed limit in a 50 km/h zone is equivalent to driving 30% over the speed limit, which largely exceeds even the highest tolerance limits of around 10% of the authorized speed limit (Paquette, 1998).

those of actors in the transportation, justice, environment, and municipal affairs sectors, as well as community partners.

This report first focuses on the problem by considering the concepts, definitions and indicators of speeding, as well as the health impacts of injuries and other consequences such as air quality and sedentary lifestyles.

Next, a review of the literature on measures aimed at reducing speed and injuries has enabled us to consider the effectiveness of key measures focusing on behavioural change, physical and socioeconomic environments, and on vehicles, aimed at reducing injuries.

In light of this evidence, the strategies and interventions that are most efficient in reducing speed-related injuries for all road users have been selected and prioritized.

The analysis of this review of speed-related studies proposes a reference framework and conclusions in order to influence the choice of policies and programs, and fulfill the government's road safety objectives, in particular those under the *Programme national de santé publique 2003-2012* of the ministère de la Santé et des Services sociaux (MSSS, 2003)

We hope that this scientific review will help in the selection of best practices as well as foster their implementation in a spirit of shared overall responsibility.

1. OVERVIEW

1.1. ROAD INJURIES: A PUBLIC HEALTH ISSUE

Each year, road injuries kill 1.26 million men, women and children throughout the world, equivalent, on average, to over 3 000 persons a day (WHO, 2004). It is estimated that between 20 million and 50 million other people are injured or handicapped by traffic collisions. This cause of premature death affects, above all, young adults between 15 and 44 years of age, who account for nearly 50% of the injuries. In Québec, 708 persons, on average, die in road collisions each year (1997-1998), which account for over 6 000 hospitalizations for all road users, i.e. the occupants of motor vehicles, motorcyclists, pedestrians or cyclists (Hamel, 2001).

The economic cost of traffic-related injuries is estimated at 2% of gross national product (GNP)[8] in high-income countries. Moreover, according to the World Health Organization, current efforts and the funds invested in prevention and road safety are insufficient to cope with this serious problem.

There is already a sufficient body of knowledge to implement policies and measures that would significantly reduce the number of road injuries to alleviate this highly foreseeable, preventable public health problem (WHO, 2004). While human error is a factor in 90% of collisions, the most effective prevention measures usually rely on technological solutions or are linked to the environment, rather than behavioural change. For this reason, the public sector must assume responsibility for the effects of policies and initiatives upon system designers; upon road, vehicle and urban planning standards; and upon transportation, justice, health, and environmental legislation and enforcement in all segments of society, from the highest level of government down to the community (WHO, 2004).

Québec has made substantial gains over the past 20 years with regards to its road injury toll through the application of standards aimed at vehicle impact absorbing devices such as airbags, lap and shoulder safety belts, and the application of measures to promote seatbelt use and to prevent drinking and driving. While the enhancement of road infrastructure is under way, the question of safety must continue to be highlighted.

Moreover, while technological improvements to vehicles have contributed to such gains, automakers have, in recent years, reintroduced some degree of risk by increasing the mass and power of vehicles. Vehicles can now attain speeds well beyond the legal limits, thus jeopardizing much of the effort devoted to improving the road injury toll. Indeed, virtually all cars can reach 150 km/h and one-third of them, 200 km/h or more. Since the speed and mass of a vehicle contributes to the amount of energy absorbed by the individuals in a collision, safety gains are being undermined by an industry whose products offer drivers more speed and a higher injury risk. It is here that contradictions arise between technological innovations in vehicles and public policy aimed at regulating and ensuring compliance with authorized speed limits.

[8] Equivalent to $1.4 billion for Canada.

1.2. TRANSPORTATION SAFETY POLICY AND THE *LIVRE VERT*

In Québec, the *Politique de sécurité dans les transports 2001-2005* (MTQ and SAAQ, 2001), acknowledges that an array of variables must be considered to counteract speeding. The road environment decisively affects driving speed. The socioeconomic environment (e.g. values, legislation and regulations, and control) is a major component of the problem.

The *ministère des Transports* (ministry of Transportation, or MTQ) notes that since 1995, a number of measures have been introduced to enhance the management of driving speed. A guide to determine the speed limits on two-lane municipal roads has been elaborated. Road network managers regularly receive training in the efficient use of these tools. Discussion has also been undertaken on photoradar, awareness campaigns, speed control programs, and the observation of driving speeds on roads.

In the 2001-2005 policy, the MTQ and the SAAQ (2001) proposed nine measures:

1. Amend the *Highway Safety Code* to allow the use of photoradar in zones determined to be problematic.
2. Implement measures that enhance compliance with speed limits in school zones through measures including the use of variable message signs and, if necessary, physical traffic calming adaptations.
3. Rely more extensively on traffic calming measures.
4. Implement awareness campaigns aimed at showing the risk posed by speeding in a way that encourages drivers to alter their behaviour.
5. Step up police surveillance and tighten speed control application criteria.
6. Examine the judiciousness of introducing speed control programs (determination of risk zones, awareness, control and evaluation) as is the case in the Mauricie region.
7. Consider the possibility of more stringent penalties for excessive speeding.
8. Continue to lodge complaints with Advertising Standards Canada (ASC) concerning advertisements centred on speed, performance and other risk-taking behaviour.
9. Continue efforts to raise awareness among automakers and advertising agencies.

To date, Québec has undertaken or planned to undertake measures that focus, above all, on behavioural change (police surveillance and photoradar, awareness, penalties and advertising). Moreover, it has begun to introduce traffic calming measures in the physical environment.

In its *Livre vert* (MTQ, 1999), the ministère des Transports proposed a single measure, photoradar, to overcome the problem of speeding. The public health sector responded to the consultation in a report published in 2000 and concluded that, while photoradar is effective under certain conditions, it is not a cure-all for speeding, and that measures focusing on the environment and on vehicles remain essential components of a comprehensive, integrated approach to speed reduction that has the potential to attain the objective of improving the road victim toll (Conseil des directeurs de santé publique and Conférence des régies régionales, 2000).

A new impetus, under the authority of the Société de l'assurance automobile du Québec (SAAQ), to define Québec's measures and policies for speeding prevention arose from an intersectoral consultation committee in which the MSSS was invited to participate in the fall of 2003. The committee submitted to its members its preliminary findings in June 2004 (SAAQ, 2004, unpublished document).

1.3. INFORMATION ROLE PLAYED BY THE PUBLIC HEALTH SECTOR IN REGARD TO GOVERNMENT POLICY

This report follows rules introduced recently by the government to ensure that all sectors take health impact into account when making their decisions. As a consequence, the Institut national de santé publique du Québec, through its enabling legislation, was entrusted with the specific mission of informing the Minister of Health and Social Services of the health impact of public policy. Also, effective June 18, 2002, section 54 of the *Public Health Act,* attributes new roles to the Minister in respect of the policies that the government adopts where it stipulates that:

> "The Minister is by virtue of his or her office the advisor of the Government on any public health issue. The Minister shall give the other ministers any advice he or she considers advisable for health promotion and the adoption of policies capable of fostering the enhancement of the health and welfare of the population."
>
> "In the Minister's capacity as government advisor, the Minister shall be consulted in relation to the development of the measures provided for in an Act or regulation that could have significant impact on the health of the population."

This report has been produced to support the Minister of Health and Social Services (MSSS) in his or her role as an advisor to the government in the realm of public policy that is favourable to health. It is one of a series of reports that will be published on public policy topics under a service agreement signed with the Direction générale de la santé publique in the MSSS. The themes adopted under this agreement include measures aimed at reducing driving speed and its health impact.

To satisfy this mandate, this report produced by the Institut must:

- document the effects of speed on health and safety;
- summarize existing knowledge and experience on all measures to reduce speed including the physical and socioeconomic environments, vehicles and behaviour;
- offer guidelines for the adoption of policies and intervention priorities based on evidence that has demonstrated significant impact on the health of the population, i.e. improvement of the road collision toll and a reduction in injuries, the promotion of active and safe transportation, and a reduction in transportation-related pollution.

2. THE PROBLEM POSED BY SPEED

This section focuses on the key concepts pertaining to speed, the multifactorial analysis model that underpins the classification of interventions and risk factors, and the causal relationship between collisions and injuries. It also examines the health impact of speed linked to the environment, and to walking and cycling.

2.1. DEFINITIONS AND CONCEPTS RELATED TO SPEED

2.1.1. Definitions

Several definitions cover the notion of speed. The *legal speed limit* is the speed limit posted on roads by law. The *driving speed* is the speed at which the driver decides to drive, whether or not it exceeds the legal speed limit. The *tolerated speed* is the speed under which the police do not issue statements of offence (Marret, 1994). Mention is also made of *design speed*, which is determined by engineers and serves as a reference to apply road building standards. Design speed usually strikes a balance between mobility and safety.

As for *violation speed*, it is usually a speed over the legal limit. The literature refers to *excess speed or excessive speed* in the case of marked breaches of the legal or average speed. Excessive speed lies at the high end of speed dispersion and is engaged in by a smaller number of drivers within the overall group of drivers who exceed the authorized speed limit.

Certain European authors, especially with respect to the comprehensive Vision Zero approach, speak of a *safe speed* when speed limits are chosen for safety and mobility, and bear in mind limits that take into account the effects of speed (kinetic energy) on road collision tolls and on their victims.

In this public health report, the term “speeding” will refer to the entire distribution of speeds, i.e. any discrepancy with legal speed limits and not only in the end part of the curve often refered to as excessive speed, which really concerns only a sub-group of offenders. This perspective is intended to avoid normalization of the failure to comply within a narrow range from the legal speed limit, an acceptance which, over time, could lead to widespread tolerance of speeding. Such tolerance would shift the speed curve to the right and thus increase average driving speeds and their health impact.

2.1.2. Concepts

Speed is the ratio between a distance and the time taken to travel it ($s = x/t$). In the field under examination, it is measured in kilometres per hour (km/h) or metres per second (m/s). While speed is frequently linked to the notion of swiftness or rapidity, even someone who is walking slowly is travelling at a given speed.

In the “person-machine” relationship while driving, the laws of physics related to speed, simultaneously concern the human and vehicular capacities and limitations. Indeed, as speed increases, visual capacity diminishes, the vehicle stopping distance increases, as does centrifugal force in curves. The only constant factor is the body’s limited capacity to absorb shocks in a collision.

2.1.2.1. Kinetic energy

Like any moving body, moving vehicles accumulate kinetic energy (KE), which increases with the speed squared (v^2) as expressed in the formula $KE = (½)mv^2$ where m = mass. It is the impact speed at the time of a collision that determines the amount of energy to be dissipated and, consequently, the risk and severity of injury. The initial wave of energy is released from the vehicle towards the obstacle upon collision. Added to this force is the energy accumulated by the body itself, unstopped until it reaches the steering wheel, a wall, the ground or the seatbelt, and which dissipates some of this energy as it decelerates. The third wave corresponds to the shock of the internal organs, which continue their movement after the vehicle has stopped. The force of the energy released in a collision as low as 30 km/h represents roughly 20 times the driver's weight (1500 kg). A shock at 50 km/h is equivalent to a three-story fall, while at 100 km/h it is equivalent to a 13-storey fall (a height of 40 m).

The probability of surviving a collision decreases dramatically as speed increases. The likelihood of a vehicle occupant's death is 20 times greater at 80 km/h than at 32 km/h. The risk is even greater when vehicle occupants are not wearing seatbelts (Evans, 1991 in TRB 1998; NHTSA, 2000). An estimated 50% of fatalities among occupants not wearing seatbelts would have been avoided by seatbelt use. Pedestrians have a 90% chance of surviving a collision when the impact speed is 30 km/h or less, but the likelihood of survival falls to less than 50% when the impact speed is 45 km/h or more, and is only 20% when the impact speed is 64 km/h or more (Pasanen, 1991; Ashton and Mackay, 1983 in WHO, 2004).

2.1.2.2. Stopping distance

The stopping distance is the distance travelled during the driver's reaction time added to the vehicle braking distance (Table 1). It is estimated that a fully alert driver[9] takes one second to start braking or between one and two seconds depending on the traffic. The reaction path is the distance travelled during this lapse of time. Given a reaction time of 1.5 seconds and a speed of 50 km/h, the distance travelled is 21 m (1.5 s x 14 m/s), after which braking starts to have an effect. To this distance, the braking distance must be added: the distance travelled until the vehicle comes to a complete stop, which depends essentially on speed and road conditions. The braking distance on a wet road is nearly twice that of the braking distance on a dry road. The coefficient of friction diminishes on a snowy or icy road, which can increase from four to eight times the braking distance. Other factors also affect braking distance, such as tire pressure and wear, the condition of the braking system, and vehicle mass. Table 1 illustrates stopping distance according to speed. However, it should be noted that the values indicated are lower than those adopted according to safety criteria when roads are designed. Safety criteria take into account less favourable conditions of the road, vehicle tires and drivers' reaction time (Bureau suisse de prévention des accidents, undated).

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9 Maximum vigilance: the driver is well rested, has neither taken alcohol, drugs or medication that alters his or her attention, is not using a telephone or changing a CD, and is not relying on cruise control as is the case on long, familiar trips during which there is little interaction.

Thus, a vehicle going 60 km/h whose driver reacts at the same point as another driver travelling at 50 km/h will still be going 43 km/h when the second vehicle has stopped completely.

Table 1 – Example: stopping distance

Speed	Reaction path m/s	Braking distance Road		Stopping distance Road	
		Dry	Wet	Dry	Wet
30 km/h	8 m	5 m	7 m	13 m	15 m
50 km/h	14 m	12 m	20 m	26 m	34 m
80 km/h	22 m	31 m	50 m	53 m	72 m
100 km/h	28 m	48 m	80 m	76 m	108 m
120 km/h	33 m	70 m	111 m	103 m	144 m

Source: Bureau suisse de prévention des accidents, *Les lois de la physique utiles aux conducteurs de véhicules*.

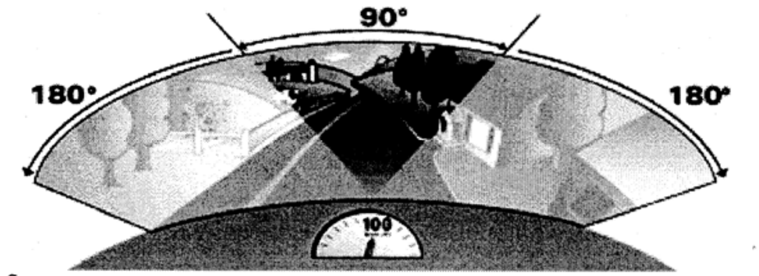
2.1.2.3. Centrifugal force in curves

Any vehicle travelling in a curve is subject to centrifugal force, a consequence of a law of physics. Centrifugal force increases with speed and the radius of the curve. When centrifugal force exceeds the available grip, the vehicle will skid. However, in practice, other factors must be added to help enhance or impair this performance, such as tire wear and pressure, vehicle suspension, the slope of the curve, and road grip. Speed in curves must therefore be adapted to geometry and to the circumstances.

2.1.2.4. Reduction in visual ability

Another aspect of speed is linked to the human brain's ability to process a substantial amount of information. On the road, 90% of a driver's decisions are apparently based on what is seen. However, as vehicle speed increases, the brain eliminates some of the information because it cannot process it, which means that visual ability is partly affected, mainly for the visual field. When an individual is standing still, the normal visual field is 180º but it gradually diminishes to 90º at 100 km/h. At this speed, a driver will not see or take into account an obstacle that springs up on either side of this reduced angle to adjust and effectively manoeuvre the vehicle (Figure 1). Indeed, as speed increases, vision becomes more concentrated on a single point straight ahead (Association des optométristes du Québec, in Marret, 1994).

Figure 1 – Reduction in visual field related to speed



Source: www.saaq.gouv.qc.ca.

In addition to a change in the width of the visual field, depth perception is also altered, and it becomes difficult to gauge distances. Because of dynamic visual acuity, for each 10 km/h the driver must be 3.75 m closer to a sign before it will be seen (Marret, 1994).

Driving a vehicle involves a complex information management activity and requires several skills organized over time to act almost simultaneously. They can be divided into four stages: see, decode the information, decide and act. Increased speed, from the perspective of physical laws, contributes to limiting certain of these faculties that are essential to driving and even more so in an emergency. A limitation in any of these abilities reduces the driver's performance and, ultimately, safety. Little can be done to alter the effects of these physical laws on human beings and the only way to abate their consequences is through a reduction in speed.

2.1.3. Measurements and indicators

The key measurements and indicators used in studies have served to establish a causal relationship between speed and the likelihood of being involved in a collision as well as in evaluating the impact of measures aimed at reducing speed on the collision toll. When reference is made to the distribution of speeds in traffic, most studies consider three measurements: average speed, the 85^{th} percentile of the speed distribution, and dispersion in travel speeds. Speed dispersion can be measured either through the speed variance, the standard deviation, a 10-km/h increment or the range (the difference between the least and greatest values) of the measurement units.

Thus, changes in the average speed will be regarded as a measurement of effect that might, for example, be observed after changes in speed limits or reinforcement campaigns. Similarly, speed dispersion, depending on whether it shifts towards greater homogeneity or greater heterogeneity, has been used as a measurement of effect. It is important to consider this indicator because of the relationship found in certain studies between broader speed dispersion and collision rates. As Kloeden *et al.* have emphasized (1997), it is very difficult to apply analysis models that allow us to conclude with certainty which of average speed or speed dispersion measurements has the strongest association with collision rates, especially since these two measurements are probably highly correlated. For this reason, we cannot evaluate a study based on its choice of measurement since the available proof derived from correlation studies suggests a positive, non-linear relationship between speed and collisions, even if it cannot always be explained.

The measurements of the health impacts of speed relate to mortality (the number and rate of deaths or fatal collisions) and the severity of injuries (number and rate of serious collisions). Several studies also use the indicator of collisions involving people (number and rate) regardless of severity.

2.2. SPEED-RELATED FACTORS: MULTIFACTORIAL MODEL

The laws of physics explain why speed affects the likelihood of being killed or seriously injured because of the energy transferred by the impact of the collision. However, the speed at which drivers decide to drive depends on human-related factors, factors related to the physical and socioeconomic environments, and vehicle-related factors (Table 2). Indeed, the layout of the road and its approaches can encourage drivers to speed or dissuade them from doing so. Similarly, vehicle power increases the ability to reach ever higher maximum speeds. Traffic conditions, legislation limiting driving speeds and the extent to which legislation and penalties are enforced are all factors in the driver's environment that affect these choices. The interaction between vehicles travelling at over 30 km/h with pedestrians and/or cyclists is also a factor that exacerbates the consequences of collisions. The age and sex of drivers, especially young male drivers, added to inexperience and other factors such as driving at night and alcohol are all linked to increases in driving speed.

Table 2 – Examples of factors that influence drivers' chosen speeds

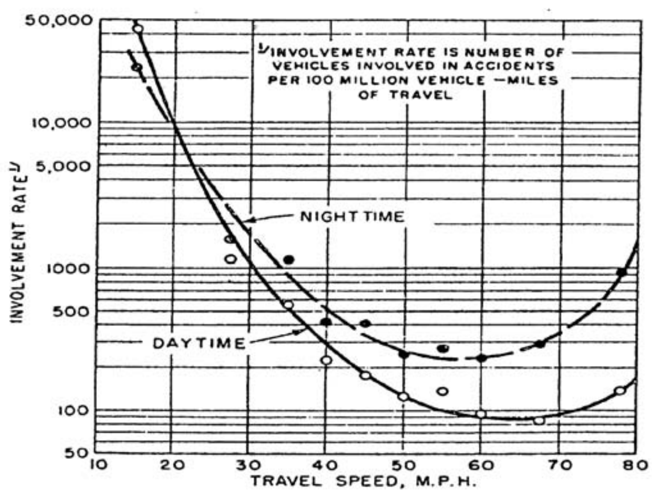
Road and vehicle	Traffic and environment	Motorist
ROAD:	**TRAFFIC:**	age
width	vehicle density	sex
slope	mixed nature of users	reaction time
alignment	general speed	attitudes
approaches	**ENVIRONMENT AND LEGISLATION:**	thrill-seeking
layout	weather	acceptance of risk
markings	condition of surface	perception of danger
quality of surface	roadway lighting	alcohol level
VEHICLE:	signposting	vehicle ownership
type	speed limit	reason for trip
power/weight ratio	enforcement of legislation	occupants
maximum speed		
comfort		

Source: WHO, 2004 - *World report on road traffic injury prevention*.

2.3. CAUSAL RELATIONSHIP BETWEEN SPEED AND THE RISK OF COLLISION

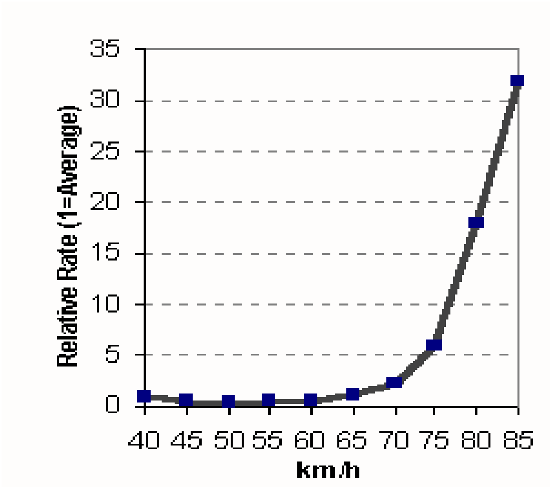
All studies appear to concur on the causal relationship between speed and the risk of collision (Gougam, 2002). The main point of contention is on the shape of this relationship. American studies maintain that the relationship is U-shaped, whereby the risk of being involved in a collision is lowest near the average speed, roughly 60 mph (96 km/h) in Solomon's data (Figure 2) and is the highest in the outermost limits for the lowest and highest speeds (Solomon, 1964; Cirillo, 1968; Research Triangle Institute, 1970). Other studies have relativized the interpretation of these findings for the lowest speeds by showing that factors other than speed explain these high rates, mainly the small numbers of cases at low speeds and the types of collisions, largely linked to intersections.

Figure 2 – Solomon's U Curve



Furthermore, according to a more recent study conducted in Australia (Kloeden *et al.,* 1997) focusing on urban areas, the authors found that the risk of a serious or fatal collision takes the form of an exponential curve (R 2 = 0.993 for speeds over 60 km/h). Thus, starting at 60 km/h, the risk of being involved in a collision doubles with each 5-km/h increment (Figure 3). It appears that the relative risk of being involved in a serious or fatal collision varies only slightly for speeds under 60 km/h.

Figure 3 – Relative risk of being involved in a collision according to speed (Kloeden *et al.*, 1997)



According to Gougam (2002), the differences observed in these models stem primarily from the influence of other variables that explain the occurrence of collisions (confounding effects) that an analysis of data does not allow researchers to take into account.

Speed and alcohol consumption

The comparison of speed to alcohol consumption through the relative risk of being involved in a collision is instructive. The only case-control study in the world that allows for the establishment of this comparison was conducted in a single city. According to this study, carried out in Adelaide, Australia (McLean, Holubowycx and Sandow, 1980, in Kloeden, 1997), the relative risk of a collision with injury was similar between a person driving at 65 km/h in a 60-km/h zone and a person driving with a blood alcohol level of 0.05 g/100 mlcompared with an alcohol level of 0. Table 3 shows that driving at 70 km/h or 75 km/h is also just as risky as driving with an alcohol level of 0.08 and 0.12 compared with the speed of 60 km/h or with an alcohol level of 0.

Table 3 – Relative risk of being involved in a collision involving injury for alcohol and speeding (McLean *et al.*, 1980, in Kloeden *et al.*, 1997)

Speed (km/h)	Relative risk Speed	Alcohol (g/100 mL)	Relative risk Alcohol
60	1.0	0	1.0
65	2.0	0.05	1.8
70	4.2	0.08	3.2
75	10.6	0.12	7.1
80	31.8	0.21	30.4

Although the level of risk may vary over a course when speed is considered, risk is more constant for the entire duration of a trip when alcohol is a factor. Here, one must also bear in mind that driving at speeds exceeding the legal limit is much more frequent than is impaired driving. Measures and penalties to counteract speeding should be at least as extensive as those designed to prevent drinking and driving. Penalties should reflect the role that speed plays as a factor in causing insecurity (Kloeden *et al.,* 1997).

2.4. HEALTH IMPACT OF SPEEDING

2.4.1. Causal relationship between speed and the severity of injuries

The relationship between speed and the severity of injuries is more direct than that between speed and the probability of a collision. When one vehicle collides with another vehicle, a pedestrian or a fixed object, the vehicle undergoes rapid deceleration that corresponds to Delta-V[10]. If Delta-V corresponds to the change of speed on impact, it is the result of the combination of three factors: absolute speed, vehicle mass and the configuration of the collision upon impact (head on, two vehicles travelling in the same direction, a concrete wall or a deformable crash barrier). Delta-V correlates very highly with serious and fatal injury rates and is an absolute measurement of severity of impact widely used in statistical analyses of cases.

The probability of a collision causing injury to the vehicle occupants increases in a non-linear manner with impact speed. In the formula mentioned earlier, $KE = (½)mv^2$, the energy thus released is proportional to the impact speed squared. For example, an 18% increase in impact speed (from 89 km/h to 105 km/h) at the time of collision would increase the energy absorbed by the occupants of the motor vehicle by 40% (TRB, 1998).

The impact of speed on deaths and injuries was first demonstrated by Solomon (1964), who reported that in 100 two-vehicle collisions, between 20 and 30 people were injured and one person was killed at 72 km/h, 70 people were injured and six were killed at 105 km/h,. While new vehicle safety standards have been introduced since then, thus reducing the consequences in absolute terms with respect to injuries, more recent studies have confirmed the same relationship. Indeed, the likelihood of a driver dying in a two-vehicle collision is twice as high at 80 km/h as it is at 64 km/h (Oei, Day and Flora, 1982 in TRB, 1998). Jocksch (1993) expressed this relationship as follows: the probability of death is equivalent to Delta-V to the power of four. Other authors have also established the same relationship to Delta-V for the severity of non-fatal injuries, thus confirming that the data collected in real situations corresponds to the laws of physics (TRB, 1998).

