# DEVELOPMENT OF THE VISIONARY RESEARCH MODEL APPLICATION TO THE CAR/PEDESTRIAN CONFLICT

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## ABSTRACT

This paper describes a study undertaken to improve road safety through a fundamentally different approach. The study draws on Sweden's Vision Zero road safety philosophy, the foundation of which is that it is ethically unacceptable to trade lives and health for other benefits in society. The research's main purpose was to develop a model to identify the research needs and priorities required to enable a "quantum step" towards safe traffic environments. The Visionary Research Model adopts an ambitious goal of eliminating death and serious injury within the road-transport system and is believed generic in form. The car/pedestrian conflict was chosen because of its relative simplicity and to demonstrate the model's potential. The model's conceptual structure has a pedestrian at the centre of five concentric layers of protection that target various threats to the pedestrian, by managing crash and injury risk, so as to avoid death or serious injury. The model challenges researchers and practitioners, encourages innovation and evidence-based risk assessment, and forces consideration of the full sequence of events in a car-pedestrian conflict. Though well-developed in its conceptual form, further research and development of the model's mathematical capability are required to enable changes in risk to be quantified.

## ACKNOWLEDGEMENTS

This project was funded through the Monash University Accident Research Centre's Baseline Research Program for which grants have been received from Department of Justice, Roads Corporation (VicRoads) and Transport Accident Commission. The inspiration for, and the original conceptualisation of, the Visionary Research Model came from the then Director of MUARC, Professor Claes Tingvall. The need for such an approach received the enthusiastic support of the Centre's baseline sponsors, with the on-going conduct of the study receiving the full support of current MUARC Director, Professor Ian Johnston. A small project team, comprising Dr Max Cameron, Dr Teresa Senserrick, Dr George Rechnitzer and Bruce Corben, assumed responsibility for developing the model's structure and defining its essential attributes. Led by Professor Tingvall, important contributions were also made by a group of the Centre's senior and mid-level researchers from a wide range of professional backgrounds.

# 1 INTRODUCTION

## 1.1 Background

Tremendous progress with road safety in Australia and overseas has made in recent decades, due largely to the use of a systematic, targeted approach, based upon scientifically rigorous methods. In Victoria, reductions in road trauma had stalled, until recently, with little change occurring since the mid-1990s. It has been apparent that when innovative or radical programs and initiatives are introduced, marked gains in safety are usually achieved. When more conventional approaches are applied, trends in road deaths and serious injuries level out or, in some instances, rise gradually as traffic growth takes over.

## 1.2 Project Aims and Scope

This paper summarises a study which set out to identify new research opportunities and priorities that will result in quantum advances in the effectiveness of crash and injury countermeasures (Corben, Senserrick, Cameron and Rechnitzer 2004). Ultimately, the identified research will bring about a paradigm shift in thinking about road safety, leading to innovative solutions, and new ways of designing and operating the road-transport system to dramatically reduce serious trauma.

## 1.3 A Generic Model Applied to Pedestrian Safety

The original study involved developing a conceptual model, termed the Visionary Research Model (VRM), of the road-transport system, capable of being applied to all types of road trauma. To facilitate its conceptualisation, the VRM was first developed for one important crash type, namely, the scenario of a pedestrian struck, or at risk of being struck, by a car. Moreover, the relative simplicity of this crash scenario makes it well suited to the initial stages of model development. The VRM examines ways of preventing pedestrians from being killed or seriously injured. Following its development for pedestrian conflicts, the VRM is believed general in nature and, therefore, able to be adapted to other significant crash and injury circumstances. Practical experience with the "safe pedestrian" VRM will be valuable, not only in further assessing its generic applicability, but also its ability to identify research opportunities and priorities, and to generate highly effective solutions.