As for pedestrians, the relationship is even more dramatic. The likelihood that a collision will be fatal for pedestrians increases steeply at vehicle speeds ranging from 24 km/h to 80 km/h, the threshold at which the chance of survival is virtually nil (Pasanen and Salmivaara, 1993, in TRB, 1998).

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[10] Delta means change and V stands for velocity or speed.

Many authors have established the relationship between vehicle travel speeds and pedestrian injuries (Pitt *et al.*, 1990; Pasanen, 1992; Anderson and Nilsson, 1997, in NHTSA, 1999), mainly in respect of severity, which increases exponentially. With few differences, most of the authors' estimates concur that at 32 km/h, 5% of pedestrians struck by a motor vehicle die, a figure that rises to 40% at 48 km/h and reaches 80% at 64 km/h (NHTSA, 1999). A study by Anderson *et al.* (1997, in NHTSA, 1999) projected the impact of reduced speed on 176 fatalities in collisions with pedestrians in a 60-km/h zone. The authors estimated that a 13% reduction in deaths would have occurred if all of the vehicles had complied with the speed limit, with a 48% reduction if the speed limit were lowered by 10 km/h to 50 km/h. Two studies reviewed by Wazana *et al.* (1997, in NHTSA, 1999) indicate that child pedestrians have a relative risk of 3.2 of sustaining injuries on roads where the speed limit is 40-49 km/h as compared to roads with 30-km/h zones, where the higher density of child pedestrians warrants the speed limit reduction.

The impact of collisions on the occurrence of injuries also varies according to the use of a restraint system: the presence of an airbag that absorbs the force of the impact, or the ability of the vehicle and the environment to dissipate the energy. Age is another risk factor since it increases the body's fragility and reduces its ability to resist shocks sustained in a collision. Compared with a 20-year-old driver, a driver between 70 and 80 years of age has a three or four times greater risk of dying at the same speed (Evans 1991, in TRB, 1998).

2.4.2. Impact of speed on injuries in Québec

The Société de l'assurance automobile du Québec (SAAQ) maintains that, based on police accident reports, speed is the leading cause of collisions, having led to 22% of deaths, 17% of serious injuries and 1% of minor injuries between 1999 and 2003. This is equivalent to an average of 150 deaths, 900 serious injuries, and 5 000 minor injuries per year (Brault, 2003). While speed is not always reported as the principal cause, it is nonetheless a contributing factor in a percentage of other collisions and an aggravating factor with respect to the severity of injuries. According to SAAQ, in Québec cases where speed is the main or second cause, it is linked to 35% of deaths, 27% of serious injuries and 19% of minor injuries (Brault, 2003). The real impact of speed on the total number of persons involved in collisons is still largely underestimated. Some authors (Fildes and Lee, 1993; WHO, 2004) estimate that speed is responsible for 30% to 50% of fatal collisions.

An overview of the statistics illustrating the scope of injuries will allow us to better perceive what is at stake when contemplating potential gains by focusing on this factor, ranked second in importance after impaired driving.

2.4.2.1. Prevalence of injuries among all road users

Overall, Québec's highway mortality rate declined markedly between 1973 and 2000, from 30 to 10 deaths per 100 000 inhabitants (Hamel, 2001). Table 4 shows that, according to this same data source, mortality for all road users stood at 722 fatalities, on average, per year between 1997 and 1999. According to SAAQ (2005), the number of fatalities declined by 6.6% between 1999 and 2003-2004.

Table 4 allows us to compare mortality by type of user. For vehicle occupants alone, the adjusted mortality rate stood at 7.5 per 100 000 inhabitants, i.e. an annual average in this period of 556 fatalities. Pedestrians ranked second (110 fatalities), followed by motorcyclists (30 fatalities) and cyclists (26 fatalities).

Table 4 – Hospital morbidity and mortality for road injuries, by category (average annual number and rate adjusted for 100 000 inhabitants, Québec)

		Occupants of motor vehicles	Motorcyclists	Pedes-trians	Cyclists	Total
Deaths[11] **1997-1999**	Average annual number	556	30	110	26	722
	Adjusted rate/ 100 000	7.5	0.4	1.5	0.4	--
Hospitalizations[12] **2000-2002**	Average annual number	3 166	606	633	1 020	5 425
	Adjusted rate/ 100 000	42.5	8.2	8.3	13.8	--
Patient person-days 2000-2002	Total number	31 693	5 404	7 887	4812	54 103
	Adjusted rate/ 100 000	418.8	72.4	100.8	62.3	--

Data drawn from D. Hamel (2001), *Évolution des traumatismes au Québec de 1991 à 1999 et 2000 - 2002* (unpublished).

Table 4 also shows that the average annual number of hopsitalizations reached 5 425 for all users and totalled 54 103 person-days between 2000 and 2002. The occupants of motor vehicles ranked first for the adjusted hospitalization rate (42.5 per 100 000 inhabitants), followed by cyclists (13.8), pedestrians (8.3), and motorcyclists (8.2). However, the data reveal that pedestrians rank second in the duration of hospitalizations both in number of days and according to adjusted rate per 100 000 inhabitants.

In the heavy truck motor vehicle sub-category, it should be emphasized that heavy trucks accounted for 2.6% of the vehicle fleet but were involved in 7% of all casualty collisions and 18% of fatalities between 1997 and 2001 (SAAQ, 2003). This over-representation of heavy trucks is due in part to the annual kilometrage travelled and the vehicles' mass and dimensions. Although casualty collisions have declined by 1% in all vehicles overall, collisions involving heavy trucks have increased 12%. This increase is mostly attributable to articulated trucks, the proportion of which has increased in recent years. The occupants of

[11] Because of the shift in 2000 in the classification of fatality data from ICD-9 to ICD-10 we are unable to use the most recent data before a validation process is implemented to reclassify the large number of unspecified cases.

[12] Hospitalization data from the MED-ECHO file used the ICD-9 classification system until 2002.

the other vehicles involved with heavy trucks account for 89% of collision fatalities. Most of these collisions appear to occur in 50-km/h and 80-km/h or over zones. More recent preliminary data (SAAQ, 2005) indicate a 15% increase in the number of persons in collisions involving heavy vehicles, which rose from 4 470 to 5 113 between 1999 and 2004.

2.4.2.1.1. Prevalence of pedestrian injuries

Pedestrians are at higher risk of injury than motor vehicle occupants because of their greater vulnerability and, in particular, the speed of the vehicles involved in the collision.

Québec experienced a significant reduction in pedestrian mortality rates during the 20-year period between 1977-1978 and 1997-1998 (unillustrated data), which fell from an annual average of 5.0 to 1.5 fatalities per 100 000 inhabitants. In the most recent period available (1997-1999), 110 fatalities were recorded (Table 4). In relation to all age groups, the 65-and-over age group has the highest mortality rates. It is noteworthy that the reductions in mortality recorded between 1991 and 1998 occurred above all in the 0-9 age group, in which the rate declined from 1.8 to 0.9 fatalities per 100 000 inhabitants, i.e. by nearly 50%, while the rate remained constant for the 65-and-over group (Hamel, 2005).

Circumstances reveal that 100% of the fatalities occurred when a motor vehicle collided with a pedestrian. The vast majority of deaths occurred in regions with the highest population densities: in Montréal, followed by the Québec, Montérégie and Mauricie-Centre-du-Québec regions. However, rural regions such as the Saguenay—Lac-Saint-Jean and Côte-Nord regions report higher adjusted mortality rates per 100 000 inhabitants (Hamel, 2005).

Despite a general decrease[13], the high frequency of hospitalization and the length of hospital stays reveal the severity of pedestrian injuries. Indeed, hospital morbidity fell by over 50%, from an average annual rate of 18.0 to 8.3 per 100 000 inhabitants between 1976-1978 and 2000-2002, distributed through all regions (unillustrated data). The average annual number of hospitalizations reached 633 between 2000 and 2002, a 28% decrease[14] in relation to the period 1991-1993. This reduction is apparent, above all, in the 0-14 age group. Pedestrian injuries resulted in an average hospital stay of 12.5 days and accounted for 8 000 person-days in hospital on average per year between 2000 and 2002 (Hamel, 2005). Collisions with a motor vehicle accounted for 95% of injuries that required hospitalization.

It is hard to ascribe the causes that account for these reductions, since few measures were applied to prevent pedestrian injuries in Québec during the observation period. Québec data show a decline in walking among young people, which leads us to hypothesize that it is the reduced exposure of pedestrians leading to the reduced number of pedestrian injuries, especially in the 0-14 age group. If this hypothesis proves to be correct, walking remains inherently risky in the absence of measures aimed at making it safer.

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13 See note 7.

14 It should be noted that changes stemming from the shift to ambulatory care may have contributed to the decreases.

2.4.2.1.2. The prevalence of cyclist injuries

The general decline in mortality rates among cyclists in recent years has stabilized at an adjusted rate of 0.4 per 100 000 inhabitants since 1991-1993 (unillustrated data). There were few fatalities, 26 per year on average (1997-1999), and they mainly affected male cyclists. The 10-14 age group is at greatest risk. It has also been observed that 90% of fatalities result from a collision with a motor vehicle. Moreover, half of fatalities are caused by cranial injuries.

The hospitalization rates of injured cyclists remained constant for 20 years, at 15.9 per 100 000 inhabitants (1997-1999), then fell somewhat in 2000-2002 to 13.8 per 100 000 inhabitants (an annual average of 1 020 hospitalizations was recorded in the latter period). Injuries accounted for 4 812 patient-person days per year, on average (Table 4). Nearly 80% of the events that led to hospitalization occurred off public roads, unlike fatalities, and 20% followed a collision with a motor vehicle (Hamel, 2001).

2.4.3. Impact of speed on the environment and health

Aside from its impact on road injuries, speed also affects other facets of health and community life. We will briefly examine the impact of speed on the environment because of the pollution generated by chemical contaminant emissions in the air and greenhouse gases.

Transportation is a significant source of atmospheric pollution. The levels and types of pollution that transportation causes depends on factors such as fuel type, the type of vehicle, its age and state of maintenance, the type of driving, engine load, and speed (Holman, 1999).

This section briefly reviews transportation's relative contribution to atmospheric pollution, the health impact of the pollutants emitted by this sector, and the impact of driving speed on vehicle pollutant emissions.

2.4.3.1. Pollution generated by transportation

Any combustion process releases contaminants into the air and transportation is no exception. The main contaminants released are nitrogen oxides (NO_X), volatile organic compounds (VOC), particulate matter ($PM_{2,5}$), carbon monoxide (CO), and greenhouse gases (GHG), especially CO_2.

The transportation sector's relative contribution to these pollutants varies depending on the specific contaminant and the environment (urban or rural). Table 5 presents this information for Québec overall.

Table 5 – The transportation sector's relative contribution to atmospheric pollution (Québec, 1999-2000)

Contaminant	%
NO_X*	84
VOC *	34
$PM_{2,5}$	17
CO	60
GHG	38

Source: Ministère de l'Environnement du Québec, 2004. * Ozone precursors.

NO_X and VOC undergo a photochemical reaction in sunlight and heat that produces ozone. Given the high percentage of these precursors that are generated by the transportation sector, it is apparent that the sector is a major source of this contaminant.

2.4.3.2. Public health impact of contaminants from the transportation sector

It is important to clearly distinguish between the components of smog and greenhouse gases such as CO_2 that contribute to global warming, whose health impact is well documented.

Smog is a mixture of noxious contaminants, one or more of which exceed acceptable levels, thus leading to a smog alert. The key components that affect public health are ozone, formed through a photochemical reaction of NO_X and VOC, and fine particles, or particles of less than 2.5µ in diameter called $PM_{2,5}$ (RSQA, 2002).

Studies conducted over the past 15 years have indicated small but statistically significant risks linked to pollution levels that are within the recommended value limits. It is important to emphasize here that a small risk of highly prevalent diseases has a striking impact from a public health perspective because of the potential number of individuals affected by such a risk (Quénel *et al.*, 2003).

High concentrations of ozone (O_3) are very irritating to the eyes, nose and upper respiratory tract. Most studies devoted to urban populations exposed to ozone confirm its impact on morbidity and mortality (Delfino *et al.,* 1997; Burnett *et al.*, 1997). A recent study suggests that ozone can also trigger the development of asthma in children who engage in outdoor sports (McConnell *et al.* 2002).

Particulate matter ($PM_{2,5}$) penetrate the pulmonary alveoli. Their toxicity also depends on their composition. Several studies have been conducted to ascertain their impact on public health. For example, two time series studies by Goldberg *et al.* (2001a, 2001b) conducted in Montréal reported excess mortality linked to an increase in the concentration of fine particles in outdoor air. These studies also took variables such as meteorological parameters and the presence of other pollutants into account in their analyses.

Prospective studies on the long-term impact of fine particulates on mortality carried out over the past 10 or so years reveal residents of the most polluted cities are at greater risk of dying of cardiopulmonary diseases and lung cancer compared with residents of less polluted cities (Dockery *et al.*, 1993; Pope *et al.*, 1995; Abbey *et al.*, 1999; Pope *et al.*, 2002).

Another way to understand the impact of transportation-related pollution on public health is to study populations that live alongside busy roads. The impact of pollution on mortality appears to be higher in populations living along such thoroughfares (Roemer and Wijnen, 2001).

Greenhouse gases (GHG) are worrisome because of the climate change that they cause. In Québec, CO_2 is the predominant GHG emitted, and accounts for 75.8% of the total (Environnement Québec, 2003). Generally speaking, in the context of climate change, impact on human health could be significant and the risk probably more negative than positive. The main impact on climate that is feared is rising temperatures, which will lead, among other things, to an increase in the frequency, duration and intensity of heatwaves in Québec and other meteorological changes such as more frequent extreme weather conditions (www.climatechange.qc.ca).

This situation will directly and indirectly affect health. Heatstroke is the most dramatic direct effect as it can be fatal (Auger and Kosatsky, 2002).

Problems indirectly attributable to heat are more common. They usually result from the exacerbation of chronic medical conditions in the elderly during heatwaves, especially cardiovascular, cerebrovascular, respiratory, neurological, and kidney diseases. City dwellers living in urban heat islands are especially at risk, above all if they are socioeconomically disadvantaged (Auger and Kosatsky, 2002).

Furthermore, some studies suggest that climate change increases exposure to chemical pollutants (VOC) and natural aeroallergens by promoting the production of spores and the dispersal of pollen.

In other words, not only are rising temperatures linked to several health problems among vulnerable individuals, but rising temperatures increase concentrating airborne pollutants such as volatile organic compounds (VOC) that are also linked to health problems in vulnerable individuals.

Specialists anticipate that climate change will promote the survival of vectors and hosts and the infectious agents that they transmit, thus increasing the likelihood of vector-borne infectious diseases. Vectors such as ticks, mosquitoes and other organisms could reach Québec by extending their current geographic distribution northward. The arrival of the West Nile virus in Canada sooner than anticipated illustrates the state of vulnerability that Québec might eventually experience in light of this type of threat.

Should the warming trend reduce the number of very cold days during the winter, there might be fewer deaths. However, forecasts by American researchers suggest that the slight decrease in mortality during the winter cannot offset the strong increase in mortality anticipated in the summer (Auger and Kosatsky, 2002).

2.4.3.3. Impact of speed on contaminant emissions

Transportation-related pollutants have a significant impact on health and any attempt to reduce such pollutants will have a beneficial effect on public health.

Speed is one of several factors that affect vehicle pollution emissions. For example, in urban areas, acceleration and deceleration, congestion, type of driving and vehicle maintenance significantly affect gas consumption and the level of pollutant emissions (Holman, 1999; Brault and Kirouac, unpublished report, 2003). Moreover, the typical pollutant emission curve is U-shaped, i.e. emissions increase at slow speeds and at high speeds (Brault and Kirouac, 2003). For example, NO_X emissions start to increase at 77 km/h and carbon monoxide emissions start to increase at 88 km/h (Pechan *et al.*, 1997). Consequently, a change in speed on expressways is likely to have an impact on emissions of these pollutants.

Much of the information on the impact of speed on transportation-related pollutant emissions comes from the United States, because of changes in speed limits. In 1974, the United States federal government set a nationwide highway speed limit of 88 km/h to reduce gas consumption. In 1987, this speed limit was increased to 104 km/h on interstate highways. In 1995, the speed limits were abolished and the states assumed control over maximum highway speed limits (Pechan *et al.*, 1997). These changes led the Environmental Protection Agency (EPA) to assess their environmental impact.

Pechan *et al.* (1997) evaluated the impact of speed on NO_X, VOC and CO in all of the American states, bearing in mind the changes in speed limits, which ranged from a minimum of 88 km/h to a maximum of 120 km/h. For example, in Wyoming, where the speed limit was raised from 104 km/h to 120 km/h, the authors anticipate that NO_X emissions will increase by 22%, CO emissions by 17%, and VOC emissions by 6%. In Delaware, where the speed limit was raised from 88 km/h to 104 km/h, the authors anticipate NO_X will increase by 1%, CO by 1%, and VOC by 3%, respectively. In the United States overall, the authors foresee that changes in speed limits will result in a 6% increase in NO_X, a 7% increase in CO, and a 2% increase in VOC. These estimates are based on Mobile 5, which applies to speeds of 104 km/h. For speeds beyond this limit, the authors applied a linear model to estimate the increases, bearing in mind that such a model can underestimate emissions at very high speeds.

The impact of higher speed limits on older and heavy diesel vehicles, which emit more particles than gas-powered vehicles, is also uncertain. There are no precise estimates on particle emissions, although the EPA maintains that such emissions should increase as speed rises.

As for CO_2, the emission level of this greenhouse gas is clearly directly linked to gasoline consumption, since CO_2 is the end product of the combustion of gasoline (EPA, 2003; Brault and Kirouac, 2003). According to the EPA (2003), an increase in the highway speed limit from 88 km/h to 112 km/h will increase gasoline consumption by 25%.

Another source of information on the potential impact of speed on pollutant emissions and gasoline consumption is the evaluation report of a British project on the automated vehicle speed control system (Institute for Transport Studies, 2000). This system provides drivers with information on the road on which they are driving and automatically limits speed in keeping with the posted speed limit. Such a system would reduce gasoline consumption by 5.5% overall, and by 8% in urban areas, which would generate a commensurate reduction in CO_2 emissions.

Such an automated speed control system would have little impact on other emissions in urban areas. Emissions, especially of CO, which fell by 4.2%, would diminish on expressways.

To summarize, United States estimates on the impact of speed limit changes on pollutant emissions and gasoline consumption have until now produced different results from one state to the next for two reasons. First, changes in speed limits have varied from state to state. The maximum speed on some expressways in certain states may be as low as 88 km/h and the new maximum speed may reach 120 km/h. Depending on the gap between the old and new speed limits and the point of departure, increases in emission levels can vary. Furthermore, there is more urban traffic in some states than in others, which affects the impact on emissions of changes in speed limits. Below are the estimated increases in pollutants linked to higher speeds evaluated overall for the entire United States and the maximum increases forecast in certain states.

- The total increase in NO_X is estimated at 6% for the US overall but could reach 35% in some states.
- The total increase in VOC is estimated at 2% for the US overall but could reach 17% in certain states.
- The total increase in CO_2 is estimated at 7% for the US overall but could reach 48% in some states.

Gasoline consumption is expected to increase by 25% when the speed limit on expressways rises from 88 km/h to 112 km/h.

The British evaluation of the proposed automated speed control suggests that such a system would:

- reduce CO_2 emissions by 4.2% on expressways;
- reduce CO_2 emissions by 5.5% overall and by 8% in urban areas.

No estimates are now available of the impact of speed on particle emissions. However, according to Pechan *et al.* (1997), it should be similar to its impact on other pollutants emitted by motor vehicles.

According to SAAQ (2003), heavy trucks travel roughly 3.8 billion km each year on highways and main roads in Québec where speeds are higher. Of the total, 2.9 billion km are travelled at maximum speed. Studies show that a reduction in the speed of heavy trucks on this road network would lead to an appreciable reduction in the amount of certain gases emitted by these vehicles. Reductions would be considerable, especially in respect of NO_X, CO_2 and VOC.

Indeed, in light of an analysis based on observed speed, it is estimated that compliance with speed limits would save nearly $35.5 million in social and environmental costs. Moreover, the reduction in fuel consumption and the attendant reduction in emissions would promote the attainment of the objectives set under the Kyoto Protocol. Such speed reductions would also reduce noise from heavy trucks.

2.4.4. Impact of speed on physical activities such as walking and cycling

Scientific and clinical proof of the link between sedentary lifestyles and health problems has been well documented over the past three decades (WHO, 2002). Physical inactivity is now recognized as a determinant along with smoking, hypertension and hypercholesterolemia in the array of risk factors for chronic diseases such as cardiovascular disease, diabetes and colon cancer.

As a consequence, regular physical activity has been shown to favourably affect health by helping to prevent the appearance and development of chronic diseases and in reducing the risk of premature death from these health problems. Physical activity includes all forms of bodily movement and applies to work, professional occupations, recreation, sports and housework and is not confined to exercise or sports.

The findings of two longitudinal studies illustrate the protective effect of physical activity among sedentary individuals who have become active, whose mortality rate fell by 23% (Paffenburger *et al.*, 1993) and 44% (Blair *et al.*, 1995, in Comité scientifique de Kino-Québec, 2004). Physical activity apparently reduces the risk of developing coronary disease by 50%, non-insulin dependent diabetes and obesity, and the risk of hypertension by 30%, and seems to effectively increase bone mass and protect against osteoporosis. Physical activity also contributes to maintaining balance, strength and endurance and to promoting psychological well-being.

The latest American (US Surgeon General, 1996) and international recommendations (WHO, 2002) on the amount of physical activity needed to affect mortality rates indicates a relatively low threshold. It is widely acknowledged that 30 minutes of moderately intense activity per day, year round, is sufficient to derive health benefits. Walking and cycling are among the most accessible activities and the most likely to be integrated into everyday activities, either as a means of travel to school or work, or for recreation (WHO, 2002; Pikora *et al.*, 2003).

Monitoring data in Québec, Canada and the United States indicates that a high percentage of the population does not achieve the recommended amount of physical activity. Indeed, the level of physical activity appears to be declining, especially among children (WHO, 2002).

According to the 1993 *Enquête québécoise sur l'activité physique et la santé*, nearly two-thirds of Quebeckers 15 years of age or over do not appear to be sufficiently active to derive benefit from activity (Nolin *et al.*, 1996 in Comité scientifique Kino-Québec, 2004). The proportion of Quebeckers who are barely active or inactive increased from 17.4% to 21.3% between 1993 and 1998, a situation that is linked to a reduction in walking as a means of travel (Nolin *et al.*, 2002, in Kino-Québec, 2004).

A review of the literature devoted to individual-related factors that facilitate or predispose to physical activity, especially walking and cycling, reveals an abundance of studies. More recently, some studies have focused on socio-environmental factors that affect physical activity. Environmental factors that are positively linked to regular physical activity (Comité scientifique Kino-Québec, 2004) include:

- a high degree of urbanization (living in an urban area rather than a rural area or in the suburbs);
- a high degree of pedestrian safety (limited automobile traffic, sidewalks, proper lighting and low crime rates);
- the availability and accessibility of infrastructure; and
- the presence of physically active individuals among family and friends.

In a recent publication, Pikora *et al.* (2003) report the development of a model, based on socio-ecological health promotion models, to explain factors that influence the decision to engage in walking or cycling. Pikora divided factors in the physical environment into four groups: functionality, safety, aesthetics and destination. Among the functionality and safety factors, the authors mention, in particular, traffic volume, speed, road signs, road intersection and crosswalk design, pollution and traffic-related noise.

Research conducted by transportation and urban planning organizations offers similar findings indicating that traffic and individual safety are environmental factors that encourage or discourage walking. More precisely, they include the presence of conflict, the level of pollution, and noise linked to urban traffic (Hawthorne, 1989; Unterman, 1987, in Pikora *et al.,* 2003).

As a sedentary lifestyle is a risk factor for several health problems, any measures to encourage walking as a means of travel need not only consider the environmental attributes that will encourage more individuals to walk, but also injury protection and prevention measures to avoid increasing the number of collision victims due to broader exposure, which whould thereby cancel out the gains achieved to date.

Several strategies to enhance these environmental conditions rely on traffic calming approaches and measures to reduce traffic density, and the addition of dedicated routes to increase the perceived level of safety (Pikora *et al.*, 2003), all of which are examined in the chapter on measures aimed at modifying the physical environment.

2.5. PROFILE OF DRIVING SPEEDS IN QUÉBEC

Having examined the health impact of speed, let us now turn to an examination of the scope of this phenomenon in Québec. Speeding appears to be widespread among drivers the world over. In Québec, survey data on driving speeds reveal that one driver in two in urban areas does not comply with a posted speed limit of 50 km/h, that two drivers out of three fail to comply with the speed limit in 90-km/h zones, and that four drivers out of five fail to comply with speed limits on highways (SAAQ, 2004). In urban areas, speeds vary according to traffic density, environmental characteristics (residential zone, boulevard or arterial road or commercial street), and the level of reinforcement implemented by local police. In a Québec study (Brault, 1994), the average speed observed in 50-km/h zones at 19 sites ranged from 32.5 km/h to 68.8 km/h.

In 2002 in Québec, there were 4.8 million motor vehicles for 4.5 million driver's licence holders. It is noteworthy that speeding accounted for 74% of the *Highway Safety Code* infractions issued by police, at nearly 600 000 per year (Tardif, 2003a). Furthermore, 87% of the infractions were issued for exceeding the speed limit by more than 20 km/h (Table 6).

Table 6 – Speeding infractions according to speed over the posted limit (number and percentage), Québec, 2001

km/h	Number of infractions	%
11 km/h to 20 km/h	79 788	12
21 km/h to 30 km/h	313 324	53
31 km/h to 45 km/h	178 026	30
over 45 km/h	23 804	4
During road construction	1 707	0
Total	**596 649**	**100**

Source: SAAQ - *Dossier statistique - Les infractions et les sanctions 1992-2001*.

In 2001 alone, the infraction rate for speeding was 13 126 per 100 000 driver's licence holders in Québec overall. While the number of speeding infractions rose slightly between 1992 and 2001, the rate per 100 000 is fairly constant.

For the purpose of comparison, the number of *Criminal Code* infractions related to drinking and driving in 2001 stood at 11 222, with a rate of 247 infractions per 100 000 driver's licence holders the same year. This type of infraction fell by 52% in relation to 1992, when there were 23 2107 infractions, with a rate of 565 per 100 000 driver's licence holders. This reduction probably follows repeated, intensive measures to enforce legislation governing impaired driving and drivers' perceptions of the greater risk of arrest.

Table 7 – Comparison of drinking and driving with speeding infractions in Québec, 1992-2001

		1992	2001	△%
Speeding				
	Number	524 051	596 649	+ 13.9
	Rate per 100 000 driver's licence holders	12 747	13 126	+3.0
Drinking and driving				
	Number	23 210	11 222	- 51.7
	Rate per 100 000 driver's licence holders	565	247	- 56.3

Source: Tardif, 2003.

In Québec in 2001, trucks and road tractors accounted for 2.6% of all speeding infractions (Tardif, 2003a). Statistics on infractions issued to truck drivers reveal that 48.3% of infractions occurred on main and secondary roads and that an equivalent percentage of infractions were issued to the drivers of other vehicles on highways (Tardif, 2003a).

A survey conducted in 2003 in the wake of the "Parce qu'il y a les autres… Pensez-y, Ralentissez" province-wide campaign revealed that the Québec drivers still trivialize the seriousness of speeding infractions. This reflects their perception that the risk of arrest for speeding is limited (Brault, 2004).

3. STATE OF KNOWLEDGE OF MEASURES AIMED AT REDUCING SPEED AND INJURIES DUE TO COLLISIONS

3.1. OBJECTIVE

The objective of this review is to update the corpus of knowledge from evaluative studies on speed reduction strategies and assess their effectiveness in terms of injury prevention.

3.2. METHOD

3.2.1. Type of evaluative studies selected

Given the extensive body of literature, meta-analyses, systematic reviews, and literature reviews were chosen when available. The articles referred to in reviews were also selected. In the absence of meta-analyses or systematic reviews, randomized or non-randomized pre-post evaluations with control groups were accepted. In the case of measures for which little evaluation was available, it was decided not to eliminate any studies based on criteria concerning the robustness of the study design. However, this aspect will be taken into account in the presentation of findings and in the discussion section.

The studies selected (1) focus on preventive measures aimed at reducing speed; and (2) attempt to ascertain the impact of various measures in reducing speed-related injuries.

The methodological design of the selected studies can vary depending on the type of measure. For example, the robustness of studies that assessed the impact of photoradar on speed reduction is possibly greater because of the feasibility of obtaining precise measurements in an experimental context where the time and place are clearly delineated and the direct relationship observed. When the question arises of attributing the same impact to a systemic approach such as area-wide traffic calming, the methodological design must take into account and control more variables, conditions that they do not always fulfil.

However, it is easier to measure the impact of speed reduction measures than to establish their impact on mortality and morbidity since the relationship is indirect, but also because it is more complex to isolate the impact of these measures from other variables that influence the occurrence of collisions and injuries.

There is considerable diversity in the bases for comparison used in the studies. Indeed, depending on the authors, the comparisons focused either on speed zones, or types of road, or different environments, or specific indicators such as average speed, speed dispersion, variations from the mean, and so on.

3.2.2. Search of the studies

The search focused on evaluative studies conducted over the past 25 years using the automated retrieval function in Medline and TRB-TRIS, and a review of international conferences that appear in indexes. A Web search enabled us to locate studies not found by other methods. Other studies were selected from the bibliographies of articles already selected.

3.2.3. Description of the studies

A description of preventive measures, the presentation of theoretical postulates where applicable and the conclusions stemming from analyses of implementation or effectiveness are provided for each section.

3.3. BEHAVIOUR – RELATED MEASURES

The measures aiming at behaviour modification include educational and informative measures such as awareness campaigns, driver training, and reinforcement measures such as police or automated surveillance.

Occasionally, an initiative combines two measures, such as the selective traffic enforcement program (STEP) in which a campaign supports surveillance operations.

Generally speaking, these measures are based on existing legislation and focus on drivers by encouraging them to abide by the law, relying on knowledge, accountability or the principle of dissuasion which is based on fear of the consequences.

These measures, also called “active measures”, require that drivers adopt a certain behaviour every time they are at the wheel and for the entire duration of a trip. They call for ongoing application of measures and allocation of resources.

3.3.1. Promotional and awareness campaigns

While debate and discussion on campaigns and their quantitative impact continue, few in-depth reviews of the literature examine the effectiveness of highway safety campaigns (Delhomme, 2000). According to Elliott (1993), the communications sector apparently sustains the notion that campaigns have the power to induce safe behaviour in the wake of a communications strategy aimed at broadening knowledge and changing attitudes. However, particularly as it concerns the subject of health, there is no evidence of a relationship between attitudes and the desired behaviour (OECD, 1994, in Delhomme, 2000). Measures designed to change attitudes are rarely reliable indicators of a change of behaviour, which explains the need to rely on theoretical behavioural change models to design more effective campaigns. This relationship is particularly weak when general attitudes are used to predict a specific behaviour. The example of a media campaign centred solely on a message that is general in scope could hardly be linked to a measurable behaviour such as a reduction in driving speed by drivers even if it can contribute to the definition of a social norm concerning the impact of speed on safety.

Numerous models and theories have been developed to study the effectiveness of messages or the impact of media communications. The minimum effect model of the 1960s, which suggested that campaigns essentially reinforce individuals' pre-existing attitudes has been replaced by more nuanced positions today. However, research is focusing principally on processes and indirect impact, which is more appropriate to the designing of campaigns than to the interpretation of the health impacts of their outcomes. Adapting a definition from Rice and Atkin (1994), Delhomme (2000) conducted a meta-analysis to examine road safety campaigns in light of the following definition:

> "A road safety campaign voluntarily seeks to inform, persuade or motivate changes of attitude and/or behaviour in favour of road safety in respect of a fairly well-defined, fairly large target, for the non-commercial benefit of individuals and/or society as a whole over a given period of time by means of communications initiatives that involve the media, often rounded out by interpersonal support frequently combined with other initiatives as a form of support for other measures." [TRANSLATION]

A review of the literature reveals two meta-analyses focusing on promotional and road safety campaigns. The first meta-analysis, by Elliot (1993), examines more specifically media campaigns. It defines the campaigns' objectives by the determination to alter or encourage behaviour respecting safety with intermediate objectives that the author attributes to the means of communication, for example the transmission of information, a change of attitude, and beliefs. Elliott (1993) followed a conventional meta-analysis approach and calculated a standardized average effect between before/during or before/after on several dependent variables. The author also sought to test the hypothesis that media campaigns alone cannot bring about the desired behavioural changes.

In his analysis corpus, Elliott (1993) selected 87 evaluated campaigns, studies that he describes as basic assessments that often fall short of compliance with scientific standards for rigour. However, no study was excluded *a priori* except those that did not present pre-post measures and did not include comparison groups. A majority of reports use as sole measurements variables concerning exposure to the campaign (memorization, awareness) instead of real measures of impact on the change of attitudes or behaviour.

Elliott (1993) does not specify how many studies focus on speed in particular, but in those that examine this theme, the two measurements presented cover only attitudes and observed behaviour. The other themes covered by a campaign are seatbelts, drinking and driving, cycling helmets, and road safety in general.

In his meta-analysis, Elliott (1993) found that the magnitude of the average effect for all of the campaigns evaluated, including all measurements of combined results (awareness or memorization of the campaign, knowledge, attitudes and behaviour) is 7.6% in relation to the pre-campaign situation. When measurements pertaining to awareness are excluded from the analysis because the measurement focuses on exposure rather than changes in individuals, the average gain is roughly 6.1%. On the sole measurement of exposure, Elliott (1993) maintains that a campaign should target an increase of at least 30% in awareness of the theme tackled. Delhomme (2000) sees in these findings an innovative contribution insofar as they indicate for the first time what we should expect of the integration of the overall impact of these campaigns. Moreover, they also demonstrate that the impact achieved falls well below the anticipated threshold of 30%.

Delhomme (2000) notes at least three significant limitations to Elliott's meta-analysis: the size of the sample (few campaigns), the absence of measurement of impact on collisions, and the limited number of comparison groups. We might add that this analysis of combined impact does not take into account the interdependence of the measurements.

Elliott's meta-analysis (1993) attempted to take into account moderator variables, i.e. those that characterize the components of the different campaigns and that are, to some extent, factors that contribute to explaining the magnitude of impact. Bivariate analyses have been applied to several moderator variables by converting them to a dichotomous scale. Although they are limited by the size of the standard deviation and the small samples, it is worth considering, at least on a qualitative basis, the key significant findings. Elliott (1993) notes that campaigns based on a theoretical model or qualitative research are superior to those based on intuition or that do not rely on a model. He also indicates that the persuasive communication approach is more effective than the educational approach, which seeks to inform and transmit knowledge. He found that the combination of advertising and strengthening legislation has a more pronounced final effect, just as it does when the campaign message calls for a specific change of behaviour like staying within the speed limit in 50-km/h zones.

The baseline level rate of the change sought, for example seatbelt use rate, at the outset of the campaign appears to be a specific, influential moderator variable. Elliott (1993) ascertained that the campaigns whose baseline rate in respect of a given measurement fell below 40% achieved better results than those with a baseline rate over 40%.

When Australian studies are grouped together, they appear to stand out because of their more striking impact, especially when compared with American studies. The findings in Australian campaigns apparently stem from a combined approach of several characteristics that generate greater impact: they are based on a theoretical model, they link the campaign to reinforcement measures, and they target a specific change.

In the multivariate analysis, only variables respecting the combination of advertising with measures to monitor and enforce the law, reliance on qualitative research and the use of television as a medium maintained their predictable value. According to the model, when the combination of advertising and monitoring is present, the value is five times higher than is the case with advertising alone.

With reference to the second meta-analysis identified, Delhomme (2000) mentions the review of a body of 265 evaluation reports focusing on road safety campaigns as defined earlier. The studies originate in 17 countries and include 43 from the Netherlands, 33 from Australia, 38 from the United States, 34 from Canada, and the remainder from European countries. Among other things, the campaigns reviewed examine a wide array of themes (41) pertaining to road safety and sometimes cover more than one dimension during a given campaign. While speed is a campaign theme in 26.8% of cases, 12.8% of the 265 measures focus solely on speed. Three-quarters of the campaigns evaluated targeted all drivers.

Over one-third (35.1%) of the evaluation design reported only pre- or post-campaign data. This trend is apparent, above all, in France and Belgium, while there is a significant tendency for the Netherlands, the United States, Australia and Canada to evaluate more frequently in two phases, either before/during or during/after. One study in four was conducted with a comparison group. Generally speaking, the analysis was conducted in light of only one type of data, such as self-reported or observed behaviours, knowledge, collisions or infrastructure. Furthermore, the campaigns included were conducted alone or linked to other measures such as legislation, law enforcement, education and rewarding.

Delhomme's meta-analysis (2000) focuses solely on a sub-group of 66 studies out of 265 that measured impact on collisions and injuries, which in most cases corresponds to the studies with comparison groups. The significant findings reported for this part are attributable to all components of the campaign as defined beforehand, and are linked to other measures such as enforcement of the legislation, the educational program, rewarding, etc., and not only to the campaign's media section.

According to Delhomme (2000), the overall effect of the road safety campaigns evaluated with reference groups was an 8.5% reduction in collisions during and a 14.8% reduction after the campaign, although the findings vary depending on the precision of the comparison group (Table 8). All of these findings are significant. The time varies from one month to one year for the "after" period depending on the study.

Table 8 – Summary of the impact of all of the campaigns evaluated with reference groups (Delhomme, 2000)

Sub-group of studies[1]	Overall impact (%)	95% confidence interval	Significant
With reference group			
During	-8.5	(-9.8;-7.1)	Yes
After	-14.8	(-17.1;-12.6)	Yes
With specific comparison group			
During			
After	-16.0	(-18.0;-13.9)	Yes
	-14.7	(-17.3;-11.8)	Yes
With control or comparison group			
During			
After	-3.2	(-5.1;-1.3)	Yes
	-15.4	(-19.3;-11.2)	Yes

[1] As defined by Delhomme (2000).

When the meta-analysis indicates specific results for the “during” period of the campaigns, reductions in collisions range from 6.9% regarding drinking and driving, 16.9% for speeding, and 8.1% for other themes. There are not enough studies with “after” measurements to obtain results for this period and thus to ascertain how well the effects held over time.

The estimated impact of the campaigns, according to seriousness, compiled in light of four outcomes in New Zealand, the United States and Australia, reveals a significant reduction in the number of casualty collisions of between 19% and 26% “during” and “after” and a reduction, albeit not a significant one, in fatalities “after” the campaign.

Some findings concerning anticipated impact focus on the features of the campaigns. Depending on whether the campaigns were conducted alone or in conjunction with other measures, the analysis was unable to demonstrate a significant reduction in the number of collisions during or after the campaign when the campaign was conducted alone (Delhomme, 2000). Moreover, campaigns linked to enforcement of the legislation significantly reduced the number of collisions during the campaign by 6.9%, although not enough studies (only one) have been carried out to measure the impact after the campaign. Campaigns linked to new legislation on alcohol level, and more stringent enforcement of legislation, reduced the number of collisions by 16.8% during the campaign, while campaigns linked to positive reinforcement (rewarding) achieved a significant 20.2% reduction. The number of studies and contradictory findings of campaigns linked to other legislative or educational measures made it impossible to subject them to more thorough analyses.

Overall, the presence of an explicit theoretical framework to help elaborate the campaign scheme was linked to a 20.1% reduction in the number of collisions during the campaign and 23.4% after the campaign.

The impact of city-wide campaigns is more striking. For the “during” phase, Delhomme (2000) reports a 15.8% reduction in collisions when the campaign covers an entire city, compared with 10.7% for a national campaign. The results are marginal at the provincial (national) level, while at the local level (equivalent to the regional level in Québec) the reductions fall between the two. In the “after” phase, only the city-wide campaign shows a significant reduction at roughly 13.4%, with no impact at the provincial (national) level and a non-significant impact at the local (regional) level.

Several limitations to the interpretation of these findings should be noted. Delhomme’s review of the literature, while it is the most extensive one available to date, is not exhaustive. Impact has been overestimated for several reasons. First, the limited number of studies properly evaluated (most of them measured a single phase and very few of them involved comparison groups) and the limited number of no-effect studies that reflect the traditional bias in publishing the best findings, contribute to the overestimation of impact. The univariate analysis that Delhomme adopted emphasizes a single dependent variable and does not control for the correlation with moderator variables. Caution must therefore be exercised to avoid attributing the results to be causal relationships.

Delhomme (2000) cites four other meta-analyses (comprising small numbers of studies) conducted on observable behaviour, only one of which, by Elvik, Mysen and Van (1997, in Delhomme, 2000), examines the impact on collisions of road safety campaigns. Of the

13 campaigns that Elvik *et al.* (1997) evaluated, only one, focusing on seatbelt use and drinking and driving, revealed a significant reduction in the number of collisions.

3.3.2. Measures of enforcement on legal speed limits

Even when environmental and social measures are adopted such as relevant speed limits and legislation geared to reinforcement, a majority of drivers exceed the legal speed limits in Québec and elsewhere in the world. The proportion of offenders ranges from 20% to 80% depending on the country, type of road, level of control, and so on (Rothengatter, 1990). In Québec, in a study devoted to driving speeds, Brault (1994) estimated the non-compliance rate at more than one driver out of two in urban areas, three out of five in rural areas, and three out of four on highways. These findings indicate the need for more effective reinforcement strategies in order to ensure optimal enforcement of the legislation.

To describe the profile of the information reviewed in this section, it should be noted that the evaluations centre on the general hypothesis of a chain of relationships between police operations and road safety. *A posteriori* theoretical conceptualization has helped to streamline links between operations, programs, drivers' behavioural responses, and impact on the road collision toll. This chain can be summarized as follows: introduction of a reinforcement measure ➔ increase in the real risk of arrest ➔ heightened perception of the risk of being intercepted ➔ increase in the likelihood of punishment ➔ reduction in speed ➔ reduction in collisions ➔ reduction in the number of victims.

In fact, few of the studies among those reviewed provide a complete analysis of impact by examining this chain of causal relationships. Most of the conclusions report instead a relationship between the linking of findings on speed or persons involved with a reinforcement measure (type of control), or a variant in implementation (intensity), or the presence or absence of a given factor, which does not constitute a body of proof that offers a convincing demonstration.

Before we examine measures such as police control, photoradar and traffic signs from the perspective of their effectiveness in enhancing safety, it is worthwhile to examine the notions underlying behavioural models, especially in the context linked to driving a motor vehicle and, more specifically, to speed.

Most programs geared to ensuring compliance with speed limits centre on theories of rational behaviour to influence the driver's choice. An initial array of strategies put forward, called dissuasion strategies, seek to ensure that drivers, once they weigh the advantages and drawbacks of breaking the law, deem the drawbacks to be greater and accordingly obey the speed limit (Rotthengatter, 1999). The principle of general dissuasion, as defined by Ross (1982, in Chen *et al.*, 2002), is "the effect of threatened punishment upon the population in general, influencing potential violators to refrain from a prohibited act through a desire to avoid the legal consequences" Based on this principle pertaining to behaviour in the context of driving a motor vehicle, Shinar and McKnight (1985 in Shinar and Stiebel, 1986) introduced the concept, now acknowledged to be crucial to the objective of dissuasion, of "the perception of the risk of arrest." Furthermore, they have suggested that the effectiveness of control measures depends on their ability to influence the perception of the risk of arrest.

Ostvik and Elvik (1990, in Fildes and Lee, 1993) observed in a series of Scandinavian studies that when the level of control, i.e. the real risk of arrest, reached at least three times its previous level, the perception of being arrested (subjective risk) also rose by 40% to 90%. If the perception of the risk of arrest is a critical factor to increase the effectiveness of the dissuasion strategy, it must, according to these authors, correspond to an equivalent real long-term risk.

In the body of literature that we reviewed, the notion of the effectiveness of control measures is evaluated according to activity and the intensity of reinforcement indicators (number of hours of surveillance, number of speeding tickets issued, number of drivers arrested), behavioural indicators (reduction in average speed and the number of drivers who exceed the 85th driving speed percentile), and indicators on collisions and injuries. All of the literature reviews report the results obtained, according to pre-post evaluation design, and some of them compare control with comparison groups. Most of the evaluations use average speed to measure results on speed, a measurement that some authors consider to be less discriminating than speed dispersion.

We will first examine regular police control measures, and then automated control measures.

3.3.2.1. Traditional police control measures

Police control is of two types: control is stationary (or fixed), when the police check speeds from their vehicles at a given location; or it is mobile, when the police travel a certain distance in their vehicles on a segment of road. Similarly, the police can use different technologies to gauge speed and identify vehicles, such as radar, laser or other portable devices. These methods require intervention by police officers parked along the road who must detect speeding vehicles, identify them, and intercept the drivers to issue speeding tickets.

Only one review, by Rotthengatter *et al.* (1999), reports the findings of a meta-analysis, by Elvik, Mysen and Vaa (1997)[15], focusing on 13 studies. This meta-analysis appears to confirm the superiority of fixed controls. The authors estimated that stationary reinforcement would reduce the number of collisions with victims by 6% and the number of fatal collisions by 14%. Armour (1984) and Fildes and Lee (1993) believe that mobile controls are as effective because they prolong the halo effect over a greater distance, i.e. as long as the police car is visible when travelling in the traffic stream. Bailey (1987, in Zaal, 1994), who reviewed the evidence available to compare the effectiveness of the fixed and mobile methods, suggests integrating the two methods into a comprehensive strategy, using stationary control at sites where there is a high collision risk, and mobile if speeding occurs over a long road segment.

Despite the apparent effectiveness of conventional police control in reducing average speed (Hauer and Ahlin, 1982; Vaa, 1997), there is no proof that it affects speed dispersion, a decisive factor in the occurrence of collisions. Furthermore, the impact of police control

[15] Available only in Dutch.

measures on driving speed appears to be limited in time and space. That is, there is a measurable halo effect over time (a memory effect, which is essentially the length of time during which the reinforcement effect is still present after the activity has ceased), and there is a halo effect over distance, (the number of kilometres upstream or downstream from the control site where the reduction in speed is maintained).

The halo effect over time ranges from one day to eight weeks according to the studies, and it appears to be directly proportional to the intensity of the control operations (Hauer *et al.*, 1982; TFD, 1978; Rooijers and de Bruin, 1991, in Vaa, 1997). In a pre-during-post evaluation with a comparison group, Vaa (1997) reports on speed reduction effects that are maintained for up to eight weeks after an intensive measure.

This evaluation, conducted on two-lane roads with 60-km/h and 80-km/h speed limits in semi-rural and rural areas, included nine hours per day of control for six weeks and a combination of stationary and mobile controls at alternating sites to enhance the random effect. The author adds that controls at variable intervals, such as three days of control, three days off and three days of control, are more suited to achieving long-term effects than continuous control.

The halo effect over distance is limited above all to the site where controls take place, ranging from 1.1 km to 3.5 km downstream and 0.5 km upstream. An inconclusive experiment reports effects ranging up to 16 km downstream (Brackett and Edwards, 1977, in Vaa, 1997). According to Hauer (1982), the halo effect on average speed is halved for every 900 m travelled from the control site.

In their experimental study, Hauer *et al.* (1982) evaluated the impact on average speed for the same drivers exposed for several consecutive days to the symbol of reinforcement without being intercepted, i.e. the police were visible but did not arrest offenders. Drivers were spread over four sites and exposed to four degrees of intensity of reinforcement (number of days exposed). The study reveals that, while greater intensity affects the halo effect over time (three days for one day of exposure and six days for five consecutive days of exposure), repeated exposure does not appear to lead to a greater speed reduction in km/h and, according to the author, failed to demonstrate any impact on speed dispersion. We could not conclude from this experiment, conducted over a short period, that symbolic reinforcement alone might maintain long-term impact.

3.3.2.2. Selective traffic enforcement programs

The effectiveness of selective traffic enforcement programs (STEPs) has been demonstrated with respect to the reinforcement of several measures such as seatbelt use or impaired driving (Homel, 1993; Levy *et al.* 1989; Ross, 1992; Dussault, 1990; Johnah and Grant, 1985). When applied to speeding they are effective inasmuch as they succeed in significantly increasing the number of drivers intercepted. To this end, the STEP strategy must satisfy the high-intensity criteria of surveillance and visibility operations and thus heighten the perception of the risk of arrest. Visibility comprises reinforcement operations, advertising and feedback to drivers. Moreover, these operations must be maintained over long periods (Zaal, 1994; Fildes and Lee, 1993), which demands significant police resources (staff and hours). In a less intensive experiment reported by Legget (1990, in Zaal, 1994), the reference period was two years.

Rotthengatter (1999) cites two intensive experiments that revealed significant impact. De Waard and Rooijers (1994) tested three levels of intensity for four weeks by intercepting one offending driver in six, then one in 25 and one in 100. Only the most intensive level, one driver in six, was effective in reducing average speed by between 1.0 km/h and 3.5 km/h. This ratio also reflects a broader police presence and, as a corollary, greater visibility. Rotthengatter also cites an experiment conducted by Vaa (1997) in which the duration of reinforcement was nine hours a day for six weeks, with a reduction in the average speed of between 0.8 km/h and 4.8 km/h and a halo effect that lasted eight weeks.

3.3.2.3. Air surveillance

Air surveillance usually involves a helicopter flying over a series of ground markings. Speeding vehicles are identified by the time they take to cover the distance between two reference points. Information is then transmitted to a highway patrol, which arrests the offending driver.

Nillson and Sjorgen (1982, in Zaal, 1994) attribute longer halo effects over time to helicopter surveillance (17 days) compared with several reinforcement methods (10 day halo effect for conventional radar control). Other authors, in similar studies, report reductions in average speed ranging from 1 km/h to 8.5 km/h (Cairney, 1988; Norrish, 1986, in Zaal, 1994). The biggest study (Kearns and Webster, 1988, in Zaal, 1994) with this type of control examined collision data over a period of 11 months at 14 intervention sites and 14 control sites. The study reported a 23% reduction in collisions at the experimental sites during daylight, and 21% at other times of the day when compared with unmonitored control sites. The authors set the program's cost/benefit ratio at 1:12.

3.3.2.4. Automated controls

Automated speed control methods are similar to police control methods and rely on the same visibility and intensity factors to heighten the perception of the risk of arrest. The main difference refers to the technology used. Speed measurement and the identification of offending vehicles are automated and offending drivers receive speeding tickets by mail once the system has validated the information. The key advantage of this method is its capacity to detect greater numbers of offenders, especially since it can be activated at any time of the day or night, intermittently or continuously, on permanent or temporary sites, on busy roads and, in most instances, without police staffing.

3.3.2.4.1. Photoradar

Photoradar consists of a radar device that detects a vehicle's speed and a film or digital camera that records the licence plate number or the entire vehicle, and the date, time and place of the infraction. Photoradar can be stationary and installed permanently at a location or moved around to increase and diversify the number of surveillance sites. Mobile photoradar can be used in a stationary police cruiser or in a moving vehicle, especially if legislation requires the presence of a police officer.

We took into account six reviews of the literature (IIHS, 2002; Rotthengatter, 1999; Oei, 1996; Zaal. 1994; TRB, 1998) and eight studies (Gaines *et al.*, 2003; Vaa, 1997; Harris, 1995; Hauer and Ahlin, 1982; Chen, 2002; Elvik, 1997; Lamm and Kloechner, 1984; Winnet, 1994) to examine the impact of photoradar.

For behavioural indicators, the reduction in speeding infractions ranges from 38% to 89% (Gaines *et al.*, 2003; IIHS, 2002). Certain authors found reductions in average speed ranging from 2 km/h to 4 km/h (Nilsson, 1992; Legget, 1988; Brackett and Beecher, 1980, in Rotthengatter, 1999), while others reported reductions ranging from 10 km/h to 20 km/h (Lamm and Kloechner, 1984, in Fildes and Lee, 1993; Ostvik and Elvik, 1990, in Zaal, 1994).

As for collision and injury indicators, a meta-analysis covering eleven evaluation studies on the impact of photoradar found that this measure reduced by 19% the number of collisions with victims, with 28% reductions in urban areas and 4% in rural areas (cited in Zaal, 1994 and WHO, 2004).