In its own right, pedestrian trauma is of major concern in Australasia and elsewhere in the world. The problem is especially severe in developing countries where pedestrian deaths make up around one-third to a half of all road deaths in places; for example, Thailand, India (Delhi), Indonesia (Bandung) and Sri Lanka (Colombo) (Mohan and Tiwari 1998). Vulnerable road users make up some 80 to 90% of all traffic fatalities in these regions.

It is clear, then, that a model that concentrates research effort on vulnerable road users, particularly pedestrians, has great significance not just for highly-motorised countries, but even more so in developing countries of the world, where pedestrian trauma is already at acute levels. In essence, the VRM offers to transform fundamentally how road safety solutions are conceived and developed, and to identify research priorities that will drive a quantum leap in real-world practice.

# 2 THE VISIONARY RESEARCH MODEL IN CONCEPT

The model was defined, both conceptually and symbolically, such that the human is positioned at the very centre of the VRM, where it is protected from death or serious injury, by either preventing a crash or managing the transfer of the kinetic energy of impact. A key feature of the model is the notion of protective layers surrounding the human. These layers address individual events, phenomena or circumstances in a potential collision. A diagrammatic representation of the model is shown in Figure 1. Layers 1, 2 and 3 mainly address injury risk (providing protection during the *crash phase)*, while layers 4 and 5 reduce crash risk (affording protection in the *pre-crash phase)*.

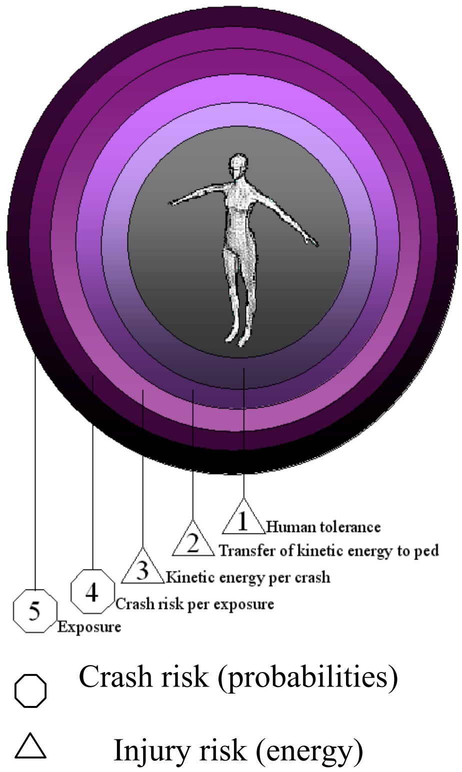


**Figure 1:** The five layers of protection

## 2.1 Injury and Crash Risk

The model is based on the idea that thicker layers provide greater protection to the human than do thinner layers. Some layers, generally located in the inner zone of the model, represent attenuators of kinetic energy reaching the pedestrian. Thus, thicker layers are better attenuators of energy at or during impact and, hence, reduce injury risk. Other layers represent estimates of the probability of specific events occurring. As with the energy attenuation concept, thicker layers are associated with greater protection (i.e., a higher probability of preventing a crash).

In summary, the inner three layers comprise physical attenuators of kinetic energy, affecting injury risk, and the outer two layers involve probability functions defining events preceding or precipitating a crash, thereby affecting crash risk. How these quantitative indicators might be combined mathematically to predict death or serious injury risk is a future research challenge.

## 2.2 Specific Threats to the Human

Above all else, the kinetic energy of individual vehicles represents the principal threat to pedestrians. Vehicles acquire kinetic energy only when in motion. Kinetic energy increases in a second-power relationship with increasing speed, but only linearly with increasing vehicle mass. Speed is clearly the most significant determinant of a vehicle's kinetic energy and, therefore, the threat it poses to a pedestrian (or other road user).

To define the layers of protection that ensure a human avoids death or serious injury in a crash, the specific physical elements posing a threat must first be defined. Drawing upon the framework of the Haddon Matrix (Haddon 1980), the initial focus of model development was on the crash phase, when energy exchange occurs between vehicle and pedestrian. Thus, the model operates in reverse direction to specify the crash and pre-crash conditions to produce an acceptable outcome.