Several authors have reported collision data findings that reveal reductions of 3% to 51% (ITE, 1999; Brackett and Beecher, 1980, in Rotthengatter, 1999; Oei, 1998; Chen *et al.*, 2002; Zaal, 1994; Cameron *et al.*, 1992, in TRB, 1998). The extent of the reduction in collisions with victims ranges from 0% to 64% (Gaines *et al.*, 2003; ITE, 1999; Nilsson, 1992; Brackett and Beecher, 1980, in Rotthengatter, 1999; Elvik, 1997). Six studies pertaining to this measurement present findings according to seriousness. In these studies, a reduction was observed in collisions involving fatalities or serious injury ranging from 0% to 67% (Gaines *et al.*, 2003; ITE, 1999; Legget, 1988; Brackett and Beecher, 1980, in Rotthengatter, 1999; Cameron *et al.*, 1992; Vulcan, 1993, in Zaal, 1994).

Four broader initiatives warrant special attention. The first major initiative using photoradar was carried out on a problematical segment of the highway between Frankfurt and Cologne, Germany. The study by Lamm and Kloechner (1984) assembled observations spanning ten years (1971 to 1982) and thus compiled the long-term impact of the use of photoradar. While the introduction of a 100-km/h speed limit immediately reduced the average speed by 30 km/h, the introduction of cameras one year later led to a further 20-km/h reduction in the average speed. Moreover, some authors (Lamm and Kloechner, 1984; Ostvik and Elvik, 1990, in Zaal, 1994) estimated a 91% drop in collisions on this road segment compared with 56% on other German highways, a decrease in the number of collisions with victims from 80 to 5, and in annual fatalities from 7 to 0. This impact is linked to the two measures adopted, i.e. a speed limit and reinforcement with cameras.

The second major initiative, in Victoria, Australia, is one of the most frequently cited because it is the biggest intensive program ever launched using photoradar. The program is part of a comprehensive action plan that includes alcohol-related programs, educational programs, and road safety campaigns, which makes it difficult to attribute a net impact to the photoradar program because of confounding effects. However, the evaluations provide a wealth of information on implementation methods and exposure.

The program was launched in 1989 and continued until 1993 for evaluation purposes. With 60 photoradar devices and over 4 000 hours/month of detection, Ogden *et al.* (1992, in Zaal, 1994) report an outstanding level of exposure: 2.4 million of the 2.9 million vehicles registered in the State of Victoria were exposed each month to a speed control. Despite restrictive legislation that made a police officer's presence compulsory at the site of issuing a statement of offence, the authors believe that, on average, each vehicle was likely to be exposed to a control at least once every six weeks or nine times a year. Another intensity indicator reveals that 1 million speeding tickets were issued in 18 months, with the result that each driver either received a notice of violation or knew someone who did.

The initiative's impact on behaviour is also impressive. The number of offending vehicles gradually declined, from 23.9% in 1989 at the outset of the program, to 4% in 1993. Similarly, the proportion of drivers who exceeded the posted speed limits by more than 30 km/h fell from 1.6% to 0.5% during the same period.

As for the road collision toll, multivariate time series analyses estimated that the photoradar control program helped reduce the number of collisions with victims for the entire State of Victoria by 18%, while the seriousness of injuries resulting from these collisions was reduced by between 28% and 40% (Cameron *et al.*, 1992). According to Cameron *et al.* (1992), the evaluation of phases 3 and 4 demonstrated a significant relationship between the number of collisions with injuries and the number of speeding tickets issued and advertising, respectively.

Rogerson *et al.* (1993) analyzed the localized impact of the Australian program, which reveals a significant 10.4% reduction in collisions with victims within one km of the camera control site, an impact linked, in particular, to the number of speeding tickets issued. However, the effects are highly variable depending on the area (rural or urban), the speed zone, the type of road, and depending on whether or not the periods observed involved to some extent drinking and driving.

Gaines *et al.* (2003) evaluated a third initiative, a program implemented in eight regions of England. The two-year pilot project, carried out between April 2000 and March 2002, with pre-post design, covered 599 surveillance sites and sought to establish the relative effectiveness of fixed sites in relation to mobile sites. Previously established criteria determined the choice of surveillance method: fixed (high collision rate at the site) or mobile (less dense or more diffuse collision rate on the road segment). At fixed sites, reductions ranged from 16% to 64% in collisions with victims (at the site) and from 62% to 67% in the case of serious injuries. At mobile sites, the authors' reductions ranged from 0% to 45% and from 0% to 62%, respectively for the number of collisions with injuries and the number of victims. The authors' conclusions confirm that the choice of sites at higher risk for collisions has a greater impact on the number of collisions with injuries.

Elvik (1997) reviewed the analysis of data from a fourth initiative carried out in Norway on 64 road segments totalling 338 km. The design compares pre-post data on collision frequency at all 64 electronic surveillance sites and controls by means of a regression to the mean analysis of general road network trends using the Baysien model (Hauer, 1992). The author reports a significant 20% reduction in the number of collisions with victims in the Norwegian experiment. The most striking observation from this study concerns the examination of impact according to the criteria governing the choice of automated control sites. The author indicates a 25% reduction in collisions with injuries when the choice of site complied with both criteria (a high collision rate and an average annual density of more than 0.5 collisions/km) compared with 5% when the choice of site did not conform to either criterion. The cameras were moved alternately during the project, given the large number of sites, thus illustrating that it is not the permanence of the site but instead the criterion of high risk in respect of the site that affects the outcome. Two observations thus emerge from this study. First, at sites that did not conform to the high collision risk criterion, speed was not the only variable that explained collisions and, as a corollary, that photoradar is not a universal measure to reduce injuries at all collision sites.

Given the limitations of the analysis, which did not take into account data on speed, traffic flows and the intensity of intervention, Elvik (1997) combined this study with seven others to apply the meta-analysis method and in lieu of external validation. The combined findings of the eight studies report a 17% reduction in collisions with injuries, an impact similar to that in the Norwegian study. He was not able to ascertain the project’s long-term impact nor did he take into account the migration of collisions, which could have shifted to sites outside the areas of influence of the control sites.

3.3.2.4.2. Issues and conditions regarding the application of automated controls

Community acceptance of automated detection measures

Zaal (1994) cites experience in Australia, which revealed that the community was favourably disposed to automated detection measures, provided that the sites selected for reinforcement met collision risk criteria linked to speeding. Similarly, he cites the opinion survey conducted by Freedman *et al.* (1990, in Zaal, 1994), which found widespread support for this type of reinforcement, mainly at locations where these measures had already been implemented. The IIHS (1999) mentions the findings of a nationwide telephone survey conducted in the United States in 1995 in which 57% of respondents chose photoradar as the means to reinforce legislation on speeding.

However, the use of photoradar at unwarranted sites where there is no risk of collisions and injuries discredits the measure and makes it more unacceptable to individuals, who perceive it as a way for the central government to levy a tax for its benefit or the benefit of local governments (Zaal, 1994; Rotthengatter, 1999; IIHS, 1999; Paquette, 1998). In Québec, Paquette (1998a) conducted a study aimed at assessing community acceptance of photoradar by means of seven focus groups made up of police officers, community residents and other interest groups. His conclusions reveal an ignorance of or failure to acknowledge the importance of speeding as a safety issue, resistance from police forces to a measure that is perceived as threatening, and widespread mistrust of the government, which, the public alleges, is using the measure as a tax grab.

These findings confirm the need to precede the introduction of photoradar by a rigorous, thorough analysis of high-risk sites linked to speeding. The care required at this stage to choose automated surveillance sites must not be underestimated. The imprecision of accident reports does not always make it possible to objectively recognize the role of speeding at sites where there is a high risk of injury. Similarly, site approval procedures must be adopted to prevent the use of sites for purposes other than safety, which, as a result, would diminish the measure's credibility.

As for the public's perception of a tax grab, the application of criteria governing the choice of sites based on safety means that a massive deployment of photoradar equipment would not arise. Moreover, the effective use of photoradar should generate declining revenues since the number of offenders should fall substantially as impact grows (Ogden *et al.*, 1992, in Zaal, 1994; Paquette, 1998a).

Tolerance limit

Given the pervasive gap between posted and actual speeds, there is agreement on the concept that speed control (detection) is based on a speed threshold stemming from a compromise, reflected in a tolerance limit (Fildes and Lee, 1993). The question that arises is how to determine a tolerance limit that maintains the credibility of posted speed limits from the perspective of safety and is realistic in terms of enforcement. Furthermore, to preserve the principle of fairness among drivers, the tolerance limit must be constant, homogeneous (applicable to limits throughout the road network) and known to users.

Most authors have observed that the tolerance limit is automatically added to the maximum speed margin posted on highways. This speed thus becomes drivers' reference when they choose their speed. For example, if the speed limit is 100 km/h on highways and drivers perceive a tolerance limit of 15 km/h, the reference speed is 115 km/h, a speed below which an infraction will be seen as unacceptable. Experience in Europe and Australia reveals tolerance limits ranging from 3 km/h to 10 km/h or 10% of the authorized speed limit plus 3 km/h to take into account the margin of error. In the United States, it appears to be 16 km/h (IIHS, in Paquette, 1998b). Ontarian experience described by Paquette (1998b) suggests that the detection limit at the outset of the implementation of photoradar focused primarily on serious speeding (excess speed > 15 km/h in a 90-km/h zone), and then was halved when average speeds fell.

Statement of offence

When infractions are detected by automated controls, the identity of the vehicle owner or driver must be verified before the statement of offence is issued. In Australia, highly efficient systems have reduced notification time to two weeks. In light of Australian experience, Rogerson *et al.* (1993, in Zaal, 1994) note that the processing time is largely offset when the perceived risk of interception is very high and, in keeping with behavioural theory, satisfies the argument that it is crucial for the punishment to closely follow on the behaviour that led to it.

Moreover, Paquette (1998) notes the usefulness of notifying the offender at the time of the infraction to ensure transparency which facilitates acceptability and also reinforces the halo effect in the driver's memory. Road signs upstream and downstream from the road segment under surveillance can offer users a general indication that they are entering a control zone or notify the driver that an offense has been detected, such as, "Your speed has been checked". However, officials must avoid allowing drivers to accurately pinpoint the site unless control sites are frequently rotated (Paquette, 1998b).

Right of privacy

Two court decisions, one handed down in Texas and the other in Alberta, pertaining to challenges to speeding tickets issued by means of photoradar, note that the operation of a motor vehicle is not a basic right but rather an administrative privilege and that the examination of the right of privacy in this context is subject to the principles of protection of life and property. In this perspective, rights are limited by regulations and control measures aimed at enforcing them, as Judge Montgomery noted in a judgment handed down in Alberta in the appeal of a case heard under section 7 of the *Charter of Rights and Freedoms* (Paquette, 1998b):

> "[T]he liberty to operate a motor vehicle … is not a fundamental liberty like the ordinary right of movement of the individual, but a licensed activity that is subject to regulation and control for the protection of life and property." (Montgomery, 1990, pages 6-7, in Paquette, 1998b)

Demerit points

When the automated system photographs the vehicle licence plate, the speeding ticket is attributed to the vehicle's owner. Consequently, when the owner is not the driver of the vehicle, certain systems do not record the penalty, in the form of demerit points that lead to the suspension of the driver's licence, on the vehicle owner's record. However, the owner is fined, and is financially responsible for offences committed by the person authorized to drive the vehicle. This situation leads to unfairness depending on whether offences are detected by an automated system or by a conventional police patrol. The message sent is confusing since it reduces the seriousness of the offence by putting it on the same footing, for example, as a less serious one.

Great Britain and Australia have solved this problem by photographing the front of vehicles, including the drivers. Other countries allow vehicle owners to designate the offender when someone else commits the offence. These solutions to driver identification allow for the application of demerit points.

Furthermore, Paquette (1998b) notes, in the wake of a study on demerit points in Québec, that in any case the deterrent effect of demerit points for speeding is limited or non-existent and that it is, for all intents and purposes, impossible to distinguish it from the entire range of infractions. This situation is apparently due to a limited control rate that does not significantly heighten the perception of the risk of arrest. The issue should be reviewed in light of a heightened perception of the risk of arrest generated by automated controls as opposed to traditional police controls.

3.3.3. Reinforcement approaches other than controls

Aside from control measures aimed at reinforcing compliance with the legal speed limit, other measures are used alone or are integrated into a control strategy. Road signs and advertising fall into the latter category, while rewarding is part of a positive reinforcement approach.

3.3.3.1. Automated road signs

Road signs have several uses. Some road signs can display messages aimed at individual drivers, such as, “Slow down, you are going xx km/h,” or at all drivers, such as, “XX% of drivers are complying with the speed limit today” with the purpose to dissuade drivers from exceeding the posted speed limit. While appreciable speed reductions have been reported, the impact, which is highly localized at the road sign site, quickly dissipates and tends to decline when no reinforcement is linked to the measure (Rogerson, 1991; Oei, 1992 and 1994, in Zaal, 1994; Oei, 1998; Keenan, 2002).

The experiments evaluated by Oei (1992, in Zaal, 1994) were carried out in 80-km/h zones on rural roads. The introduction of fixed photoradar devices was preceded by an information campaign and the location of the controls alternated between four sites. Pre-post measurements revealed an average reduction in collisions of 35% on the roads overall. In another study by Oei (1994, in Zaal, 1994), the installation of road signs indicating excess speed in a 100-km/h zone on rural roads preceded by an information campaign sought to reduce driving speed to 70 km/h at the approach to an intersection. In addition to the signs, the police effected occasional controls. The author notes that the impact of the reduction of the 85^{th} percentile speed, from 95 km/h to 70 km/h, declined when police surveillance became sporadic.

Road signs can also be used to display the fines levied for speeding. Pennsylvania tested this type of sign in the 1980s and 1990s but abandoned it when it did not observe any dissuasive impact (Beauchemin, 2003).

3.3.3.2. Positive reinforcement strategies (rewarding)

An impressive body of literature in psychology appears to demonstrate that positive reinforcement, or rewarding, is a more effective way to modify human behaviour than negative reinforcement, especially in respect of health-related behaviour. Zaal (1994) cites several authors who maintain that, in the context of road safety, such incentive programs devoted to seatbelt use have proved to be very effective, especially because of financial incentives. Vaaje (1990, in Zaal, 1994) describes an insurance program, which, after it had fully refunded surplus premiums to young drivers with collision-free records, reported a significant 35% reduction in the collision rate in the 18-22 age group. However, this type of alternative to a negative reinforcement strategy was not applied to speeding. According to Zaal (1994), it could offer a promising avenue for research.

3.3.3.3. Advertising and the media

When advertising and the media support surveillance operations they enhance the impact of control in comparison with control measures alone (Zaal, 1994) because they heighten the perception of the risk of arrest, especially by increasing visibility. To maintain heightened subjective perception, it must correspond to a genuinely high level of risk of arrest (Ross, 1982; Zaal, 1994; Fildes and Lee, 1993).

3.3.4. Driver education programs and driving courses

Christie (2001) notes that driver education programs and driving courses refer to two distinct notions, even though the literature does not deal with them in a distinct way. In this section, we will use the same terminology that the authors use to distinguish them.

3.3.4.1. Driver education programs

The DeKalb Project, carried out in the United States in the late 1970s and in early 1980 to evaluate the effectiveness of an extensive driver education program, is the leading reference to date because it was a large-scale undertaking with robust study design. It covered a sample of over 16 000 students randomly assigned to the Safe Performance Curriculum and Pre-driver Licensing sections offered in schools and a comparison group that was not exposed to either program but whose participants could learn to drive from their parents or at a private driver training school. The close, thorough examination to which this study was subjected and the repeated use of the data have only confirmed the key finding, that exposure to driver education programs cannot be linked to a significant reduction in the risk of being involved in a collision (Mayhew, 1998).

In a major review of the literature on this topic, Mayhew (1998) reports that the most recent evaluations draw the same conclusion. He cites, among others, a major study conducted in Oregon (Jones, 1989, in Mayhew, 1998) devoted to the effectiveness of a high school driver education program that found no significant difference in collision rates in the first year after individuals obtained their driver's licences between drivers who participated in the program and the comparison group that was not exposed to it. Indeed, a Swedish study (Gregerson, 1994, in Mayhew, 1998) even revealed higher collision rates in a group exposed to an enriched driver education program. In New Zealand, another study (Wynne-Jones, 1984, in Mayhew, 1998) suggests that if the impact is null among male drivers, it is negative among female drivers.

More recently, the Cochrane Group produced a literature review on driver education programs offered in Great Britain's schools as collision-prevention measures, as part of a government strategy to introduce this type of intervention within a comprehensive plan to reduce mortality and serious injury by 40% by 2010. This approach, which is supposed to target the 17-21 age group and proposes a program developed by the Driving Standards Agency, involved 125 000 secondary school students (the government wants to include

750 000 other young people). For this review, Roberts *et al.* (2002) selected three studies out of the 926 inventoried that satisfied the randomized and controlled trial criteria, and that evaluated the impact of school-based driver education programs upon young people from 15 and 24 years of age. Those selected were by Strang (1982), Stock (1983) and Wynne-Jones (1984).

The Cochrane Group's conclusions (Roberts, 2002) once again confirm not only that this type of intervention has not demonstrated any potential to reduce involvement by young people in collisions but also that it has a worrisome impact in that the programs encourage young people to obtain their driver's licences earlier, a factor that is linked to an increase in the number of young drivers involved in collisions. Roberts (2002) estimates that a 2% increase in the driver's licence issuing rate would lead to an additional 27 fatalities or serious injuries each year as a direct result of this program in Great Britain. Road collisions in Great Britain account for an estimated 3 500 fatalities and 40 000 serious injuries each year (www.dft.gov.uk/stellent/groups/dft_rdsafety/documents).

3.3.4.2. Driving courses

In the most recent review of the specific effectiveness of driving courses as a road safety measure, Christie (2001) concludes that the acquisition by student drivers of knowledge of legislation and basic driving skills through driving courses does not contribute to reducing collisions involving injuries or traffic violations. The author also offers abundant proof to confirm that training centred on the acquisition of advanced or specific skills, such as controlled skidding, appears to increase the risk of collisions, especially among young males (Christie, 2001). Furthermore, the evaluations show overall that this type of intervention lowers the age at which drivers obtain their licences and subsequently increase their exposure to risk (Mayhew, 1998; Potvin *et al.*, 1988; Christie, 2001; Roberts, 2003).

In Québec, Potvin *et al.* (1988) evaluated the impact of the legislation adopted in 1983 that made driving courses compulsory for anyone obtaining a driver's licence, regardless of age. The time series study tested the impact of this legislation in light of four indicators covering data for 56 months between January 1980 and August 1984. Potvin *et al.* defined the 16-17 age group as the comparison group since it was compulsory for the individuals to take a driving course, while individuals 18 years of age or over were considered as the experimental group. The findings indicate an increase in collisions with or without injuries for all categories of novice drivers regardless of age after January 1983, but more markedly among 16- and 17-year-olds in the comparison group.

Aside from the null effect of the legislation on the collision rate, statistical analyses revealed the only other impact the introduction of the legislation appears to have had was that it masked the increased risk of collisions involving injuries in the 18-25 age group and the lowering of the average age at which driver's licences are obtained. The author explains that, in the absence of economic benefits of delaying the obtaining of a driver's licence until age 18, 16- and 17-year-olds, especially girls, obtained their licences earlier. This led to a 20% increase among girls and a 12% increase among boys under 18 who obtained their driver's licences in relation to the preceding year. This study by Potvin *et al.* (1998), in the

Québec context, confirms the assertion by Robertson (1984, in Potvin *et al.*, 1988) that driver education programs and driving courses are among the least effective of all prevention measures aimed at reducing road collision injuries among young people.

Another author (Mayhew, 1998) reiterates that driving courses provide no additional benefits and even cancel out this measure's impact on safety when the training entitles the driver to a time credit, i.e. when it reduces the anticipated waiting time for a permanent driver's licence with full privileges. Mayhew (1998) attempted to examine the question of training when it is linked to an intervention strategy that consists of inexperienced drivers obtaining their driver's licences in two or three stages The effectiveness of this measure lies in the several stages which lengthens the learning period involving supervised driving with restrictions (Simpson, 2003; IISH, 2003; Foss and Goodwin, 2003, Begg and Stephens, 2003). The accumulation of experience, because it postpones solo driving to a later age and will thus reduce exposure to conditions of risk, appears to be the most convincing contributory factor to the reduction of collision risk among young, inexperienced drivers (Mayhew, 1998; Christie, 2001).

Mayhew (1998) also examined the proof of effectiveness concerning motorcyclists. Based on the strength of several quasi-experimental study designs subjected to analyses with paired comparison groups, this review concludes that training has not been linked to any benefit in the reduction of collisions. The only significant difference observed was drawn from a recent study conducted in Los Angeles (Billheimer, 1996, in Mayhew, 1998) showing that, in the six months following the course, the difference in the collision rates between inexperienced riders who obtained training and those who did not was due to motorcyclists with little or no riding experience prior to the training.

The promotion of driving courses as a means to broaden knowledge and enhance skills follows from the premise that the absence of such skills increases the risk of being involved in a collision. These assertions are, by and large, false and the beliefs are unsupported by any scientific proof. In addition, the acquisition of knowledge and skills does not necessarily alter behaviour, nor does it modify other risk factors to which young drivers are exposed, such as the perception of risk, the road environment, and the absence of controls (Christie, 2001).

The proponents of this educational approach are constantly elaborating modified or improved versions but none of them has yet demonstrated a positive impact on the road collision toll. Thus, emphasis must be placed on alternatives that delay the age at which young drivers enjoy all of the privileges of driving a vehicle and, consequently, delay their exposure to risk, such as graduated licensing not linked to time credits following training.

Since DeKalb's study and all of the ensuing studies conducted in Australia, New Zealand, North America, Europe and Scandinavia over the past 30 years, abundant empirical proof has been collected that unambiguously concludes that neither school driver education programs nor driving courses have enhanced safety or reduced young people's collision risk during the year following their obtaining driver's licences.

3.4. PHYSICAL ENVIRONMENT – RELATED MEASURES

While not all measures focusing on the physical environment specifically target speed, they may still help to decrease speed's impact on the risk of collisions and injuries. Physical measures are often more compelling than legal measures in forcing drivers to slow down, thus modifying their choice of speed in a specific context, such as a residential setting, for example.

The broader field of highway design and road development is partially examined in the socioeconomic environment section, for example regarding the norms for determining speeds. It is not covered more specifically due to a lack of evaluative studies on the impact of speed and driver injuries.

In the first place, the notion of traffic calming and its applications will be reported. The focus will be set on the comprehensive approaches through which these applications can be dealt with in local, regional and national jurisdictions. We are referring here to the management of road development that includes trips and road design, development plans, city plans, transportation policy, and urban transportation plans.

3.4.1. Traffic calming measures

Several expressions are used to designate a single measure, a combination of measures or a comprehensive intervention strategy such as traffic calming and user-friendly streets. We have adopted the expression "traffic calming" in this report because it applies to broader road networks than the expression "user-friendly streets," which applies mainly to urban or residential areas.

Broadly speaking, the traffic calming approach is regarded as a traffic management method adapted to the environment, in particular through an array of measures aimed at reducing speed and rebalancing all needs to allow cohabitation in a given area while enhancing safety. Moreover, one of the key justifications for the adoption of this approach on local road networks is the safety of pedestrians and cyclists, whose risk of injury and death increases exponentially as speed rises, even at the slow speeds designated in urban areas.

The prevailing definition of traffic calming is that of the Institute of Traffic Engineers (ITE): "Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour and improve conditions for non-motorised street users." (Ewing, 1999)

Ewing (1999) emphasizes that this traffic calming approach differs from road infrastructure improvements and signposting aimed at regulating traffic such as stop signs and posted speed limits that require reinforcement. Contrary to measures that require reinforcement, traffic calming measures are designed to be self-enforcing, i.e. they rely on the laws of physics instead of persuasion to lower speed.

The Victoria Transportation Prevention Institute (VTPI, 2003a) in Australia summarizes traffic calming as follows:

- the proposal of road design standards adapted to the urban environment that reflect community objectives;
- the proposal of a comprehensive, local perspective of transportation functions linked to the quality of life;
- the reversal or fair rebalancing of the needs of pedestrians, cyclists and residents through a new hierarchy in relation to motor vehicles;
- the perception of objectives pertaining to the overall volume of motor vehicle traffic;
- the perception of speed reduction;
- broader reliance on alternative non-motorized transportation and a broader mix of users;
- the perception of a reduction in road collision related injuries.

The approach is essentially an environmental one that relies on a combination of mainly physical but also regulatory measures. It emphasizes design to heighten compliance with posted speed limits through physical constraints to encourage drivers to slow down (traffic circles, elevated roadways, speed bumps, curves, and so on) or by acting on perceptions (narrower streets, visual or audible effects, barrier posts, surfaces, and so on).

In the analysis of the effectiveness of the traffic calming approach, a distinction should be made between the comprehensive or area-wide application of measures and the application of individual measures such as traffic circles or speed bumps.

3.4.1.1. Woonerf

The traffic calming approach originated in 1960 in Delft, the Netherlands, where residents decided to halt through traffic in residential neighbourhoods by converting the streets into living spaces. The woonerf concept sought to recover space formerly reserved for vehicles to devote it to other uses such as parking, play areas, benches and tables, thus turning the streets into obstacle courses for motor vehicles and slowing traffic to a speed of about 15 km/h. It led to the total integration of users. The concept, which can resemble a yard or inhabited alleyway, is undoubtedly the most intense, integrated form of traffic calming application.

The woonerf concept, endorsed in 1976 by the Netherlands government, spread during the following decade to Germany, Sweden, Denmark, England, France, Japan, Israel, Australia and Switzerland (Ewing, 1999). The approach was subsequently deemed to be fairly costly and warranted only over short distances and on local streets with limited traffic. The Dutch then sought to apply these principles to a broader range of situations but at lower cost. To this end, the government first endeavoured to compare the effectiveness of the wooneven with two other traffic calming measures, specifically:

- layouts designed to restrict access to streets (dead-end streets) and one-way streets;
- physical traffic calming measures such as those now in use, e.g. speed bumps.

Of the three types of intervention (woonerven, restricted access and physical measures), physical traffic calming measures have been emphasized since 1983 in the Netherlands since they display the highest cost/benefit ratios.

3.4.1.2. Area-wide approach

The comprehensive area-wide approach relies on several of the measures indicated earlier and covers an area greater than a street, such as a neighbourhood or city. We found two meta-analyses focusing on the impact on collisions and injuries of the comprehensive traffic calming strategy in an area-wide zone.

The meta-analysis by Elvik (2001) is often cited and attributes a 15% overall reduction in collisions involving injuries to the approach. It covers 33 studies conducted in seven European countries and Australia over the period from 1971 to 1994. Despite the considerable heterogeneity of the projects, all of the selected studies:

- were carried out in residential zones, often near the business centre in a big city;
- covered an area ranging from 0.25 km^2 to 1.5 km^2;
- involved the classification of the street network;
- introduced measures to reduce traffic volume and complementary speed reduction measures, usually speed bumps; and
- included the addition of signposting on heavily-travelled main streets.

Similarly, all of the studies selected are pre-post, non-experimental, non-randomized, open studies, none of which meets all of the quality standards set by Hauer (1997) for pre-post studies, as the author emphasizes.

Elvik (2001) notes that all of the studies reveal a reduction in collisions. The author reports that area-wide measures (when main and local roads are combined) achieve a significant 15% reduction in collisions, but that the same is not true of local roads alone, where non-significant reductions in collisions ranging from 10% to 24% were observed. Similarly, on main roads, the results are very heterogeneous, with non-significant reductions ranging from 7% to 41%.

When the studies are regrouped according to the robustness of design, the most acceptable studies (pre-post with paired comparison groups) for the area-wide zone reveal a significant 12% reduction in collisions involving injuries (95%; IC: -21, -1), the less robust studies reveal an even greater impact of up to a 36% reduction. The most robust study (Ward *et al.*, 1989a, b, c) measured a 9% reduction in collisions involving injuries. Elvik (2001) notes that over the 25 years covered by the studies in question, the downward trend for collisions involving injuries remained constant, regardless of the period in question. The impact is similar in all countries.

The author also notes that, in the analysis of impact, the relationship between the number of collisions and the speed reduction measures is mixed up with measures designed to reduce the volume of traffic. Indeed, according to Elvik, a trend has been noted whereby the biggest reductions in collisions are linked to the biggest reductions in the volume of traffic.

Another meta-analysis by Bunn *et al.* (2003), conducted by the Cochrane Group, examined the potential of comprehensive area-wide measures to reduce collisions involving traumas (deaths and injuries). The analysis covered 16 non-randomized pre-post studies with control groups carried out over a period of 20 years (1970 to 1990), most of them in Europe (seven in Germany, six in Great Britain and one in the Netherlands) and two in Australia. The measures evaluated were implemented in residential areas near the commercial centre of a big city. To be included in the group of measures, the studies had to combine two or more traffic calming measures, which modified road design, the road network hierarchy or the environment. Legal, educational or fiscal changes were excluded. Conversely, projects in the control group were characterized by the absence of engineering measures or the presence of studies describing legal, educational or fiscal measures. The anticipated objective was to demonstrate the impact on safety through changes made to the physical environment compared with the impact stemming from the absence of such measures or attributable to other measures.

The combined findings of the 16 studies reveal a non-significant 11% reduction in collisions with injuries (injuries and deaths) (95%; RR.-0.89 IC: 0.80-1.00). In the eight studies that measured the number of fatal collisions, the reduction in the combined studies is 37% (95%; RR.-0.63 IC: 0.14-2.59). These non-significant findings must be interpreted cautiously since the numbers involved are often very small. Nine studies report the total number of collisions and the combined findings indicate a relative risk under 5% in the intervention group compared with the pre-post control group (95%; IC: 0.81-1.11). The 13 studies that report data on the number of collisions involving pedestrians did not show any impact between the intervention group and the control group.

The authors (Bunn *et al.,* 2003) emphasize that the analysis, which controls for randomized impact to take into account the studies' considerable heterogeneity, can explain in part these conservative findings. While the analysis cannot conclude that area-wide traffic calming measures were effective in significantly reducing collisions and collisions with injuries the authors note that the impact observed in most of the studies is similar.

Aside from these two meta-analyses, two reviews of the literature (Stuster and Coffman, 1998; Victoria Transport Policy Institute, 2003b) report essentially the same conclusions, that few studies have clearly demonstrated that traffic calming measures reduce the incidence of motor vehicle-related injuries and deaths, primarily because of the difficulty in establishing a direct causal relationship for an array of measures. To this we add the blurred results or interference created between effects attributable to traffic volume reduction or to speed reduction as intermediate effects. Several of these measures also ease down conflicts between users whose speeds differ widely. However, the growing literature on the topic, including several serious evaluations, supports the hypothesis of a promising approach with most studies revealing a positive safety impact.

Stuster and Coffman (1998) maintain that measures that lead to a vertical deviation, such as speed bumps and speed tables, are the most effective but that their effectiveness also depends on spacing. The biggest reductions in speed and collisions resulted from a combination of measures, and the traffic calming strategy systematically covered a broader area-wide zone than several isolated streets. Since most of the collision data are drawn from police reports, another limitation of the array of studies reported upon concerns the measurement of pre-collision speeds.

Physical measures that modify traffic by imposing constraints on vehicles such as horizontal or vertical deflections are said to be self-enforcing or passive because they do not require a police presence to be effective. Conversely, so-called active measures, which deflect, restrict or prohibit, and depend on compliance with prescriptive signs, may require police surveillance to be effective. Consequently, regulatory measures that rely on surveillance are not as effective as self-enforcing measures over time (ATC/ITE, 1998).

3.4.1.3. 30-km/h zones

A 30-km/h zone is a road segment or series of road segments that make up a homogeneous traffic zone in which the speed is limited to 30 km/h. These zones are in residential or commercial areas, and usually (but do not always) have a fairly high density of pedestrians and cyclists. Indeed, this concept involves, like woonerving, a redefinition of the hierarchy of modes of transportation to favour pedestrians and cyclists over motor vehicles.

The 30-km/h zone first requires amendments to speed by-laws and changes in road layout. It is an urban project that calls for the user-friendly organization of space: street furniture, qualitative treatment of public space and pedestrian crosswalks, specific treatment of crossroads and devices to slow down traffic such as chicanes, textured pedestrian crosswalks, curb extensions, landscaping, and so on. Signposting and specific layouts indicate the zone's entrance and exit.

The 30-km/h zone has been implemented in Great Britain, Germany and France, where the zone was created in the 1990s. By late 1999, there were over 2 000 30-km/h zones in French communes (municipalities).

The traffic calming approach is applied to varying degrees depending on whether the 30-km/h zone is subject to a speed bylaw alone or is sustained by physical development. There are different levels of application of the concept.

In Graz, Austria, 10 years after the introduction of 30-km/h zones, the city decided to apply the concept to the entire local road network, except for the transit network, where the speed remained at 50 km/h. This project was part of a transportation strategy that promoted walking, cycling and mass transit. The findings indicate a 12% reduction in collisions and a 0.5-km/h reduction in average speeds between intersections and 2.5 km/h at intersections. Moreover, the proportion of drivers who drove over 50 km/h fell from 7.3% to 3%. However, when the reinforcement was halted, speeds gradually returned to their previous levels (Wernsperger and Sammer, 1995 in UK Department of Transport).

Another study, from Sweden, focuses on individual measures such as speed bumps incorporated into 30-km/h zones. Engel and Thomsen (1992) showed that the latter measure in a 30-km/h zone reduced collisions with victims by 45% for up to three years after the intervention. These collision reductions are attributable to the speed reduction brought about by the introduction of speed bumps in the context of this speed limit.

Only one study was found that measured speeds before and after the implementation of three different levels of application of the 30-km/h zone. In the first region considered in this Swedish study, only the posted speed limit was reduced from 50 km/h to 30 km/h, and no significant reduction was observed from the prior 85th percentile speed to that observed roughly three months after the introduction of the signposting (35.8 km/h to 34.3 km/h).

In the second region, where signposting was added at the entrance to the zone, the 85th percentile speed fell from 39.0 km/h to 36.7 km/h. When examined individually, the 48 observation sites did not reveal any significant change but when they were combined for each of the two regions, the data indicate a significant decrease included in the 90% confidence interval.

A third region in which other traffic calming measures were introduced has still not been evaluated. Ekman (1996) notes, however, that the decreases fell short of expectations.

In 2003, North Vancouver introduced speed bumps in 30-km/h zones. This policy requires a petition from residents, an engineering study confirming that the site satisfies predefined criteria, and follow-up to ascertain the measure's effectiveness.

It should be noted that this type of road development, because it affects traffic in neighbouring streets and in drivers' route choices, must be part of a broader perspective, and be integrated into urban transportation planning as well as land-use planning.

3.4.2. Specific measures

There are several ways to classify traffic calming measures that affect the environment. A first typology classifies them as physical, self-enforcing (passive) measures, as distinguished from legal, prescriptive (active) measures (ATC/ITE, 1998).

Control measures include reduced-speed zones (30 km/h), one-way streets, restrictions on heavy vehicles, and dedicated roads. Design measures refer to components such as a dead-ends, gateways, traffic circles, staggered intersections, chicanes, traffic islands, speed bumps, raised or textured surfaces, and narrowed traffic lanes.

The *Canadian Guide to Neighbourhood Traffic Calming* (1998) proposes a division by function: vertical deflection, horizontal deflection, barriers and signposting. This classification is not exhaustive since it excludes certain measures such as development and the environment along streets.

The next section examines the best documented physical and self-enforcing measures individually. Regulatory and legal measures will be grouped together and reviewed in the socioeconomic environment-related measures section.

3.4.2.1. Traffic circles

A traffic circle comprises a traffic lane surrounding an island or a raised impassable circular median strip (> 4 m) (AQTR, 2002). Traffic moves counterclockwise and drivers in the traffic circle have priority and compel approaching drivers to reduce their speed because of deflection, also described as the obligation to deviate from a straight line. In 1998, intersections accounted for half of collisions involving injuries in the United States. Traffic circles eliminate violations at red lights and limit crossing conflicts that cause a number of critical collisions with severe injuries. The limitation of complete stops enhances traffic flow and reduces gas consumption. Speed is controlled by the dimension of the central island and the traffic circle's very geometry compels drivers to slow down. To be safe, traffic circles must include traffic islands at their entrances and on approaches for pedestrians and cyclists. There are several types of traffic circle, including normal circles, mini-traffic circles and double traffic circles, chosen according to the volume and speed of traffic or the presence of pedestrians, the number of lanes, and so on.

Retting *et al.* (2001) attribute the effectiveness of traffic circles to two key factors: they induce a speed reduction and eliminate conflicts at intersections. Fildes and Lee (1993) mention effective means to break up the length of road segments without causing undue delay. Herrstedt (1992, in Fildes and Lee, 1993) notably concluded that big traffic circles are effective in reducing speed at gateways but that mini-traffic circles are not effective. Big traffic circles are also more effective when traffic is light to moderate and at three- or four-branch intersections.

While traffic circles are common in Europe and Australia, they were only introduced into the United States in the 1990s. Few studies have evaluated the impact of traffic circles on the road collision toll and on health. Retting *et al.* (2001) mention several studies reporting substantial reductions in collisions and cite, in particular, the study by Schoon and Van Minnen (1994) that examined 181 intersections converted into traffic circles in the Netherlands. They report a 47% reduction in collisions, a 71% reduction in injuries, and an 81% reduction in collisions that required hospitalization. In Australia, Troutbeck (1976) also reports a 74% reduction in collisions with injuries after 73 intersections were converted into traffic circles. Retting *et al.* (2001) cite the study from the United States by Flannery and Elefteriadou (1998), who observed eight traffic circles with promising results. Retting *et al.* (2001) believe that these studies may have overestimated the extent of gains because of limited statistical analyses. Therefore, they repeated the analyses of the 24 initiatives launched to convert intersections to traffic circles in California, Colorado, Florida, Kansas, Maine, Maryland, South Carolina and Vermont, between 1992 and 1997. Fifteen of the 24 initiatives are found on single-lane roads and nine on two-lane roads.

The pre-post study by Retting *et al.* (2001) applied the Bayes procedure. This procedure reduces the degree of uncertainty in the findings that take into account differences in traffic volume and the period covered by collision data before and after the implementation of the measures, assuming a Poisson distribution. In light of these statistical analyses, the findings for collisions overall reveal a significant 38% reduction at the 24 sites combined and a 76% reduction for collisions with injuries. The reductions observed are similar for single-lane per direction for urban and rural roads that were converted from intersections with stop signs (two or more) into traffic circles. Partial findings regarding roads with two or more lanes per direction are not as conclusive. Similarly, impact on mortality and collisions that led to disabilities could not be measured as reliably because of the small numbers. However, the reduction in the number of deaths (from 30 to none) and disabilities (from 27 to 3) before and after the measure is substantial (89%) and proved to be significant ($P < .001$).

Based on a literature review of evaluation studies focusing on initiatives to reduce collisions between motor vehicles and pedestrians, Retting *et al.* (2003), conclude that traffic calming measures have the greatest potential to prevent injuries in residential areas where there are numerous children. Citing studies by Brilon *et al.* (1993) in Germany, Schoon and Minnen (1994) in the Netherlands, on the basis of pre-post and no control design studies and no verification by regression to the mean, Retting *et al.* (2003) report that the conversion of intersections into traffic circles appears to have reduced the collision rate between motor vehicles and pedestrians by 25% to 73%. The study by Brude and Larsson (2000, Retting *et al.*, 2003) in Sweden showed that the frequency of collisions with pedestrians was one-third or one-quarter the anticipated level at intersections with traffic lights because of the introduction of 72 one-lane traffic circles. The authors report no difference for traffic circles with two lanes per direction.

3.4.2.2. Speed humps

A speed hump is a raised table that deflects the wheels and the chassis of a vehicle that crosses it (ATC/ITE, 1998), and is designed to reduce speed. The dimensions and the spacing between humps determine the speed beyond which speed humps cause vehicle occupants' discomfort. They are found on local residential and collector roads, usually in 30- to 50-km/h zones. They should not be confused with speed bumps (which are shorter and more abrupt than speed humps). Speed bumps are principally intended for parking lots.

Engel and Thomsen (1992) analyzed the impact of several measures, including speed humps, in 15-km/h and 30-km/h speed zones in residential areas in Denmark. The findings of this pre-post study with a control group did not reveal any significant reduction of collisions per km travelled in 15-km/h zones compared with the 19 000 km in the control group. Moreover, in 30-km/h zones, the authors report a 24% reduction in collisions and a 45% reduction in collisions with injuries over a three-year post-intervention period. An 18% reduction in collisions and a 21% reduction in collisions with injuries was also observed in streets adjacent to the 30-km/h zone. These findings are significant ($p < .05$). Another measurement of impact, according to the kilometrage travelled by users, reveals a 72% reduction in the number of injuries in regions where measures were adopted compared with regions where no measures were adopted.

In the same study, Engel and Thomsen (1992) sought to pinpoint the factors that most significantly affected changes of speed from the pre to post period on the 1 002 segments observed. It was possible by means of the regression analysis to calculate changes in speed in the wake of the implementation of six different measures. The model reveals that the height of the speed humps appears to explain, by and large, the reduction in speed. For each centimetre of height, the reduction in speed observed in relation to the anticipated speed was 1 km/h. A 10-cm speed hump should thus cause a 10 km/h reduction in speed. Fildes and Lee (1993) cite the literature review by Stephens (1986) centred on numerous empirical studies on the effectiveness of speed humps conducted in Australia, the United States and Great Britain. Stephens (1986) apparently found that pre-post speed reductions were biggest where speeds were highest prior to the implementation of measures and concurrently that the smallest reductions, on the order of 10 km/h, were observed at sites where pre-intervention speed was the lowest (between 30 km/h and 40 km/h).

3.4.2.3. Other measures

Measures that call for a narrowing of traffic lanes, such as chicanes, which are sidewalk curb extensions projecting into the road, appear to reduce speed by 4.7 km/h in the case of double chicanes and by 2 km/h in the case of single chicanes. Similarly, the study by Engel and Thomsen (1992) revealed that the impact on speed reduction at 30 km/h extended up to beyond 50 m from either type of chicane.

The treatment of gateways and through roads is a specific method of intervention through which drivers are notified that they are about to enter a transitional zone between rural and urban areas and that they must reduce their speed. The measure usually involves narrowing the traffic lanes and adding vertical elements that give the illusion of entering through a door. We did not review the impact of this type of treatment on collisions and injuries. However, such intervention appears to have had variable impact on the reduction of speed depending on the type of layout, the number of lanes, and so on.

There was no examination of individual speed-reduction measures such as rumble strips, raised intersections and islands, some of which are aimed primarily at managing pedestrian crosswalks, due to limited documentation on each measure's effectiveness.

Furthermore, with regard to measures aimed specifically at pedestrians, a study by Retting *et al.* (2003) divides such measures into three categories: the separation in time and space of pedestrians, measures that enhance visibility, and measures aimed at reducing vehicle speed. While measures such as sidewalks, advanced stop bars, barriers and refuge islands designed to separate pedestrians from traffic focus more on reducing their exposure along roads and at intersections, speed reduction measures such as traffic calming, speed control and chicanes appear to decrease the likelihood of collisions and the severity of injuries.

As for the effectiveness of measures to modify the physical environment in reducing speed and preventing injuries among pedestrians, Retting *et al.* (2003) reviewed six evaluation studies, mainly pre-post studies without comparison groups or control for regression to the mean that examined impact. Three of the studies focusing on traffic circles report an average reduction of 75% in collisions involving pedestrians (Retting *et al.*, 2003). One study (Brilon and Blanke, 1993) and one systematic review of 13 studies (Bunn *et al.*, 2003) examined the impact on pedestrians of the area-wide traffic calming approach. While the first study, which is less robust than the others, indicates a 25% reduction in collisions with pedestrians following modifications, the review by Bunn *et al.* reports a relative risk of 1.00, which indicates that this type of measure had no impact on collisions involving pedestrians.

In a recent report on maintaining a physically active life through daily transportation, WHO (2002) inventoried European experiments over the past 20 years that revealed the positive impact of more extensive walking and cycling and the enhancement of safety. Among the measures linked to these results (the key objective being to reduce speed), WHO's recommendations head the list: traffic calming, especially in 30-km/h zones, the presence of sidewalks, public policy that fosters respect for and the place of pedestrians and, in the longer term, the revision of urban land-use planning policies.

Among these policies is the *European Charter of Pedestrian Rights,* adopted by the European Commission in 1988, and designed to create favourable environments. The US Centers for Disease Control and Prevention (CDC) launched an initiative in 1997 that assembled 30 experts in different disciplines to find new ways to promote physical activity. The initiative promoted the *Pedestrian and Cyclist Equity Act* (PACE) tabled in Congress, a bill calling for US$280 million in funding to test projects such as the Transportation and Active Living Program and the Safe Routes to School Program.

3.4.3. Comprehensive management of development

3.4.3.1. Urban travel plan

The urban travel plan (UTP) is a local urban travel planning document that is intended essentially to define a comprehensive system for the transportation of individuals and goods within city boundaries. This tool can be useful to ensure safe travel in the city. Urban travel plans were initiated in France in 1982 and consolidated in 1996 under legislation governing air quality and the rational use of energy. The legislation proposes fairly innovative guidelines with a view to "ensuring sustainable balance between the needs for mobility and ease of access and environmental protection and health" (Fleury, 2000). [TRANSLATION]

The first UTPs were highly heterogeneous but, despite certain shortcomings, adjustments made it possible to redirect initiatives and objectives from the point of view of reducing the number of collisions with injuries in the medium term. Most of the measures focus on the environment to reduce speed, such as introducing 30-km/h zones, gateways or neighbourhoods, and layouts devoted to pedestrians and cyclists. We have not found an evaluation that allows us to pass judgment on the safety advantages of this management method. However, we understand the UTPs are an upstream tool for any planning to enhance traffic conditions because they offer a community-wide anchor to launch and justify studies, objectives and more precise intervention projects.

3.4.3.2. Road design

"The road's geometric characteristics affect a driver's behaviour and, more specifically, the speed at which he travels. Wide, flat, straight roads encourage high speeds" (Bellalite, undated). [TRANSLATION] Among the measures intended to ensure coherence between road design and drivers' expectations in order to limit the number of mistakes made, the reduction of inconsistencies between driving speeds and road characteristics have been examined by several authors (Anderson *et al.*, 1999; Poe *et al.*, 1996; Garber and Gaadiraju, 1998; Bellalite, undated; TRB, 1998; FHWA, 1995). Inconsistencies between design speed, posted speed and actual speeds, because they generate broader speed dispersion, are a contributing factor to the risk of collisions (Poe *et al.*, 1996, in TRB, 1998). To counteract this adverse effect, certain authors (Poe *et al.*, 1996; Garber and Gadiraju, 1998, in TRB, 1998) report that a new approach demonstrates potential for reducing collisions by achieving a greater convergence of design speed and travelling speed during the planning stage. However, more research is needed to determine the true benefits before extending this approach.

3.4.3.3. Treatment of the areas surrounding roads or perceptual measures

The characteristics of the roadway and the area surrounding it help explain driving speeds. According to Martens (1997, in Bellalite, undated), visual influences apparently play a key role in determining such speeds. Martens bases his claim on experiments in which a reduction in side clearance was accompanied by a speed reduction on the order of 13% to 16%. The observational study conducted by Bellalite (2003) in Québec on actual driving speeds in relation to the layout of the areas surrounding roads confirmed this trend in 50-km/h zones on two-lane regional roads and on through roads in small urban centres.

3.5. VEHICLE-RELATED TECHNOLOGICAL MEASURES

Technological developments over the past 10 years offer another approach to speed management and numerous possibilities for application. Since the advent of conventional systems such as cruise control, used above all on fast lanes or highways, more advanced technologies have appeared such as speed-limiting devices, smart cards and other electronic sensors. These technologies are classified as intelligent adaptive systems and are regarded as driving aids. The devices inform or warn the driver, or fully take over certain manoeuvres, either to maintain a safe distance between vehicles, allow for a lateral movement, or reduce speed. They can thus be used in voluntary mode with human intervention, and are one of the means designed to reinforce appropriate behaviour or to dissuade drivers from breaking the law, especially the authorized speed limit. In automatic mode, they apply the principle of intrinsic or structural safety to maintain the authorized speed through a control external to the driver.

3.5.1. Speed limiters

Speed limiters are control systems that confine a vehicle to a speed set either by the driver (selective) or by means of an external command (automatic). The vehicle responds to information without intervention by the driver to adapt to the authorized speed limit. The operation of a speed limiter is governed by an electronic device installed in the vehicle that compares the vehicle's speed to a limiting value. Driving is normal below this value. When the value is reached, the on-board computer takes control of the ignition system, fuel flow, the accelerator or the brakes and the maximum may not be exceeded or is re-established gradually if the vehicle enters a lower speed zone.

A device allows the driver to temporarily override the speed limiter to pass or react to an emergency, up to roughly 20% above the limiting value. Hyden (1987, in Varhelyi and Mäkinen, 2001) found that acceleration as an avoidance measure was used in only 2% of collisions and conflicts contrary to the widespread belief that the need to accelerate is an important manoeuvre that is deemed to hinder the use of speed limiters.

There are currently two types of speed limiters:

- in a "maximal" speed limiter, an electronic device in the vehicle usually regulates the flow of gas to prevent the driver from exceeding the highest maximum authorized speed limit in effect (90 km/h or 100 km/h). This type of speed limiter applies only to main roads and highways;
- adaptive speed limiters confine the vehicle to a variable speed determined either by the driver (selective) or by means of an external command (automatic) that adjusts to the authorized speed, depending on road network position through signalling posts or the global positioning system (GPS). A more advanced generation of these limiters can make them dynamic when speed is adapted to information that takes into account temporary factors such as road conditions, temperature, traffic jams, road closures or construction, and school zones.

Similarly, these systems can be described by the degree of external constraint they exercise, as indicated below:

- in informative mode, a simple speed display unit indicates to the driver by how much the authorized speed may be exceeded or an audible alarm connected to the odometer warns the driver, sometimes until the legal speed has been reached. Other options add resistance to acceleration when the speed is exceeded;
- in voluntary or selective mode, the driver can activate or deactivate the system;
- in automatic mode, a control external to the driver limits the vehicle to the legal speed at all times[16].

[16] The driver can briefly override the system at any time and accelerate to a limited percentage of the legal speed in order to pass or engage in another manœuvre.

Speed limiters in which the maximum speed is set in the factory have already been adopted on mopeds and tractors in France and, more recently, on heavy trucks under Geneva Regulation No. 89 elaborated by the United Nations over a decade ago and adopted by the European Community. Since January 1, 1996, speed limiters have been introduced in 15 member nations of the European Union for all heavy trucks over 12 tonnes registered since January 1, 1988 and for buses over 10 tonnes. The maximum speeds proposed, 90 km/h for goods and 100 km/h for passengers, are considered acceptable. In December 2001, a directive was adopted to broaden the field of application to all heavy vehicles over 3.5 tonnes. The retroactive application of the measure to all eligible vehicles was to come into force in 2006.

Experimental projects devoted to adaptive speed limiters are under way in the United Kingdom, Sweden, France and the Netherlands. Experiments have been conducted since 1990 in Sweden, since 1997 in the UK, and since 1999 in the Netherlands and France (the LAVIA project). Other projects are under way in Belgium and Denmark.

Evaluations are focusing on the technology's reliability, its acceptability to users, its overall safety impact (collision reduction) and its effects upon pollution. While the experimental models differ somewhat, they reflect a shared determination in Europe to test the applicability of speed limiters in relation to different speeds and driving contexts, and to compare the findings in light of the different types of limiters or speed control methods (voluntary, selective or automatic).

An initial evaluation phase examined models obtained by simulation. Adaptive speed limiters are still in the experimental stage. The anticipated theoretical impact on road safety or the reduction in collisions and injuries centres on the relationships observed when the average speed and the variance between observed speeds falls. According to the modelled evaluations of the speed limiter project in Great Britain that applied the most recent research by Baruya (1998a, b), the reduction in casualty collisions varied from 10% to 59% depending on the type of limiter and the utilization rate (the greatest impact was linked to more exhaustive use) (Carsten and Fowkes, 2001). British researchers believe that to achieve a significant impact on traffic overall, at least 15% to 20% of the vehicle fleet must be equipped with speed limiters.