The main characteristics of the human, vehicle and road that contribute to the risk of death or serious injury to a struck pedestrian, during the crash phase, are now discussed.

**The Human**

*Intrinsic Vulnerability to Kinetic Energy*
In a collision between a pedestrian and a car, the most fundamental of threats comes when the kinetic energy of the car exceeds the level that can be tolerated by the human, without causing serious injury. The tolerable level will vary with factors such as age, health status and physical stature. In a pedestrian crash, the orientation of the pedestrian relative to the car has the potential to affect injury outcomes, partly because of the differential vulnerability of various body parts of the human and their different physical abilities to share in the energy exchange. Pedestrians commonly suffer severe leg, thorax and head injuries resulting from contact with car body parts, such as bumpers, bonnet edges, windscreens, roof pillars (A-pillars), scuttle and even windscreen wiper spindles sitting above the surrounding surfaces of the car (European Transport Safety Council 1993; Jarret and Saul 1998). Thus, the pedestrian's orientation may affect the direction of impact forces and, hence, the ability of knee and hip joints to absorb energy without serious injury. Injury outcomes to the face and head may also be affected.

**The Car**
*Mass and Speed*
When two objects collide, the physical law of conservation of momentum applies. The momentum of an object is defined as the product of mass and velocity. In a collision between a car and a pedestrian, the mass of a pedestrian is typically more than an order of magnitude less than the mass of a vehicle. For example, the mass of an adult might commonly fall between, say, 60-90 kg while the mass of a passenger car might range from, say, 800 kg for a small car and up to around 1,500 kg for a medium-sized car. To illustrate the significance of the conservation of momentum law, consider the case of a human of 80 kg struck by a vehicle of 1200 kg. The change in velocity experienced by the pedestrian is some 15 times greater than for the car. The change in velocity experienced by the occupants of the striking car is reduced according to the crashworthiness of the vehicle, however, in the absence of protective clothing and a vehicle body with the ability to deform at impact, the pedestrian experiences close to the full value of the fifteen-fold change in velocity.

Acceleration is a physical variable commonly used to indicate injury risk for humans involved in collisions. If the acceleration imparted to a pedestrian in a collision approaches or, indeed, exceeds a human's tolerance level, then death or serious injury is more probable. In the context of the VRM, this is unacceptable and ways to keep acceleration within human tolerance levels must be found.

*Stiffness*
Car stiffness determines, in part, how kinetic energy is shared between pedestrian, vehicle and environment, particularly with respect to the concentration of forces on the human. Vehicles with stiff design features affect the kinetic energy exchange during the crash phase by imparting higher accelerations to the pedestrian, resulting in more severe injuries (Crandall, Bhalla and Madeley 2002). Less stiff structures reduce acceleration levels (as forces act over a longer period), which can have a marked beneficial effect on injury risk (Rechnitzer 2000). Vehicle stiffness, however, is also driven by crash-test requirements, which may conflict with pedestrian impact performance.

*Shape and Geometry*
The impact heights and contact points on the pedestrian are a direct function of shape and geometry of vehicle body design, and the pedestrian's age and stature. Geometric design features of cars (e.g., bumper height, bull bars, height, length and shape of bonnets, grilles and headlights, area and slope of bonnets) can each contribute significantly to a struck pedestrian's injury risk (McLean 1996; Terrel 1997; Crandall et al. 2002; Yang 2002). Important interactive effects exist between car geometry and body stiffness. For example, some styling features, especially on older models, have stiff, defined leading edges on bonnets (Yang 2002), while newer styling favours smoother, sloping bonnets which typically reduce the concentration of impact forces. The Honda Civic, for example, has made considerable advances in pedestrian protection through car design improvements, at minimal additional cost to the purchaser (Breen 2002). In-depth studies of pedestrian crashes have shown that injuries are more severe when only limited deformation of body panels is possible before contact with rigid components located immediately beneath the bonnet (Crandall et al. 2002). Vehicle design factors may perform differently for pedestrians of varying age, stature and health status.