The most significant initial assessments in the field were conducted in Sweden. The trials conducted on nearly 5 000 vehicles in four cities for three years, from 1999 to 2002, compared three modes: informative, with warning, and active (resistance to acceleration). Biding and Lind (2002) report a positive impact on safety and behaviour. These authors observed an average speed reduction of 10%, even though a very small proportion of vehicles was equipped with the device. Average speeds fell by between 3 km/h and 4 km/h and were more homogeneous. The authors noted few differences between the three modes.

Another pre-post study with a quasi-experimental study design was conducted in Sweden, Spain and the Netherlands, in urban and rural areas, with drivers between 25 and 55 years of age. An automated speed limiter was used equipped with resistance on the accelerator sufficient to dissuade drivers from exceeding the speed limit. The device had a statistically significant impact in reducing average speeds by between 5 km/h and 10 km/h in urban zones where the legal speed ranged from 30 km/h to 60 km/h. In rural areas, a significant reduction in average speeds occurred solely on roads with a 70-km/h speed limit. Significant impacts on the reduction in variations in speeds were noted (Varhelyi and Mäkinen, 2001).

Around the use of the speed limiter, three studies examined the impact on incorrect behaviour (speeding in curves and failure to yield) in respect of pedestrians and cyclists and reached different conclusions. Results showed no effect according to Varhelyi and Mäkinen (2001), an increase in incorrect behaviour according to Persson *et al.* (1993), and a decrease in such behaviour according to Almqvist and Nygard (1997).

As for the acceptability criterion, a Swedish study also reports a high social acceptability rate, higher than in respect to seatbelt use prior to the adoption of legislation (Biding and Lind, 2002). Between 70% and 80% of drivers who tested the speed limiters regard the concept as effective and two-thirds of them would continue to use the system were it free of charge, while one-third of the respondents would be willing to purchase it at a reasonable price. The authors also report a significant reduction in collisions involving injuries and a decrease in negative interactions with other users (pedestrians and cyclists), and a broader overall awareness of safety.

Similarly, in the experiment conducted in Spain, Sweden and the Netherlands, Varhelyi and Mäkinen (2001) note, in the wake of an opinion poll, that the least restrictive systems (informative as opposed to automatic) are the most acceptable. Acceptability also apparently rises when speed limits are credible and drivers acknowledge the relationship between speed, collisions and injuries. Moreover, one-third of the 66 participants in the experiment believe that a selective system should be compulsory and 50% of them would install such a system voluntarily (Varhelyi and Mäkinen, 2001).

In addition to this impact on safety and speed, there is a positive impact on the environment directly linked to reduced gas consumption. Gas savings linked to speed limiters in the project in Great Britain apparently ranged from 1% to 8% depending on the type of road. In the Netherlands, a cost/benefit study on the reduction of the speed of motor vehicles concluded that simply maintaining existing maximum speeds would help reduce gas consumption and curb polluting CO_2 emissions by 11% and NO_x emissions by 15% (Dutch Ministry of Transport, 1999).

Among the adverse effects of speed limiter use (lengthening of passing time, reduction in the distance between vehicles) the British study at Leeds University did not attribute any observable adverse effects to the devices (Carsten *et al.,* 2001).

3.5.2. Black boxes

Black boxes, which record cockpit conversations and flight data, have long been used in aircraft. They are used in crash investigations to determine the cause of mechanical failures and, possibly, to remedy shortcomings. This technology adapted to road vehicles to record traffic data was first used by automakers in the 1970s to test or improve systems. Starting in 1999, General Motors, followed more recently by Ford, has incorporated event data recorders in certain models, which record and store data for several seconds before and during a collision when the airbags deploy.

How can this technology help prevent collisions and speeding-related injuries? These electronic indicators fall midway between technology and behavioural change. Black boxes can broaden engineers' knowledge from the safety perspective when they are used to objectively analyze the causes of collisions (expert reconstructions), or they can be used to openly monitor individuals with a view to influencing their behaviour.

There are two types of systems. One system, which is found on commercial vehicles mainly in Europe and certain American ambulance fleets, is designed to manage entire fleets in order to control hours of driving, speed, distance travelled, and certain manoeuvres, thereby reducing fuel and insurance costs while also limiting pollution. Another data registration system more specifically documents collision information. In this instance, speed, braking, seatbelt use, engine rpm and other technical information is recorded for a period of 5 to 50 seconds before a collision and up to 5 seconds afterward, thus providing a sequential snapshot of conditions surrounding the event.

Several experimental evaluations reveal the potential preventive impact of collision data recording devices. Lehmann and Reynolds (undated) reported the findings of experiments conducted on black boxes to document their contribution to collision prevention. Laidlaw, an American school bus manufacturer, incorporated data recording systems into half of its buses and for six months compared them with vehicles not equipped with the devices (comparison group). Follow-up of the bus drivers' management of their manoeuvres recorded minute by minute was provided, ultimately with a view to modifying their behaviour. The school buses without a black box were involved in 72% of the collisions inventoried compared to 28% in the experimental group. The authors of this research estimated a 30% reduction in collisions for this group, or 19 fewer than the 62 anticipated.

A quasi-experimental research project with pre-post design and a control group was carried out in conjunction with the SAMOVAR Project under the European Community research program (SWOV, 1997). Of the 840 vehicles included in the study, 270 were equipped with a surveillance device then available on the market. The theoretical objective underpinning the demonstration was to show that drivers who knew they were being observed or faced with feedback on their manoeuvres would alter their behaviour.

In this study, seven experimental groups of vehicles were compared with 12 comparison groups without the devices. Collision data and exposure data were collected for one year prior to and one year subsequent to the installation of the devices. The study revealed a statistically significant reduction in the number of collisions in several groups in which driver behaviour was thus controlled. The small samples can explain in part the wide confidence intervals. Having examined the overall findings for all of the groups, the study's authors estimate a 20% reduction in the number of collisions and a 28% decrease in the collision rate for equipped vehicles. However, the authors emphasize that more research is needed, particularly on ways of sustaining long-term effectiveness (SWOV, 1997).

In the same vein, the oft-cited experiment conducted by the Berlin police in 1996 in which 62 patrol cars were equipped with black boxes revealed a 20% reduction in the number of collisions attributable to drivers and 36% in the case of urgent trips. The authorities subsequently decided to install the black boxes in all 400 vehicles in the police fleet.

As for the potential knowledge to be drawn from these objective witnesses, they make it possible to pinpoint vehicles' system flaws and to enhance preventive devices such as seatbelts, airbags, brake systems, and so on.

In 2003, the black box technology was adapted and marketed with respect to young drivers. Parents rely on its key function of recording data as a surveillance, supervision and control tool. Using the smart card, they can observe in real time or *a posteriori* compliance with directions given to young drivers concerning speed, seatbelt use, abusive braking or erratic driving, and apply penalties or other measures such as a temporary ban on driving or any other restriction.

Beyond the deterrent effect sought, some observers have proposed extending the use of this device in individualized control mode as an alternative or complement to the suspension of the driver's licence, for example in cases of repeat speeders, in the same way as the alcohol-ignition interlock device is used (Got, 2003).

The question of the ownership and use of data collected by the black box has not been settled, but attempts are being made in the United States and Germany to define fair, acceptable standards of practice that take into account both privacy and researchers' needs for reliable objective data, especially when the most serious collisions that activated airbags are analyzed. In Québec, the recent case of a fatal collision shows how the data were used in court to indicate that the vehicle was going 157 km/h in a 50-km/h zone, despite the defence's attempt to dismiss proof provided by the black box. Moreover, the same information could be used to demonstrate technical rather than driver failure.

Some positive findings indicate that the potential deterrent effect of an individual's awareness of being observed suggest that the introduction and use of black boxes can be evaluated in light of the following criteria:

- they add, through the choice of data recorded, the safety dimension to gas savings and pollution reduction in commercial, ambulance or police fleets;
- they link financial incentives to voluntary use of black boxes, with discounts on insurance premiums, for example;
- they rely on the notion of transparency (acceptability) whereby those who have done nothing wrong have nothing to fear (this silent witness can even show that the driver's behaviour was not in question during the incident);
- they can be used to penalize repeat offenders, provided that detection systems make it possible to pinpoint them;
- police or government vehicle fleets are suited to the experimentation and the evaluation of implementation that have proven profitable in experiments reported elsewhere; and

- should the effectiveness of black box technology be better demonstrated, its installation could be made compulsory on the entire motor vehicle fleet.

3.5.3. Limit vehicle power at the time of manufacture

It goes without saying that vehicle power influences driving speed. Not only is vehicle performance a key factor at the time of purchase, but also when driving speed is chosen. Drivers drive new vehicles at higher speeds, and the more powerful the vehicle, the higher the driving speed (Fildes *et al.*, 1991). Quimby *et al.* (1999, in SAAQ, 2004) report that people who drive powerful vehicles drive 4% faster than those who drive less powerful vehicles. Today, one-third of motor vehicles can exceed speeds between 150 km/h and 200 km/h, considerably over legal speed limits. Furthermore, external reference points that once allowed the driver to perceive speed have diminished. Vehicles are well soundproofed and noise is softened by better tires and reduced vibration so that drivers are less aware they are travelling at higher speeds.

According to Marret (1994), the frequency of collisions increases exponentially with vehicle power. According to French data, for every 30 collisions in the 2-4 power group[17] there are 93 in the 8 power group and as many as 154 in the 14 and over power group.

Some observers argue in favour of increased vehicle power to respond to emergencies or maintain constant speed while climbing hills, for example. Such needs for additional power should be examined in light of drawbacks and costs, reassessed according to objective criteria (genuine needs), and surveyed to determine what is socially acceptable in terms of limiting vehicle power at the time of manufacture. The automobile industry, which is constantly offering new, high-performance products, must not alone define power standards.

3.5.4. Other safety-related driving aids

Several technologies in the rapidly changing intelligent systems sector are available: odometers located in the driver's visual field, not on the dashboard, sensors activated by visual or audible signalling posts when the authorized speed is exceeded, more advanced speed regulation systems that adjust speed to maintain a safe distance behind the vehicle in front, or smart cards that regulate maximum speed for repeat offenders or young drivers with probationary licences (Comte, 1997, in TRB, 1998). However, the impact of these measures in preventing speeding under actual driving conditions and reducing collisions and injuries has yet to be demonstrated.

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[17] A French government power measurement calculated since January 1, 1978 in light of engine displacement and a parameter describing the gear reduction of movement and fuel. Formula: P = m (0.0458 x 1.48), where C = engine cylinder displacement, K = reduction ratio, m = 1 for gasoline-powered vehicles and 0.7 for diesel-powered vehicles.

3.6. Socioeconomic environment-related measures

The section devoted to measures aimed at modifying behaviour examines facets of compliance with speed limits. The following section focuses on the very principle of speed limits, including the determination of a maximum speed, criteria for setting the speed, and impact on safety. Legislation and the attendant penalties are then examined, in particular within the framework of Québec and Canadian legislation.

3.6.1. Determination of speed limits

While vehicle performance and roads formerly limited speed, the more recent development of powerful vehicles means that speeds can clearly exceed the capacity of even the best designed roads. Such speeds also exceed the ability of drivers (reaction time), the capacity of vehicles (braking time) and the limited ability of the human body to absorb shocks during impact. These capacities have not really changed over time.

When drivers rely on their own judgment, they are not always aware of these limits prior to a collision; or, they are prepared to take risks. Moreover, the acceptable risk threshold varies from one individual to the next. The driver’s choice of speed does not necessarily reflect a balanced compromise between mobility and safety; and it is a choice that has consequences for the driver and third parties. For this reason, society accepts that speed limits will be set by legislative or administrative means.

The speed limit as a safety measure centres on the acknowledgement of a relationship between speed, the likelihood of being involved in a collision and the driver’s risk of injury. Speed limits play a coordinating role between different kinds of roads, in addition to their effect on mobility. They also help reduce the dispersion of driving speeds. Speed limits thus stem from a compromise between mobility and safety. However, as is readily apparent, the potential conflict that arises in striking a balance between the two persists through the entire decision-making process, which explains the need to rely on criteria to determine speed thresholds according to a functional road network hierarchy.

3.6.1.1. Criteria to determine a speed threshold

The widespread acceptability of credible speed limits is the best way to ensure high voluntary compliance rates in the absence of reinforcement. A consequence of this is that a high non-compliance rate appears to stem from speed limits regarded by drivers to be unreasonable in relation to road conditions.

The relevance of speeds refers to different approaches for the determination of credible thresholds. It may be useful at this point to distinguish between general speed limits established by legislation that apply to a province, state or country and speed limits in speed zones that are more often set by an administrative entity, which introduce local variations on a road segment, for example in the wake of an engineering design study.

The first approach is integrative, determined at the time of road design, in light of criteria pertaining to road geometry, the environment, urban centres, the number of lanes, and so on. Among the key sources of non-acceptance and non-compliance is the difference between design speed and the posted speed limit. For example, if the design speed is 130 km/h but the posted speed limit is 100 km/h or 110 km/h, drivers will find it hard to maintain their speed at less than 130 km/h. This gap can be justified in order to reduce the number of injuries but it is essential, then, to maintain the social norm to foster its acceptability. Similarly, greater control must be exercised to ensure compliance with the speed limit; otherwise it will not be credible (Fildes and Lee, 1993). In such a case, this amounts to asking whether it is better to raise speed limits to reflect the design speed and usual driving speeds or to lower the design speed when authorized speeds are undesirable. Design speed can be lowered by modifying the road environment through traffic calming measures that use constraints to induce or compel compliance with speed limits.

A second approach is the 85th percentile speed, the speed at or below which 85% of drivers drive. This appears to be the most widespread method of determining speeds. Indeed, the approach arises from observations by Witheford (1970, in Fildes and Lee, 1993), who note that the abrupt drop in the speed dispersion below the 85th percentile speed reveals that the choice of a slightly lower speed limit substantially increases the number of offenders. Other researchers have also found that the collision rate is relatively independent of speed up to the 85th percentile speed, beyond which the rate increases exponentially. However, the 85th percentile speed has its limitations when it does not take into account information that drivers must incorporate into their analyses to choose their driving speed (Fildes and Lee, 1993). Furthermore, the 85th percentile speed is not static and its value increases with higher speeds, for example, in the absence of reinforcement.

Another approach, originally developed by Carter (1949, in Fildes and Lee, 1993) and advocated by certain authors is the pace speed, which is the upper limit of the 15-km/h segment within which most vehicles fall. For example, when the speed distribution is examined, if 50% of vehicles travel at between 100 km/h and 115 km/h, the upper limit would be set at 115 km/h. The same limits as those in the 85th percentile speed apply to this approach if driving speeds increase depending on the level of tolerance or reinforcement exercised. The result of the limit thus obtained, called the pace speed, often corresponds to the 85th percentile speed.

Other approaches propose linking speed dispersion in relation to collisions on a given road to the severity of injuries. However, this raises the question of the acceptable injury threshold in respect of other mobility criteria and also the injuries attributable to certain speeds (Nilsson and Cameron, 1992; Salusjarvi, 1981, in Fildes and Lee, 1993).

The Swedish Vision Zero approach adopts the notion of safe speed to determine speed limits that emphasize safety over mobility by opting for thresholds that take into account the impact of speed on the road collision and victim tolls. As is true in the traffic calming approach, some observers have opted from the outset to designate certain 30-km/h zones based on a redefinition of the hierarchy of users to restore fairness to pedestrians, where their numbers warrant doing so.

To summarize, the choice of speed limits arises from a compromise that must reflect the road environment, the living environment, the array of users, and environmental concerns. Several countries have drawn up lists of multifactorial criteria that serve as an evaluation grid, equivalent to experts' judgments, to determine zone boundaries when they are under the jurisdiction of local authorities. Generally speaking, these criteria focus on the characteristics of the road environment without taking into account other facets that affect the development of mass transportation, walking and cycling, and air quality.

3.6.1.2. Safety impact of speed limits

Based on the laws of physics, lower speed limits will affect the frequency and severity of collisions and injuries, given the relationship between speed and the energy released in a collision. Proof of the positive safety impact of speed limits focuses, by and large, on the postulates of a chain of indirect relationships between authorized or posted speed, actual driving speed, the likelihood of a collision, and the consequent risk of injury. From the outset, it is apparent that components of the chain are missing, in particular the other variables that affect actual driving speed, such as reinforcement, but also all of the other risk or protection factors that affect impact on injuries, such as legislation and seatbelt use rates, alcohol, exposure, and so on. This is the key difficulty and main weakness that all of the studies encounter, in so far as they endeavour to establish an associative relationship by isolating the speed limit from the other variables. Still, the relationship is indirect.

Indeed, all of the literature reviews included in this section call for caution in the interpretation of the findings that deal with impact of lower speed limits. Speeds limits depend on several factors and it is virtually impossible to control for confounding effects based on data collected in a non-experimental context. The study designs, most of which are pre-post, are especially vulnerable to the impact of external factors in the absence of comparison groups. Some of the studies incorporate into their analytical models one or two factors such as the level of reinforcement or exposure, which results in a significant adjustment of impact. This observation further confirms the need to validate basic analyses through a multivariate approach that is rarely found in the documents consulted.

Bearing in mind these limitations and the abundant literature, we relied on two main summaries to describe trends and the quality of the evidence available on the impact on injuries of speed limits as a measure. The evidence collected concerns both the introduction of speed limits in areas where there were none and the raising and lowering of authorized speed limits.

The first review, prepared by Finch *et al.* (1994), examines the key studies conducted in Europe and the United States between 1962 and 1990 in regard to the indirect relationship between speed limits and collisions with injuries. These authors report the findings of a study that analyzes aggregate data from 21 countries in which substantial gains were achieved following a reduction in speed limits, primarily in urban areas (Fieldwich and Brown, 1987, in Finch *et al.*, 1994). They also cite a meta-analysis (Hillman and Plowden 1986, in Finch *et al.,* 1994) focusing on the results of the introduction or lowering of a speed limit in

26 countries (Europe and New Zealand), that reports that these measures led to striking reductions in injuries (from 3% to 56%) on an absolute percentage basis.

Statistical analyses also reveal that the change is directly proportional to the absolute change in speed limits (per kilometre) by a factor ranging from 1.0 to 2.5 for collisions and from 1.5 to 2.7 for fatalities. This leads Finch *et al.* (1994) to conclude that this model, which predicts a 15% to 27% decrease in fatal collisions in rural areas when speed limits are reduced by 10 km/h, confirms similar trends noted in urban areas by Fieldwick and Brown (1987, in Finch, 1994). More specifically, the latter authors' examination of fatality rates in 12 Western nations suggests that the 1.6-km/h drop in speed in urban areas has as much impact on fatalities as an 8-km/h decrease on highways.

Another review (TRB[18], 1998) examined the safety impact of speed limits, mainly in the United States. The review distinguishes three series of studies, each corresponding to a wave of speed limit changes in the United States. The first series covers the period that followed the 1974 imposition of a nationwide maximum speed limit of 89 km/h (55 mph) on highways in order to save gasoline after the oil shock. The conclusion drawn by TRB (1984, in TRB, 1998) emphasized at the time that the lowering of speed limits reduced actual driving speeds and fatalities by 16% in relation to the preceding year, a previously unequalled reduction.

A second, very prolific series of studies that followed the 1987 decision by the United States Congress to raise the maximum speed limit to 105 km/h (65 mph) on rural highways was adopted by 40 states. An examination of speed data collected by 18 states between 1986 and 1990 led the NHTSA[19] (1992, in TRB, 1998) to conclude that average speeds increased, as did the variance between speeds, when compared with states that maintained the 89-km/h (55-mph) speed limit. Overall, in an analysis encompassing all of the states, the impact on fatal collisions appears to be a 15% increase according to Garber and Graham (1990, in TRB, 1998). These authors believe that the preponderance of the statistical proof supports the conclusion that this impact is linked to the increase in speed limits. Similar estimates were found in a series of subsequent studies, in particular by Baum *et al.* (1991), who noted that the risk of fatal collisions rose 19% even when an adjustment was made for exposure (TRB, 1998).

Other authors, in particular Lave and Elias (1994, in TRB, 1998), dispute the scope and even the interpretation of these findings based principally on comparisons between states. They argue for the analyses' limitations stemming from the absence of control for other factors such as the difference in size of the states included in the comparisons, and reinforcement or the diversion of traffic to other roads not affected by the new speed limit. Despite this trend, a majority of studies revealed an upturn in fatal collisions, although these findings are not homogeneous between states (TRB, 1998).

[18] Transportation Research Board.
[19] National Highway Traffic Safety Administration.

A third series of studies followed the 1995 abrogation of the 105-km/h (65 mph) maximum speed limit by the United States Congress, thus allowing individual states to raise the posted speed limit to 120 km/h (75 mph) or more on rural and urban highways. Two major studies in this series conclude that speed limits increased (average speed and 85th percentile speed) following this resolution and that these increases contributed to the increase in fatal collisions in 1996. The NHTSA (1998) study analyzed the impact of higher speeds in three groups of states: 11 states that raised the speed limit when the new legislation came into force, 21 states that did so later in 1996, and 19 states that maintained the speed limit at or below 105 km/h. The IIHS[20] study (Farmer *et al.*, 1997, in TRB, 1998) instead compared 12 states that raised the speed limit to 113 km/h (70 mph) with 18 other states that did not or that did on less than 10% of the urban freeway system. These findings, which are regarded as preliminary because they cover data for only one year following the introduction of the measure, nonetheless confirm the trend described by all of the studies in this series. Not only did average speeds increase (from 2 km/h to 5 km/h), but the authors report the impact on speed dispersion, particularly with regards to the highest speeds. For example, the proportion of drivers who drove over 113 km/h rose from 15% to 50%, and those who drove over 121 km/h rose from 4% to 17% (Retting and Greene, 1997, in TRB, 1998).

In conjunction with an actuarial study conducted for Québec, Tardif (2003b) re-examined American data banks covering the third wave of speed limit changes that occurred in 1996 in the United States. To analyze changes in the number of fatalities and the fatality rate for the periods prior to (1993-1995) and subsequent to (1997-1999) the change, Tardif used the variation in absolute risk (number of deaths) and relative risk (mortality rate per 100 000 inhabitants or 100 million km travelled). From the point of view of absolute risk, his combined analysis of all states reveals that if the states that increased the speed limit to 113 km/h (70 mph) or more on rural highways had experienced a variation in the number of fatalities equivalent to that observed in the states where the speed limit was 105 km/h (65 mph), nearly 4 000 fewer fatal collisions would have occurred between 1997 and 1999 in the United States. In terms of relative risk, if the states with a speed limit of 113 km/h (70 mph) had experienced a variation in the road fatality rate per 100 000 inhabitants equivalent to that observed in the states with a 105-km/h (65-mph) speed limit, 1 850 fewer deaths would have occurred during the period. According to the same calculation applied to a measurement of exposure (the road fatality rate per 100 000 miles travelled) 2 243 fewer deaths would have occurred. This projection is solely intended to show that, even if the road fatality rates declined slightly on a large part of the United States road network during the periods examined, it was undoubtedly linked to other factors such as seatbelt use. Meanwhile, the less substantial reductions on roads with higher speed clearly contributed to excess mortality from the point of view of absolute risk and relative risk that could have been avoided through the maintenance of lower maximum speed limits (TRB, 1998).

Furthermore, research that emphasized state-by-state rather than multi-state analyses produces mixed findings inasmuch as there is greater heterogeneity among the states. There is a major trend that confirms the same findings as for the states overall. In the absence of

[20] Insurance Institute for Highway Safety.

an exhaustive analysis to control for factors that explain these differences, several authors once again stress the impact of variables such as the states' specific traits (population density, number of kilometres of roads) but, above all, the importance of reinforcement to broaden compliance with the speed limits imposed. In other words, as Stuster *et al.* (1998) report, another factor that explains the differences between the states or between roads arises, in particular, because in certain states no changes occurred in actual driving speeds before and after the changes in speeds limits, as drivers were already driving over the legal speed limit in the absence of reinforcement (TRB, 1998).

A study conducted in New Mexico illustrates these differences in a given state by comparing two roads on which the speed limit was increased from 105 km/h to 121 km/h. On the road on which over 1 000 speeding tickets were issued during the period of observation, the number of collisions involving injuries declined slightly, while a slight increase in such collisions occurred on the road where no major reinforcement was introduced. Average speeds increased on the latter road as did the number of drivers exceeding the 85th percentile speed. Moreover, the increase in collisions involving injuries was linked to broader speed dispersion.

3.6.1.3. Differential speed limits

The concept of differential speed limits underpins two types of adaptation of general speed limits. In the first case, reference is made to discriminatory maximum speeds according to vehicle category, for example 90 km/h for trucks and 100 km/h for other motor vehicles. Proponents of this speed discrepancy refer to the intrinsic threat posed by the length of time it takes trucks to decelerate and their weight when involved in a collision. Opponents argue that this discrimination exacerbates discrepancies in speeds, thus increasing potential conflicts and negative impact linked to speed dispersion. Two American studies examined the impact of differential speed limits on roads in the wake of the change in speed limits in 1987. The studies compared states that opted for a differential speed limit (89 km/h [55 mph] for trucks and 105 km/h [65 mph] for other vehicles) with those that adopted a uniform 105-km/h raised speed limit for all vehicles.

Garber and Gadiraju (1992) measured the impact in a pre-post study with comparison control sites using indicators such as average speed, standard deviation, 85th percentile speed, the percentage of vehicles exceeding the posted speed limit, and the number of collisions at 11 sites in four states. The speed data are drawn from a 36-month period prior to the change in the speed limit and a 12-month period subsequent to the change. The findings indicate that there is no significant difference between pre and post periods and between the two types of speed limits (65/55 mph and 65/65 mph) on collision rates and on fatal collisions or collisions involving injuries in the four states. The authors conclude that the differential speed limits do not have a positive impact.

Baum *et al.* (1991) evaluated impact on speed by comparing California and Illinois, which adopted differential speed limits for trucks and other vehicles, with Arizona and Iowa, which maintained uniform speed limits following the 1987 abrogation of the 89 km/h speed limit on rural highways. The findings reveal a significant link between lower average speeds for trucks (2 km/h) in states with differential speed limits compared with the same vehicles in states with a uniform speed limit. The authors also found that automobiles travelled at slower speeds in states with differential speed limits. The principal impact of differential speed limits of more than 15 km/h is a significant reduction in the number of trucks travelling at high speed (over 113 km/h). Proof of the impact of these less uniform speeds that are offset by slower speeds is inconclusive for or against differential speed limits, all the more so as the methodological study designs on which they are based are not very solid.

In the second case, variable speed limits are used to counteract the drawbacks of fixed speed limits: that is, posted or non-posted speed limits that adapt to temporary conditions such as the weather, traffic, construction and collisions, or to satisfy the needs of other users in delineated zones or periods, such as school zones, cycle paths, and so on. Lower speed variations are usually deemed to have a positive impact on the credibility of speed limits. Indeed, when speed limits are adjusted in light of an objective analysis of the environment, modified temporarily by unusual conditions, the new speeds alert drivers to risks that are not usually present but that must be taken into account.

Whether in school zones, construction zones or highway corridors, variable speed limits have little impact on actual driving speeds without some form of control, as indicated in the section on behaviour. Where such speed limits are linked to dynamic traffic management systems accompanied by automatic reinforcement, they do affect speed and the number of collisions (Fildes and Lee, 1993).

3.6.2. Legislative measures and penalties

Among the legislative measures aimed at dissuading drivers from exceeding the authorized speed limit, prosecutions and penalties are in keeping with reinforcement and control strategies

In most countries, the legal system deals with traffic violations through a combination of administrative and criminal measures. The criminal or penal system follows four stages: detection, prosecution, sentencing and the administration of penalties. In the administrative system the four stages are combined into a single phase in which a penalty is attached directly to the statement of offence.

The effectiveness of legislation in altering behaviour towards targeted norms depends on several factors. First, the prescription must be known, clear, and credible; it must rally the support of all interveners (users, the police, judges); and its soundness must rely on recognized social values linked to safety and a demonstration of the anticipated benefits.

Moreover, since the fear of punishment is supposed to be a key element that explains the dissuasive effect of legislation, the latter must be supported by a minimum detection threshold that is sufficient to heighten the perception of the risk of arrest and a significant sentencing rate. This is referred to as the certainty concept.

Although certain authors have suggested that police surveillance can only have an effect through the threat of punishment, this hypothesis is called into question by a literature review in the realm of psychology in which most of the research focuses on the impact of the certainty of punishment. The findings reveal that the certainty of punishment does not appear to have a predominant impact on long-term behavioural change (Fildes, 1993). No study to date has conclusively demonstrated the long-term impact attributable to the threat of punishment. The hypothesis raised is that the legislation's positive impact on general change of attitude in the community appears to stem from intensive campaigns repeated in the long term instead of only from the risk of punishment linked to the legislation. Programs such as STEP, as operated in Australia, are effective by virtue of their intensity and the use of mixed strategies that more broadly intended to alter the social standard by making speeding unacceptable. It then becomes hard to isolate a measure's impact when it is part of a strategy combining legislation, advertising, control operations and penalties.

As for the severity of the penalty, the second criterion examined, all behavioural change theories stipulate that it is the intensity of the punishment or the reward that modulates the impact on the desired behaviour. However, few studies repeat these conclusions. While the type of penalty is deemed to be an important determinant in the behavioural change process (Mäkinen, 1988, in Zaal, 1994) in terms of a gradation toward more stringent measures, no study focusing on statutory penalties has shown any impact on behaviour (Fildes and Lee, 1993; Zaal, 1994; Master, 1998; Goldenbeld *et al.*, 2000). Furthermore, the most stringent penalties can have a perverse effect and offenders may resort to avoidance strategies for fear of being punished, as seen for example in hit-and-run offences (Goldenbeld *et al.*, 2000).

As for the notion of the promptness of the offender's punishment, Rothengatter (1990) advocates the need for such promptness, at least in the form of immediate feedback to the offender, while other experiments, especially with cameras at red lights, maintain that information indicating that drivers are entering a surveillance zone is sufficient to establish the perception of the risk of punishment and that it takes the place of a warning. No evidence supports the importance of promptness.

3.6.2.1. Fines

With specific reference to fines, one Swedish study that evaluated fine increases in 1982 and 1987 did not find any change in behaviour linked to speed and concluded that severity is less crucial in dissuading drivers than the very existence of a penalty, such as a fine (Andersson, 1989, in Fildes and Lee, 1993). According to Mäkinen (1988, in Zaal, 1994), it appears to be as effective to send a simple letter as to send a statement of offence accompanied by a fine for minor offences. When the likelihood of arrest is limited and static, an increase in the amount of fines did not demonstrate any deterrent effect in reducing the number of speeding offenders (Zaal, 1994, Goldenbeld *et al.*, 2000).

3.6.2.2. Demerit points

A gradual approach ranging from a simple warning to a fine followed by the suspension of the driver's licence and, ultimately, seizure of the vehicle, helps to enhance the credibility of penalties. Demerit points are, by definition, part of this approach. This type of system involves a central registry in which each offence, equivalent to a number of points, is added up for a given period (two or three years) in the driver's file, after which the points are erased. In addition to treating offenders uniformly, the system applies the principle of graduated severity depending on the number and seriousness of the offences. While the system advocates leniency for the first offence, it also calls for the ultimate punishment, which is the suspension of the driver's licence when a driver reaches or exceeds the maximum number of points set. Indeed, from a theoretical perspective, leniency in respect of an initial offence is based on sociological studies on cooperative behaviour that reveal that cooperation between interveners increases when a single incidence of non-cooperative behaviour does not lead, in exchange, to a non-cooperative (punishment) response (Goldenberg, 2000).

According to Zaal (1994), who divides offenders into three groups, this system makes it possible to convince those for whom the offence committed is an exception of the advantages of continuing to obey the law. It is also intended to dissuade drivers who occasionally commit offences but who try to avoid accumulating too many demerit points. This progressive system seeks to punish more severely a third group of repeat offenders through the suspension of the driver's licence when they reach the upper demerit point limit. According to Zaal (1994), the latter punishment appears to be highly effective in modifying behaviour. Suspended drivers who often break the suspension rule appear to adapt their behaviour to avoid being intercepted when driving illegally.

An Australian study appears to confirm to some extent the effectiveness of demerit points in that they lengthen the lapse of time between the second and third offence in relation to the time elapsed between the first and second offences (Haque, 1987, in Zaal, 1994). According to Oei (1998), we can only assume that demerit points added to more stringent penalties for repeat offenders, such as seizing the vehicle or revoking the driver's licence, will bolster reinforcement, although no scientific evidence is available to prove it. The system is also subject to criticism, especially because it only works at the threshold at which the number of accumulated points is likely to lead to the suspension of the driver's licence.

It thus appears to exacerbate deviant behaviour since the ultimate punishment that has a dissuasive effect (the suspension) only applies at an extreme point (Zaal, 1994). For example, under the Québec system, the holder of a regular driver's licence could accumulate as many as 15 infractions for exceeding the speed limit by 20 km/h over a period of two years before reaching the upper limit of 15 points leading to the suspension of the licence. This type of infraction (driving 20 km/h over the speed limit) is equivalent to only one demerit point (under the regulation in force as of June 2002). Alternatively, a driver who drives 120 km/h over the authorized speed limit once would lose 15 points and have his or her licence suspended.

In Germany, in 1998-1999, 12% of drivers who accumulated points among the 50 million driver's licence holders were recorded in the central registry of offenders. Of the 12%, 0.3% (roughly 17 000 drivers) had reached the maximum of 18 points (Jagow, 1998-1999, in Goldenbeld *et al.*, 2000). In Québec, of the 4.6 million driver's licence holders, 24% accumulated between one and 15 points or more in 2001-2002. Of this number, 0.18%, or 8 174 drivers, reached the maximum of 15 points. One possible explanation for the twice as many Québec drivers as German drivers who accumulated points is the possibility for drivers with demerit points on file under the German demerit point system to take courses in exchange for a reduction in points.

3.6.2.3. Other measures

Among the measures that target repeat offenders, consideration is given to the installation of automated speed limiters. Since this measure has not been evaluated, we can only refer to a similar measure aimed at repeat drinking and driving offenders and the installation of an alcohol-ignition interlock device. An assessment of a Québec alcohol-ignition interlock device program attempted to measure the impact on the recidivism rate and collisions (Vézina, undated). The voluntary program, which began in 1997, was aimed at drivers convicted of impaired driving, and participation reduced the period of suspension of the driver's licence. The prospective study with comparison group reported a significant reduction in the recidivism rate in the exposed group, but solely for the period covered by the program. Following the withdrawal of the alcohol-ignition interlock device (after 12 months in the case of first-time offenders and 24 months for repeat offenders), the risk of driving while under the influence of alcohol was higher than in the control group. Similarly, no significant difference was found on the measurement of single-vehicle collisions at night between the groups with and without the interlock device. A stratified analysis reveals that the risk ratio for all collisions is even higher among program participants following the device's removal than in the control group.

The authors conclude that the alcohol-ignition interlock device's effectiveness applied to offenders is limited to the period when the system is installed and thus becomes a control rather than a rehabilitation measure. The findings appear to be consistent with those of Tippetts and Voas (1998 in Vézina) and the research of Beck *et al.* (1999 in Vézina), which points in the same direction.

3.6.2.4. Rehabilitation

Rehabilitation is becoming increasingly widespread in Europe among high-risk drivers and chronic repeat offenders. This type of intervention has been tested primarily with respect to drinking and driving, and occasionally towards speeding.

This approach centres on the hypothesis that it is neither skills nor knowledge that are deficient, but that mental health problems are the source of inappropriate attitudes. Four types of intervention are mentioned: medical follow-up in respect of mental health problems or other disorders; social activities in the community such as those aimed at persons involved in road collisions; driver training; and psychological follow-up. While rehabilitation is the most extensively investigated of all types of legal measures, evaluations using epidemiological models have not produced convincing results, in particular because the impact cannot be attributed to rehabilitation alone as it is difficult to isolate from the other measures with which it is usually combined, such as suspension of the driver's licence, and so on.

European examples that focus on impaired driving show that the courses, while they alter knowledge, hardly succeed in significantly altering behaviour. In Austria, an administrative decision to offer repeat offenders recourse to sessions devoted to psychological conditioning was evaluated. The evaluation found the recidivism rate of participants was half that of non-participants (Michalke *et al.*, 1987, in Goldenbeld, 2000).

However, drivers do not perceive speeding to be as serious a deviant infraction as drinking and driving. Speeding is not thought to be deviant based on the same medical or psychological phenomena, and is instead perceived as a variation of normal behaviour. No information is available on the evaluation of these programs focusing on speeding in Switzerland, Finland and Austria, the countries where they are offered.

A single evaluation devoted to a course comprising four three-hour sessions on lifestyle habits with a psychologist and driving instructor, applied to a group of 989 young repeat speeding offenders, reports that novice drivers appear to display favourable results, while an approach based on knowledge or skills apparently has no effect on the recidivism rate. However, no other convincing findings support this experience. Some European countries have integrated such rehabilitation measures into their overall driver's licence granting systems but such measures are part of criteria to end the suspension of the licence and thus restore the right to drive.

3.7. COMPREHENSIVE APPROACH

Québec, like a number of industrialized nations, has witnessed a striking improvement in road safety since 1973, when the annual carnage on Québec roads culminated in over 2 000 deaths. In the context of ever-increasing mobility, the road collision toll was reduced to an annual average of roughly 700 fatalities and over 6 000 hospitalizations in 1997-1998. This improvement ranked Québec fourth internationally for mortality rates per billion km in 1998, behind Sweden, the United Kingdom and the State of Victoria in Australia. Several factors explain the impressive improvement in Québec's road collision toll. Québec had one of the worst tolls in the industrialized nations and was able to achieve above-average gains through measures focusing on impaired driving, seatbelt use rate (one of the highest in North America), and improvements in vehicles and the road environment.

Since then, debate has centred on setting a precise objective to improve Québec's fatality and injury road collision toll (percentage improvement) to further reduce the number of victims. Several approaches prevail for the elaboration of this objective. The first approach consists of an analytical framework that is confined to juxtaposing a series of initiatives and adding the potential gains to be derived from each one according to their relative effectiveness and to determine an overall reduction objective of 15%, 20% or 25% for road victims in a given period. The second approach consists of examining the laws of nature where the only limiting factor in the case of road safety is the transfer of energy that causes injuries.

> "There are no technical limitations to designing a road transportation system that does not expose the human body to shocks beyond its tolerance limit, if only by reducing the energy (induced mainly by speed) in the system in terms of what the vehicle can absorb, e.g. airbags, the road environment, e.g. impact attenuators, and ultimately, the human body (tolerance limit)" (Dussault, 2000). [TRANSLATION]

This explains the approach of pushing this threshold to the smallest denominator and setting objectives according to the unlimited possibilities of these systems.

3.7.1. The Swedish Vision Zero model

It must be noted that the Swedish Vision Zero model is not synonymous with the objective of achieving zero death or serious injury following a collision, but that it expresses the determination to push back the generally accepted limits by acknowledging that such limits do not reflect technical possibilities but instead the willingness to tackle them. Sweden has taken this new direction by formulating an approach encompassing all of the measures likely to contribute to the attainment of this objective.

While Sweden already has an excellent road collision toll (it reduced fatalities by 35% between 1990 and 1994), it is using innovation to modify the usual perspective of balance between mobility and safety as the ideal objective. More explicitly, Sweden is specifying that mobility must not be achieved to the detriment of safety and is putting safety first.

In other words, the old paradigm has been reversed whereby losses of life are regarded as the price to be paid to achieve, maintain or increase the current high level of mobility. The new paradigm pushes the tolerance limit to zero, to the minimum threshold and not absolute zero, insofar as it is acknowledged that there is no technical limit to the enhancement of road safety and that it is unacceptable over the long term that people die or are seriously injured in collisions, as is true in the air transportation sector. The only limits are those imposed from the perspective of economic and political will.

The Swedish parliament adopted the Vision Zero objective (road fatalities and injuries), and obtained national support. This approach has not only brought road safety to the political forefront but has also encouraged the public, the media, the police and politicians to share their concerns. The approach for the strategy centres on a genuine sharing of responsibilities between society, users, the business sector and industry. However, the state, which must define norms, bears the main responsibility. It is also incumbent upon the state to ensure compliance by all concerned parties in the application of the measures proposed in their respective fields of jurisdiction. The 11 measures include, among other things, electronic verification of the driver's licence before the vehicle is started, an ignition interlock connected to the seatbelt, and an automated device to detect alcohol in the passenger compartment.

Speed is a key component of the strategy. Among the measures focusing on speed, it is important to mention limit-lowering strategies such as: a simple hierarchization of roads on which speed limits are set according to the risks that users encounter, land-use planning geared to speed limits, and voluntary smart speed limiters on vehicles. These are examples of measures undergoing widespread experimentation. Other measures focus, for example, on graduated licensing for young people (supervised driving between the ages of 16 and 18 and issuing of the licence when the driver turns 18).

The approach, implemented with the policy's adoption in 1997, influences all initiatives linked to vehicular traffic by giving priority to pedestrians and cyclists. It now serves as a model or a source of inspiration for other European countries. While the objective to eliminate risks is not always synonynmous with sustainable safety, the political determination to make road safety a national health priority has been apparent for several years in Australia, is clearly a priority in the Netherlands and Great Britain, and has emerged more recently in France. A harmonization process has been initiated in the European Community overall on highway speed limits, maximum speed limiters on heavy and commercial vehicles, and the development of smart systems for motor vehicles.

The initial impact of such an approach results from the synergy between the unified efforts of all interveners with political and public support. The approach provides a powerful lever to introduce and to ensure the coherence of numerous measures with long-term integrating objectives, and to allocate the necessary resources to their realization.

3.8. OTHER COUNTRIES

It is enlightening that all countries who have achieved the best results have adopted significant medium-term targets (see Table 9), especially Sweden (- 50%), the State of Victoria in Australia (- 50%) and the United Kingdom (- 40%).

Table 9 – Injury reduction targets in a number of industrialized countries

Country	Sweden	France	United States	Canada	Australia	United Kingdom	Québec
Objectives	-50% deaths	-50% deaths	-20% deaths/ serious injuries	-30% deaths/serious injuries	-50% incidence and severity	-40% deaths/serious injuries	-15% deaths/ serious injuries
Target	2007	2007	2008	2010	2010	2010	2005
Period	10 years	5 years		10 years	10 years		5 years

The Australian model, whose objectives are similar to those in Québec, is making a greater effort to heighten awareness and exercise control. In Australia, the speed management action plan is part of a comprehensive 2000-2010 plan in which speeding is a priority. In particular, the plan seeks to place infractions for excessive speeding on the same footing as drinking and driving offences.

3.8.1. The perspective of road safety in Canada and Québec

Under the Vision 2010 framework, Transport Canada (2001) proposes to make Canada's roads the safest in the world. The scope of this objective refers to the absence of technical limitations to the enhancement of safety. The national objective is to reduce the average number of road users killed or seriously injured by 30% between 2008 and 2010 in relation to the period between 1996 and 2001. One of the objectives concerns speed-related collisions. The mandate has been assigned to the task force on speed and intersections, which has proposed four strategies: education and awareness, research, infrastructure and road construction standards, and their implementation. This has led to agreements between all road safety stakeholders for a concerted research approach, the elaboration of national standards concerning the speed limits imposed on different types of roads, and the elaboration of standards governing the enhancement of road infrastructure.

In Québec, the *Transportation Safety Policy 2001-2005: Road section,* adopts an approach that consists in pinpointing a series of objectives that focus on 29 issues, including speed. It sets an overall objective of reducing fatalities by 15%. These orientations wish to strike a balance between mobility and safety, where the desire is to "design measures enabling the greatest possible reduction in risk of collisions while ensuring the preservation of mobility" (MTQ, 2001) [translation]. The policy defines the sharing of responsibilities through the elaboration of a comprehensive integrated perspective and by allowing communities the freedom to act locally. The approaches emphasized to implement the policy are cooperation, exchanges of expertise and know-how, consultation, information and awareness.

4. DISCUSSION

This literature review was conducted bearing in mind the classification of measures according to the four factors in Haddon's Matrix, i.e. human factors, agent (vehicle-related) factors, environmental factors and socioeconomic factors, to which the comprehensive approach has been added as a fifth category. The choice of measures to recommend is based on sound results that showed a significant impact on the reduction of speed and its consequences for health. Therefore, the measures will be discussed in terms of their contribution to:

1. increasing the speed limit compliance rate;
2. reducing average speed and speed dispersion; and
3. reducing speeding-related injuries.

Human factors

Measures focusing on human factors seek to alter the behaviour of road users, in terms of compliance with speed limits, either through promotional and awareness campaigns or educational or coercive control measures. However, not all of these measures guarantee the desired behavioural change or an improvement in the road collison toll since, depending on the scope, duration and intensity of the measures, their effectiveness is sometimes not demonstrated or else varies highly from one measure to the next.

Promotional and awareness campaigns

- Media-based promotional and awareness campaigns devoted to road safety, when conducted alone, do not induce the anticipated behavioural changes, nor do they produce significant reductions in the number of collisions. However, the combination of advertising and control measures appears to heighten the impact of control on the anticipated behaviour.
- The evaluations indicated, above all, that certain qualitative traits appear to enhance the campaigns' effectiveness. The presence of an explicit theoretical framework to underpin the development of the campaign has been linked to a greater reduction in collisions. Promotional campaigns conducted at the municipal level have a greater impact than national or regional campaigns. Persuasive campaigns aimed at bolstering or modifying attitudes or behaviours appear to be more effective than educational campaigns and information campaigns.
- Campaigns linked to other measures such as the enforcement of legislation, educational programs, and rewards appear to help reduce collisions during campaigns to a greater extent when they focus on speed than on other themes. Impact is limited over time, that is, for the duration of the campaign. Some findings indicate a reduction in collisions involving injuries during the campaigns but we do not know on what themes they focused.

Traditional police control measures

- The effectiveness of control measures relies on their capacity to influence the perception of the risk of arrest and this perception must correspond to a genuine equivalent risk.
- Traditional police control appears to be effective in reducing average speed but there is no evidence that it affects speed dispersion. However, this impact on speed is temporary, lasting from one day to eight weeks depending on the intensity of the control and limited in space, over a distance of several kilometres upstream and downstream from the control site.
- The studies reviewed do not report on the impact on collisions or injuries due to this type of reinforcement.
- Selective traffic enforcement programs (STEPs), when integrated into the array of effectiveness criteria (intensity, high visibility, collision-prone sites linked to speed, advertising and feedback), are strategies that add to the limited impact of conventional police control inasmuch as they significantly increase the number of drivers intercepted. Only very intense experiments have shown a reduction in average speeds, those in which (for example) one offending driver in six is intercepted over a four-week period, or nine hours of reinforcement per day for six weeks. Selective application programs thus assume a substantial investment in human and financial resources if they are to be maintained over time and cover an extensive territory.
- Despite the high number of speeding tickets issued in Québec, the percentage of non-compliance remains high on the road network overall.
- In Québec, the number of speeding tickets issued is highest on highways while, according to the surveys, the biggest ratio of drivers who exceed the legal limits is found on 50-km/h urban roads and 90-km/h primary or secondary roads.

Automated photoradar

- The impact of automated control on the road collision and injury toll has been subject to more extensive evaluation than conventional police control. The studies overall, some of which are fairly rigorous despite the methodological difficulty they encounter in demonstrating a causal relationship, tend to reveal a positive impact on safety through a reduction in average speeds, collisions and victims without being able to quantify them with certainty. Some studies indicate a reduction of around 20% in collisions with injuries at control sites.
- While automated photoradar has a greater demonstrated impact than conventional police control, this does not make it a universal measure to solve speeding-related problems everywhere. Nonetheless, it is an important measure among those devoted to reinforcing speed-related behaviour. In particular, the presence of photoradar has proven to be five times more effective at selected sites according to criteria linked to speed-related collisions compared with sites that did not meet such criteria. We must not underestimate the importance of the process and the resources required to identify collision-prone sites where speed is a factor. The process requires established methodology and the implementation of the mechanism for approving the sites selected.

- The superiority of automated photoradar is also due to its broader intensity (detection and statements of offence) over longer continuous periods. Police resources can be advantageously allocated to other safety priorities for which an equivalent technology is not available.
- Several issues must be factored in when photoradar is introduced and applied. The acceptability of the measure depends on the choice of sites. Each site must be demonstrated, and perceived by drivers, as a risk for collisions and injuries. Its credibility also relies on the presence of speed limits that are consistent with the environment. Moreover, the reference speed beyond which drivers are intercepted must be reviewed in light of credible speed limits where the tolerance limit will be gradually drawn closer to the legal limit as average speeds fall. The penalties must reflect the seriousness of speed-related offences in the same way as penalties pertaining to drinking and driving. Implementation models that have favoured the maintenance of demerit points are more effective in confirming this message and maintaining the dissuasive impact of penalties for speeding. Different options are available to maintain demerit points: cameras that film the licence plate and the driver or the approach whereby the vehicle owner names the offender when the owner was not driving the vehicle at the time of the offence.

Driving courses and educational programs

- Despite the pressure exerted by public opinion and road safety officials to promote this approach among decision-makers, overall worldwide scientific proof leads us to conclude beyond any doubt that neither driving courses nor educational programs devoted to road safety at schools have proven to have any positive impact on the reduction of the road collision toll among young drivers.
- Empirical evidence reveals instead a worrisome impact inasmuch as this type of measure, by promoting the obtaining of a driver's licence at an earlier age, increases exposure and the risk of collisions and injuries.
- The time credit to obtain a driver's licence granted to novice drivers who take driving courses even partly offsets the positive impact of the graduated licensing program because it reduces waiting time and supervised driving among young drivers, although that is the program's key effectiveness criterion.
- Claims that driving courses enhance knowledge are predicated on the premise that the absence of such skills increases the risk of being involved in a collision. This premise is, by and large, false and is not confirmed by any scientific proof.

Other behaviour reinforcement measures

- Reward as a behavioural modification strategy has had some impact among young people in the realm of road safety and might be a worthwhile avenue for experimentation in respect of speed.
- Advertising and reliance on the media as a support measure enhances the impact of control measures compared with control measures alone.

Vehicle-related factors

As for **measures aimed at modifying vehicles** to reduce speed and their effectiveness in reducing collisions with victims, various avenues are available but passive measures are the most promising in terms of effectiveness.

Speed limiters

- The feasibility of installing by legislative means maximum speed limiters in truck fleets has been demonstrated in Europe and, to date, the evaluations primarily reveal benefits in terms of a reduction in gasoline consumption. Speed limiters also reduce pollution and can contribute to the attainment of sustainable development objectives.
- The adaptive speed limiters available are already deemed to be technically reliable and safe. The technology has allowed for the effective, flawless passive reduction of speed in the vehicles tested in experiments conducted in Great Britain and Sweden.
- While impact evaluations have focused primarily on simulation models with a few experimental evaluations in the field, and while they remain somewhat theoretical, the European countries engaged in the development of this technological measure are already predicting substantial gains attributable to speed limiters. They are relying on the devices' intrinsic effectiveness in controlling and reducing variance between speeds, a factor in respect of which few other measures have demonstrated a genuine impact.
- Another effectiveness factor is due to the measure's universal nature. Indeed, the scope of the speed limiters integrated into the vehicle means that, depending on the degree of implementation, the measure applies to all types of roads or speed zones in urban and rural areas or on highways, or on all types of vehicles. It can thus be applied across the board to the entire automobile fleet, except for vehicles that predate the technological standards allowing its integration, a limitation that will disappear as the vehicle fleet is renewed.
- Aside from the impact on road safety, speed limiters are credited with a positive impact on the environment since the reduction in gasoline consumption has a direct impact on the reduction of polluting emissions.
- The introduction of this technology reproduces all the phases of the innovation introduction model on a social scale and must go through an experimental phase (under way in Europe), for use on a voluntary basis, followed by widespread application through legislation. The acceptability factor of such innovation among users, manufacturers and political decision-makers who must adopt the norms required to implement the technology explains the significant delays preceding widespread implementation. Great Britain is considering a production phase by 2013, gradual voluntary use in 2019, when 60% of the vehicle fleet should be equipped with an adaptive speed limiter, and regulation by 2020. The Swedish government also plans to adopt standards governing the integration of speed limiters in new vehicles such that 80% of the vehicle fleet will be equipped with a compulsory speed limiter by 2019. Moreover, were the regulation to be extended to the entire European Community, all speed signposting and photoradar would become useless.