**Road and Roadside Features**
A pedestrian struck by a car may experience a significant secondary impact when landing on the road surface (European Transport Safety Council 1993; McLean 1996) or, depending on the trajectory, when striking a roadside object (e.g., trees, poles, parked vehicles or traffic signs). In these circumstances, road infrastructure may affect injury outcomes when the pedestrian lands on the road or within the roadside. Narrow, rigid roadside objects may cause more severe injuries than would have resulted from the initial impact with the car. The orientation of the pedestrian in secondary impacts may also affect injury risk.

## 3 LAYERS OF PROTECTION

The protective layers needed to address threats defined above are now described in conceptual terms, starting at the model's centre, working outwards from the main layers of protection aimed at energy reduction or attenuation at impact, towards the main layers of protection aimed at eliminating or, at least reducing, crash risk. Through this sequence, the model establishes how the road-transport system should "look and operate" to keep the pedestrian safe, and then progressively defines at the layer interfaces, the system performance required to achieve this. The original study (Corben et al. 2004) described and, where possible, quantified the layers of protection in greater detail than here. Ultimately, any measures considered for implementation should be fully assessed in terms of their effectiveness, as well as their potential to compromise other safety or general transport objectives.

### 3.1 Conceptual Overview
The VRM consists of five main layers of protection for the human, which aim to provide:

1. Increased biomechanical tolerance of the human to violent forces (or kinetic energy);
2. Attenuation of the transfer of kinetic energy to the human;
3. Reduced level of kinetic energy to be managed in a crash;
4. Reduced risk of a crash for a given level of exposure;
5. Reduced exposure to crash risk.

Within each main layer lie more specific forms of protection, categorised on the basis of crash and/or injury risk factors, namely; human, vehicle design, road infrastructure (including roadsides) and system operation risk factors. It is conventional to focus on human, vehicle and road infrastructure factors in assessing crash and injury risk. However, it is less common to focus explicitly on system operation risk factors, which tend to be addressed implicitly as part of human, vehicle or infrastructure factors, or otherwise overlooked. System operation risk factors were viewed within the VRM as characterising the formal policies, practices and decisions on, for example, the setting and enforcement of speed limits, the design, location, timing and operational strategies of traffic signals, guidelines for using traffic-calming measures on high volume roads, and the priority afforded to various road user categories such as pedestrians, public transport users and cyclists.

**Groupings of Layers**
The five main layers fall into one of two broad groupings; the first grouping focuses on injury risk reduction and consists of layers 1, 2 and 3, namely increased human biomechanical tolerance, attenuation of kinetic energy transfer and reduction in kinetic energy at impact, the second grouping focuses on crash risk and comprises layers 4 and 5, namely reduced crash risk for a given level of exposure and reduced exposure.

**Quantifying Crash and Injury Risk**
The model has been developed to enable changes in crash or injury risk to be quantified so that it becomes possible to determine objectively whether safety is improved by a particular measure and, if so, to what extent. Quantification of the effects of particular countermeasures on the level of protection offered by both individual layers and the model in aggregate makes it theoretically possible to predict whether the road-transport system is operating within safe boundaries (i.e., that avoid death and serious injury). The model also provides insights into the mechanisms by which risk is reduced. Ideally, the VRM would be developed so that a variety of countermeasure scenarios could be evaluated in advance of their possible implementation. This would require the model to have a mathematical capability. The VRM seeks to apply the best knowledge and scientific evidence available from empirical and theoretical research to quantify crash and injury risk for pedestrians in conflict with a car. Thus, the model would have an interactive, mathematically-sound basis for assessment of potential countermeasures to prevent death or serious injury to pedestrians.