- Social acceptability also depends on feasibility and the costs associated with the measure. According to the study conducted in Great Britain, vehicle owners would assume 97% of the cost of adaptive speed limiters and the government, 3% (management of the system). Safety gains would be five to 17 times the investment in the basic system (public portion of the system). This notion of cost sharing is important in a context where funds allocated to other measures such as the modification of infrastructure (traffic calming) or more intense control (police surveillance, photoradar) may slow their implementation since the public system covers most of their costs.
- Like many of the most effective passive measures, speed limiters are integrated into the vehicle and serve both as a driving aid and an external control.
- From a public health perspective, any measure aimed at controlling speed should result in a reduction in overall speed (actual driving speed, average speed and variance between speeds) and not only so-called excessive speed. The target should include 100% of vehicles so that they are equipped with adaptive speed limiters and the measure is applied to all types of vehicles on the entire road network. Speed limiters meet all the effectiveness criteria of passive measures.

Black boxes

- Midway between technology and behavioural change, black boxes act in two ways: to analyze the causes of collisions after the fact, and to openly monitor drivers in order to influence their behaviours.
- Some positive results in reducing collisions drawn from experimental evaluations indicate that knowing that one is being observed has a potential dissuasive impact.
- Furthermore, the choice or addition of recorded safety-related data would have an impact on the knowledge acquired through the objective analysis of collisions.

Limit vehicle power at the time of design

- Few studies have sought to demonstrate this measure's effectiveness. However, it does appear that the greater a vehicle's power, the higher the driving speed. The marketplace offers vehicles that can exceed authorized speed limits considerably and this trend is growing. The latest models of motorcycles can reach speeds of 300 km/h or more.
- We might ask what levels of power are useful and acceptable from the point of view of consistent public policy, which both allows the sale of such vehicles, prohibits the speeds that they can attain, and sets polluting emission reduction objectives under the Kyoto Protocol. The automobile industry must not alone define these standards, which are not purely technological but also reflect social values.

Physical environment-related factors

Measures aimed at modifying the physical environment to reduce speed mainly rely on the traffic calming approach. Their effectiveness in reducing collisions with injuries varies depending on the measure's scope, duration and intensity.

Traffic calming measures

- Not all physical traffic calming measures focus specifically on speed; they may reduce traffic volume and restore balance in favour of pedestrians and cyclists by proposing a new hierarchy of needs. They target road design and areas surrounding roads to heighten compliance with speed limits by creating physical or visual constraints (perceptions) that encourage drivers to slow down.
- European layouts that integrate space and user safety have revealed a positive impact on the reduction of speed. The principles of the traffic calming approach, mainly carried out in Europe, and used in part in Australia, are applicable and well-adapted to the urban context in North America. While the approach is usually implemented in urban residential settings, it now extends to feeder roads and even to highways such as gateways. No evaluation of this new context is available.
- Overall, while data are not conclusive about traffic calming measures being effective in significantly reducing collisions and collisions with injuries, most studies have revealed a positive impact on safety, particularly due to reduced speed.
- Moreover, the evaluation of the area-wide traffic calming strategy applied in residential zones near central business districts in big cities has not established sound proof as to this strategy's level of effectiveness in reducing collisions with injuries.
- As for the specific impact of traffic calming measures on pedestrians, a reduction in speed has been linked to reductions in pedestrian deaths and injuries. Yet pre-post studies have not demonstrated impact between exposed and unexposed groups. The small numbers of pedestrian deaths and injuries may explain why the results cannot be attributed directly to these measures when the data are subjected to more rigorous analysis. Indeed, if there is a direct relationship between speed and the severity of injuries sustained by pedestrians, who are more vulnerable to impact, we might conclude that the measures indirectly affect injuries. The quality of the proof available does not allow one to draw such a conclusion.
- Given the vast potential for physical traffic calming measures, the predominance of certain measures, such as speed humps that effectively reduce speed, could contribute to more limited impact for pedestrians compared with other measures that offer some protection, such as refuge islands that separate them in space from vehicles.
- The biggest reductions in speed and collisions were achieved when a combination of area-wide rather than isolated measures was implemented.
- Similarly, among traffic calming measures, physical measures are more effective than regulatory measures because they do not require reinforcement, e.g. a 30-km/h zone with a physical component rather than without.

- Among the individual measures, those that induce a vertical deviation, such as speed humps, appear to be the most effective.
- According to some studies, traffic circles appear to have achieved significant reductions in collisions with injuries on single-lane per direction roads in urban and rural areas but the findings concerning two-lane per direction roads are not as conclusive.
- Although not readily quantifiable, other benefits are ascribed to traffic calming measures, including a reduction in pollution and noise, an increase in walking, and the enhancement of residents' quality of life.
- In terms of of acceptability, involvement of concerned residents facilitates the implementation of these measures.
- The reduction of inconsistencies between the road's design criteria and posted speeds has the potential to improve the road collision toll by influencing speed dispersion, a phenomenon with a known relationship to collision risk. Broader convergence between road design and legal speed limits is primarily important in terms of heightening the credibility of speed limits, as it is an incentive for voluntary compliance.

Socioeconomic and legislative environment-related factors

Speed-reducing measures are aimed at modifying the socioeconomic and legislative environment to reduce speed. Their objective is the reduction of collisions with injuries, but also concerns urban transportation management tools such as the establishment of credible speed limits, penalties, the reduction of polluting emissions, and reliance on other modes of transportation.

Urban travel plans

Urban travel plans are a potential tool for land-use planning, the realization of studies and the development of community-wide projects. Furthermore, the municipal and regional (in Québec, MRC) master plans and development plans are also management tools with which to plan speed-related measures linked to the physical environment, bearing in mind the socioeconomic and legislative environments.

Speed limits

- The non-credibility of speed limits appears to be the principal cause of non-compliance. It may be linked to the gap between the road design speed or the layout of the roadside and the authorized speed, but also to the tolerance limit applied by the police to exercise surveillance, which then becomes the reference speed. Non-compliance also depends on the users' perception of the risk of arrest.
- The determination of speed limits is a compromise between safety and mobility that traditionally favours vehicle mobility. An approach emphasizing safety will promote the adoption of certain criteria, in particular the analysis of data pertaining to collisions and victims. It is a given that speed must be identified as one of the contributing factors when conducting site analyses for example. Other road network hierarchization criteria based

on safety and not only on mobility can also restore balance in favour of pedestrians in relation to motor vehicles.

- There is a preponderance of evidence that speed limits, even indirectly, affect the road collision toll. While reductions in legal speed limits have been linked to substantial gains in urban areas and on highways, increases in legal speed limits have led to an increase in average speeds and speed dispersion and, above all toward higher speeds. Both in terms of absolute numbers and in terms of relative risk (rates), speed increases have clearly contributed to excess mortality that could have been avoided through the maintenance of lower maximum speed limits.
- Despite the effectiveness of differential speed limits in reducing the number of trucks travelling at high speeds, the evidence concerning the impact of differential speed limits between trucks and other vehicles is inconclusive.
- Speed limits adapted to specific situations such as school and construction zones or variable speed limits geared to congestion on highway corridors have little impact on driving speeds without some form of control. When automated reinforcement is present, they have some impact on speed and collisions.

Legislative measures and penalties

- The effectiveness of legislation in influencing behavioural change depends on the demonstration of the anticipated safety-related benefits.
- The fear of punishment is supposed to be the key factor in the mechanism that dissuades individuals from breaking the law but no study focusing on statutory penalties has shown any impact on behaviour one way or the other. Even the certainty of a penalty has not shown any long-term impact. Moreover, it appears that the penalty must be accompanied by a minimum detection threshold. Indeed, it is not so much the type or severity of the penalty that determines impact but instead the real likelihood of being arrested. This suggests that a higher reinforcement rate is more effective than more stringent penalties without broader reinforcement. The severity of fines appears to be less crucial than their very existence and does not seem to have any dissuasive impact when the likelihood of being arrested is limited and static.
- While no scientific evidence is available to show that the demerit point system enhances the impact of reinforcement, one study appears to reveal some degree of effectiveness in that there is a longer time between offences after the second offence. There is no specific data concerning speed.
- The application of penalties considered for repeat offenders did not have the anticipated impact on behavioural change or the drivers' involvement in collisions. However, the evaluation of alcohol-ignition interlock devices in the case of repeat impaired driving offenders concludes that the devices are effective while they are present but that benefits are limited to this period. Indeed, the risk of repeat offences increases after the device's withdrawal in the group exposed when compared to the control group that did not use interlock devices. We conclude that this measure is a control measure with limited impact over time rather than a rehabilitation measure. The introduction of speed limiters in the case of repeat offenders should be assessed before it is broadly implemented.

- Similarly, evaluations of rehabilitation measures such as courses, psychological or medical follow-up and community activities using epidemiological models have not produced conclusive results, in particular because the impact could not be attributed to the measure alone when it was combined with other penalties such as the suspension of the driver's licence. Studies focusing primarily on impaired driving, and a single evaluation centred on speed, did not produce conclusive findings.

Pollution and contaminant emissions

- Speed affects gasoline consumption and emission levels. Even if we attribute reductions in pollution to lower speeds on Québec roads, other data would be needed to assess the true impact of reduced polluting emissions on public health. First, we must ascertain the number of people living along busy roads where a reduction in speed might affect polluting emissions. Next, we would have to anticipate the impact of these reductions on the concentration of pollutants in ambient air in inhabited areas. However, anticipated reductions in CO_2 emissions could be used to calculate the impact of a speed reduction on meeting objectives under the Kyoto Protocol.

Reliance on other modes of transportation

- Reliance on other modes of transportation can reduce pressure on the road network and, potentially, reduce the number of motor vehicles. For example, mass transit, intercity buses, trains, car pools, taxis, cycling and walking are avenues to alleviate road network congestion, reduce the number of collisions, and encourage active transportation.
- A sedentary lifestyle is a risk factor for several health problems. Environmental factors are among the measures to encourage walking as a means of active transportation. Pedestrian safety, the presence and access to infrastructure, the absence of conflict between users, and the level of pollution and noise linked to urban traffic have been identified as factors that positively influence regular physical activity, particularly walking. Traffic calming measures restore a certain balance in favour of pedestrians and cyclists, especially through a reduction in vehicle traffic and speeds.

A comprehensive approach to safety

The comprehensive approach seen in the Swedish Vision Zero reflects the determination of the state, which acknowledges both its responsibility to set objectives, and the means to which all interveners and the public must adhere and contribute in their respective fields of jurisdiction. The state assumes a leadership and coordination role to implement the appropriate measures. The approach's adoption requires considerable cohesion and reflects a level of recognition of safety standards as stringent as those adopted by the international air transportation sector.

This type of approach also implies adhering to the principle that it is ethically unacceptable that individuals are killed or seriously injured on the road network.

Reflection leading to the adoption of such an approach includes:

- the determination of the lowest possible threshold of road injuries, expressed in a clear objective;
- recognition of the principle that there are no technical limits to the reduction of traffic-related mortality and morbidity;
- a long-term comprehensive revision of transportation policy in keeping with government health and environment objectives, including sustainable transportation;
- a preference for safety over mobility;
- guidelines in the general framework respecting measures and initiatives likely to allow for the attainment of objectives;
- the definition of the sharing of responsibility;
- the choice of resources allocated according to objectives; and
- a strategy to achieve a consensus among all interveners.

CONCLUSION

At almost the same time that the Institut national de santé publique du Québec launched a study on speed-related issues under an agreement with the ministère de la Santé et des Services sociaux pursuant to section 54 of the *Public Health Act*, the Société de l'assurance automobile initiated a collaborative approach devoted to the same theme. The SAAQ invited representatives from several sectors, including the health sector.

The findings of this study can serve in a timely manner to shed light on the orientation of a government policy on the safety of road users that focuses on speed and integrates public health concerns.

Speed and health: a direct relationship

While the risk of being involved in a speed-related collision has been established, the cause and effect relationship is complex because several factors overlap. The problem of road injuries is multifactorial in that, as Haddon has shown, more than one risk factor is involved at the time of a collision. Factors could include, for example, speeding, drinking and driving, a sharp, poorly lit curve, the driver's lack of experience, and the absence of control.

However, the amount of energy released in a collision is directly linked to speed and is ultimately always the cause of mortality and morbidity. Under the injury prevention approach, the choice of priority measures focus, first and foremost, on the effectiveness of measures in preventing, limiting or mitigating the accumulation and transfer of energy from the agent (the vehicle) to the host (the individual), and in eliminating preventable injuries.

Several protection factors, such as shock-absorbing fenders, seatbelt use, airbags, energy-absorbing steering columns, enhanced braking systems, door reinforcement standards, and the use of protective helmets by motorcyclists and cyclists, have to date decreased the impact when energy is transferred and significantly reduced injuries. Future technological developments will further enhance the protection of vehicle occupants. However, current vehicle- and equipment-related protection measures are limited and do not totally offset the law of physics that prevails: the amount of accumulated energy increases with speed.

Moreover, serious and fatal injuries to pedestrians occur at low speed thresholds. For pedestrians, the risk of dying after a collision with a vehicle rises from 5% at 32 km/h to 80% at 64 km/h. Similarly, the risk of dying increases rapidly for motor vehicle occupants at speeds of 60 km/h or over. The relative risk of a driver travelling at 70 km/h in a 60-km/h zone being involved in a collision involving injuries appears to be equivalent to the relative risk of a driver with 0.08 milligrams of alcohol per millilitre of blood (the legal limit in Québec) being in a collision involving injuries. For this reason, the application of speed reduction measures on local road networks is as much a priority in urban as in rural areas even though the posted speeds are lower than on the high-speed upper-tier road network.

Interventions and a preventive strategy

Although there is a growing number of speeding offences and studies reveal the problem is becoming widespread, speeding is still trivialized by the public. This points to the need to redefine a comprehensive strategy aimed at reducing speed on Québec roads. This strategy must seek to reduce risk not only for all drivers but also for pedestrians and cyclists. It is not sufficient to reduce risk in the groups at greatest risk of speeding.

This concern for broadly protecting the population at the lowest cost is an incentive to give priority to passive measures such as self-enforcing ones, applicable to all vehicles at all times. Once such measures have been introduced, they do not require the drivers to act in any particular manner to attain the objective of reducing the risk factor (speed) and its consequences in terms of injury and disability.

Among the measures in this category, physical traffic calming measures, which are less convincing but nonetheless have a positive impact on safety, can be introduced in the medium term on an experimental basis. The gradual introduction of adaptive speed limiters, a vehicle-related technological measure that solves the problem at the source, is desirable and feasible in the medium and long term. Initially, the government could equip its vehicle fleet on an experimental basis.

In the short term, solutions that focus on behaviour, such as police control or automated control, can be considered bearing in mind the criteria that enhance their effectiveness, in particular through the choice of sites where speeding is acknowledged to be a problem.

As for the increased risk posed by serious speeding offenders in terms of age or annual kilometres travelled, the relevance of specific measures must also be examined in light of the effectiveness of such measures in altering risk behaviour. And yet, with regard to training, penalties or rehabilitation, evaluative studies do not demonstrate a decisive impact on behavioural change or on the measures' effects lasting over time, nor has any impact been demonstrated in terms of reducing collisions with injuries. The effectiveness of these measures aimed more specifically at high-risk groups has yet to be demonstrated. They fall more within the realm of research and require more evaluation before they are broadly introduced.

From a public health perspective, speed-related measures must be part of a comprehensive safety approach and must set an objective that determines preventable mortality thresholds at the lowest achievable level using the means available. To this end, measures that display the greatest potential to reduce the problem at the source must be given first consideration. Adaptive speed limiters are a technology that offers the greatest potential effectiveness to attain this objective over a period of 10 years provided that they are promptly implemented on an experimental basis.

GUIDANCE PRINCIPLES AND RECOMMENDATIONS

In light of the knowledge-based approach and key principles advocated by WHO and adopted by several countries, the guidance principles proposed by the public health sector pertaining to speeding can be summarized as follows:

1. adoption of a comprehensive multifactorial safety approach for all stakeholders concerned;
2. identification of speed control as a priority in transportation policy;
3. a choice of objectives that shifts the acceptable threshold of road victims to the threshold attainable through current technological limits;
4. the prioritization of measures that have proven effective in reducing the number of road victims;
5. a reduction of the problem at the source, in particular through passive measures that generate medium- and long-term benefits;
6. inclusion of the potential benefits that a widespread reduction in speed would have upon environmental assessments;
7. consideration of gains linked to walking and cycling in urban development planning and transportation planning.

Three general policy directions result from these principles. Recommendations for intervention are classified according to four categories depending on the objective: behaviour, vehicles, the physical environment, and the socioeconomic and legislative environments. These recommendations for intervention support measures whose effectiveness or potential effectiveness has been demonstrated.

GENERAL GUIDANCE PRINCIPLES

1. Adoption of a comprehensive road safety policy that concerns all stakeholders and that clearly sets ambitious targets

In conjunction with current reflection on speeding, it would be timely to discuss the relevance of adopting a comprehensive road safety policy according to the Vision Zero concept[21]. This concept seeks to implement all possible and necessary measures to reduce preventable mortality and morbidity on roads. Such a policy is intended to mobilize the public, engage the state at the national and local government levels, and engage the responsibility of all concerned stakeholders.

[21] Four principles support a road safety policy: ethics (human life and health are of prime importance and must have priority over mobility); responsibility (shared with all stakeholders in the system); safety (human beings are fallible and we must reduce consequences to the minimum); and change mechanisms (the authorities responsible must do as much as possible to guarantee public safety and mutual cooperation).

The countries that have achieved the best results in reducing traffic-related mortality have adopted such a concept or a comprehensive prevention policy in the realm of road safety. Australia, England, the Netherlands and, more recently, France, have all given priority to speed reduction as one of many strategic objectives to attain their targets. These objectives include legal, environmental, behavioural and technological measures. Indeed, measures designed to enhance infrastructure and vehicle safety, and to reduce risk factors such as impaired driving are essential to the attainment of the overall targets.

In all instances, government policy developed an action plan that took into account all facets of road injuries and implemented a broad range of measures. Programs of this nature, such as the one in Australia, among others, have relied on intensive means that have allowed for substantial safety gains.

2. Adoption of a multifactorial intervention strategy that promotes speed reductions on the entire road network, in particular through credible speed limits and measures to ensure compliance with those limits

Numerous factors contribute to speed-related collisions, but all injuries originate from a single factor: the transfer of energy.

Moreover, the strategy adopted must include medium- and long-term measures that take into account and are implemented in a consistent manner with short-term measures. A certain intrinsic logic must guide the order in which they are introduced.

For example, before controls are broadened or legislation is enforced, it is necessary to ensure that the posted speed limits are credible and consistent with the environment and that criteria to determine speeds take into account the principles of safety for all users. This assumes a prior redefinition of the classification and hierarchization of upper-tier and local road networks according to comprehensive planning of transportation and city plans. Criteria that take into account environmental objectives, sustainable development and that favour pedestrians and cyclists should also be included in the analysis when a comprehensive strategy is adopted.

Also, before more stringent penalties are considered, authorities must ensure that reinforcement reaches a level likely to affect the perception of being arrested and correspond to the real risk of arrest. Indeed, if the interception threshold and the risk of arrest are perceived as being low and offences remain constant, the adoption of more stringent penalties will have little impact. Moreover, to heighten the perception that speeding is equally serious whatever the means of detection, whether by the police or by photoradar, one must consider the impact of introducing photoradar control without demerit points.

3. A comprehensive speed reduction strategy must target all users

While drivers in the 16-34 age group are overrepresented with regard to speeding offences and their involvement in collisions, non-compliance with legal speed limits is widespread in the population and accounts for 74% of all *Highway Safety Code* offences. Furthermore, the majority of the 600 000 offences each year concern exceeding the speed limit by 20 km/h or more. There is sufficient evidence linking average speeds to higher collision and collision victim rates to justify measures to reduce average speeds and speed dispersion.

Similarly, despite an increase in the number of offences, it appears that Québec drivers continue to trivialize the seriousness of the role of speeding in the road collision toll, which reflects their perception of a low risk of arrest for this type of offence. Unlike drinking and driving, the message that speed kills has not had the desired effect, beyond the memorization of the theme, leading to broader compliance with legal speed limits.

It is not sufficient to target the groups at greatest risk. Measures targeting repeat drinking and driving offenders have not produced convincing long-term results. In addition, no evaluation has been conducted of these measures applied to repeat speeding offenders.

RECOMMENDATIONS FOR INTERVENTION

4. <u>Behaviour-related measures</u> that should be targeted:

a) Heighten awareness of speeding among Quebeckers, stakeholders and decision-makers by raising its seriousness up to the level of drinking and driving. Awareness campaigns should be linked to controls to ensure their impact.

b) Control measures such as selective traffic enforcement programs, photoradar or police surveillance should be based on an analysis of collision-prone sites from the point of view of speeding and use very precise criteria to determine their relevance. Therefore, photoradar should not cover a large part of the territory since its effectiveness will be limited to very specific zones such as intersections or road segments.

c) Carry out selective traffic enforcement programs[22] at the local or regional level, applying intensity criteria that have produced the most convincing results and where the site analysis has targeted this measure. This type of reinforcement is now carried out mainly on highways although the mortality rate linked to speeding is higher on 80-km/h and 90-km/h roads.

5. <u>Vehicle-related measures</u> that should be targeted:

a) Gradually install adaptive speed limiters on all vehicles over a period of 10 to 15 years. For example, an initial short-term experimental phase might cover the installation of speed limiters on government vehicles and the evaluation of the measure's impact on fuel economy and collisions and injuries. This measure can be applied as the vehicle fleet is renewed or to existing vehicles that are compatible with the technology available. The savings achieved would probably allow the project to be self-financing.

b) Participate in experimental projects on adaptive speed limiters like the ones conducted in Europe.

[22] Selective traffic enforcement program, e.g. seatbelt use or barriers to counteract impaired driving.

c) Define and adopt a Canadian standard similar to the one in force in the European Community to incorporate maximum speed limiters on heavy trucks over 3.5 tonnes at the time of manufacture both to achieve road safety and environmental objectives. Until the federal government adopts this standard, Québec could introduce a regulation to compel all vehicles registered in the province in this category to install the devices. Maximum speed limiters have already been installed voluntarily on roughly 10% of the heavy truck fleet (± 15 000/107 000 registered vehicles), mainly to save fuel.

d) Use speed data recorded by black boxes on vehicles equipped with them in the event of collisions with victims in order to broaden knowledge in this area.

e) Establish a Canadian standard to define the norm governing maximum motor vehicle power.

6. <u>Physical environment-related measures</u> that should be targeted:

a) Assess the environmental context as a potential opportunity to reduce driving speeds, inasmuch as the speed reduction has a positive impact on the road collision toll.

b) Carry out and evaluate experimental traffic calming projects at gateways and in urban residential areas adapted to the North American context, where the density of pedestrians and cyclists warrants doing so, and where speeding poses a safety problem or a constraint to walking or cycling, based on safety benefits (reductions in speed and collisions with injuries).

c) Opt for a combination of area-wide traffic calming measures instead of isolated measures such as one or two speed humps on an isolated street.

d) Select passive physical traffic calming measures that compel drivers to slow down instead of measures that require reinforcement such as signposting alone.

e) Develop road environments that are consistent with posted speed limits. Credible speed limits are the key incentive to compliance.

f) Ensure fairness toward pedestrians and cyclists through physical and functional development of the road network intended for their use.

g) Integrate traffic calming concepts into urban planning models.

h) Support local stakeholders in the realm of road safety through the elaboration of tools and training for project planning, design and management.

7. <u>Socioeconomic and legislative environment-related measures</u> that should be targeted:

a) Reduce driving speeds for all users, bearing in mind that any speed increase automatically raises mortality and morbidity rates. An increase in speed limits leads to higher driving speeds and requires a commensurate increase in the level of reinforcement (surveillance) merely to maintain the status quo.

b) Review speed limits on the existing upper-tier and local road networks in light of safety-related parameters, i.e. speeds suited to the road environment, terrain, functions, and users' and residents' needs. Credible speed limits are the key measure to ensure voluntary compliance with legal speed limits.

c) Set uniform tolerance limits consistent with posted speed limits, based on practices recognized elsewhere. Users must be informed beforehand of a reduction in the tolerance limit, which can be introduced gradually.

d) Establish a road network hierarchy that ensures fairness towards pedestrians and cyclists. To determine speeds that reflect fairness, adopt criteria favourable to pedestrian and cyclist safety and mobility, smooth traffic flow, and speed limits such as creating 30-km/h zones where numbers warrant doing so.

e) Intensify reinforcement of legislation in order to significantly heighten drivers' perception of the risk of arrest and the real risk. The full potential of the existing system must be used before assessing the need to increase the severity of speeding penalties.

f) Adopt a sustainable development perspective and include criteria that take into account environmental objectives when speed limits are set, especially in congested areas, by fostering other modes of transportation such as mass transit, intercity transportation, car pooling and active transportation.

g) Eliminate the time credit granted to novice drivers who follow driving courses to obtain a driver's licence since the credit has a worrisome impact. This measure encourages young drivers to obtain their licences earlier and shortens supervised learning time. It hastens their exposure to risk and increases their numbers in the road collision toll.

h) Evaluate measures to target repeat offenders such as speed limiters before resorting to widespread introduction of the measures. The alcohol-ignition interlock device, a measure pertaining to impaired driving and used on repeat offenders, has proven effective as a control measure during its application but has had no impact on rehabilitation, after the measure's withdrawal.

i) In the perspective of a comprehensive, concerted approach, determine the roles and responsibilities of the stakeholders, in particular the ministère des Transports, the regions (MRCs) and the municipalities, and stipulate these roles and responsibilities in the relevant legislation to ensure that the measures adopted are implemented. For example, ensure that road safety objectives in regional (MRC) land-use planning schemes target measures adopted with respect to the road network hierarchy, town boundary planning (services, schools, businesses, residential areas) and transportation choices (automobile access, trucking, cycle paths, and so on). All of these aspects influence the design of new neighbourhoods, the choice of modes of transportation, the volume of traffic and, consequently, safety.

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N° de publication : 847