Injury risk to pedestrians is commonly expressed using a variety of physical measures, such as linear acceleration, Head Injury Criterion (HIC), rotational acceleration or force, bending moment or bending angle, or shear displacement of, for example, the knee joint. The success of the VRM depends to a large extent on its simplicity, including its ability to utilise the least number of physical or probability measures. While kinetic energy was adopted as the best single measure for the three main layers protecting the pedestrian during the crash phase, future development of the model should be able to convert research findings to units of kinetic energy. Over time, refinements may be introduced, such as more specific variables describing injury risk (e.g., rotational acceleration, bending moment and bending force). Similarly, for the layers describing crash risk, the probability of threatening events was chosen as the most appropriate single measure for estimating the effectiveness of a particular initiative. This is convenient as much of the relevant research deals with probability functions. The model should also enable both probability and kinetic energy measures to be combined, either additively or multiplicatively, depending on their physical relationships.

**Kinetic Energy and the Protective Layers**
Consider the circumstances of a pedestrian, exposed to the threat of kinetic energy, expressed mathematically as $\_mv^2$ kJ, for a car of mass m kg travelling at speed v m/sec. Conceptually within the model, a proportion of the kinetic energy is deflected from its trajectory towards the pedestrian by the two outer-most layers of the model, namely layers 5 and 4 (refer to Figure 2). These outer layers reduce crash risk by reducing either exposure to a car's kinetic energy (layer 5), or the intrinsic risk of a crash, for any given level of exposure (layer 4).

The proportion of potentially harmful kinetic energy deflected away from a pedestrian depends on the overall effectiveness of countermeasures within layers 4 and 5. Thicker layers (i.e., more effective countermeasures) provide greater protection through the harmless redirection of a greater proportion of kinetic energy. However, a residual amount of kinetic energy continues to pose a threat and must be successfully managed during the crash phase. Layers 3, 2 and 1 are the only remaining means by which death or serious injury is avoided. These three inner-most layers protect the struck pedestrian by minimising kinetic energy at impact, attenuating the transfer of kinetic energy from the car to the pedestrian and raising or restoring the biomechanical tolerance of the human to kinetic energy. In this sense, using a car's kinetic energy to represent a threat appears both physically meaningful and helpful in conceptualising the surrounding protective layers.

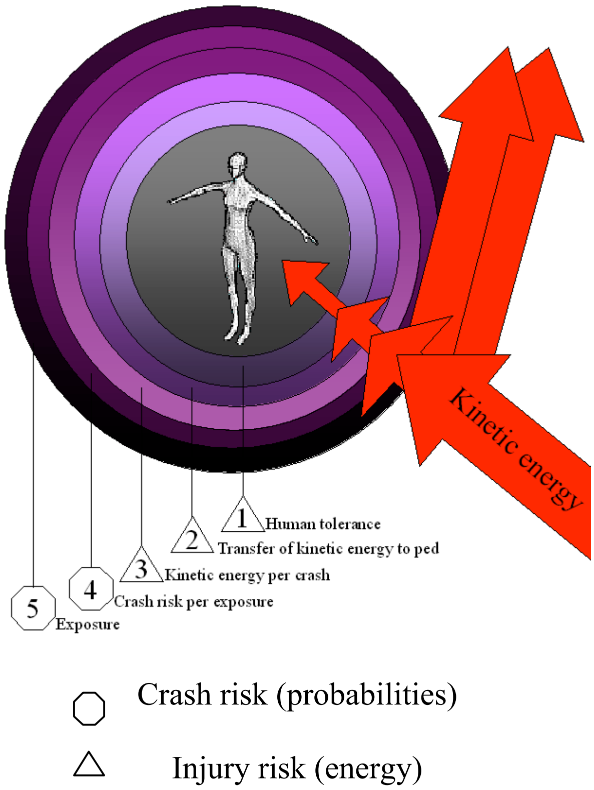


**Figure 2**: Kinetic Energy and the five layers of protection

### 3.2 Practical Application of the VRM

The characteristics of all layers were defined originally (Corben et al. 2004) in terms of four main risk factors; the human, the car, the road and roadside, and system operation. These characteristics encourage a more comprehensive and systematic approach, as well as focusing attention on measures that directly address the most important sources of risk. However, the most effective countermeasures do not necessarily come directly from the main source of the risk. For example, improving pedestrians' gap selection through education or skills training may be less effective than constructing a median, central refuge or traffic-calming measures that are forgiving of human errors.

The five layers have previously been described and discussed in greater detail (Corben et al. 2004). However, this paper presents some illustrative examples only, of the main outputs of the model, namely, countermeasure options and high priority research opportunities generated by the VRM. Table 1 shows the practical relevance of the four main risk factors for individual layers.

**Table 1: Relevance of the Five Main Layers of Protection**

| Protective Layer | Crash and/or Injury Risk Factors | | | |
|---|---|---|---|---|
| | **Human** | **Car** | **Road Infrastructure** | **System Operation** |
| 1. Increased biomechanical tolerance | ✓ | **N/a** | **N/a** | **N/a** |
| 2. Attenuation of kinetic energy transfer | ✓ | ✓ | ✓ | **N/a** |
| 3. Reduced level of kinetic energy | ✓ | ✓ | ✓ | ✓ |
| 4. Reduced crash risk for given exposure | ✓ | ✓ | ✓ | ✓ |
| 5. Reduced exposure to crash risk | ✓ | ✓ | ✓ | ✓ |

*N/a signifies not applicable*

1. **Increased biomechanical tolerance** – aside from the intrinsic tolerance of humans, which varies with age, health status, stature and other factors, there are few practical methods known for raising or preserving the level of biomechanical tolerance of the human. New, unexpected possibilities may emerge in the future.
2. **Attenuation of kinetic energy transfer** – research into improvements to car-front design features offer considerable promise for increasing protection to struck pedestrians. Options include optimising styling, geometry and stiffness, and developing energy-absorbing features and devices. Other possibilities include protective clothing and helmets for pedestrians and, depending on the extent to which injuries occur on impact with the road surface, development of energy-absorbing road surfaces in pedestrian activity areas.
3. **Reduced level of kinetic energy** - kinetic energy, proportional to the square of a car's speed, is reduced most effectively by lower travel (and impact) speeds. In-vehicle technology, such as crash warning/avoidance systems or intelligent speed adaptation (ISA), improved sight distances, skid resistant pavements, traffic-calming measures (e.g., roundabouts, medians, road narrowing, speed platforms), narrower roads/wider footpaths and lower speed limits are among the more promising options for lower speeds at impact.
4. **Reduced crash risk for given exposure** – similar countermeasures, and research needs and priorities, apply to layers 4 and 3. Infrastructure improvements to assist with complex gap selection, combined with traffic-calming and lower speed limits in pedestrian areas, also show promise. Such measures substantially lower both crash and injury risk, especially the latter, through reductions in a car's kinetic energy. Education, publicity and other behaviour change initiatives, while helping pedestrians and drivers to cope better with the demands of the traffic environment, do not change basic risk levels within the physical/traffic environment.
5. **Reduced exposure to crash risk** – research areas identified include: disincentives for private-car use; incentives for public transport use; revisions to road functional classifications; traffic design and management, or ITS (e.g., in-vehicle or infrastructure-based) route guidance systems to discourage drivers from pedestrian-sensitive routes; and innovative operation of traffic signals and co-ordination strategies.

## 4 PRELIMINARY OUTPUTS OF THE MODEL

As set out in the original study (Corben et al. 2004), the VRM has successfully identified a large number of new areas of research with the potential to improve dramatically the safety of pedestrians in the road-transport system, such as the following:

*Layer 2*

- Better understanding the relationship between car design and pedestrian injury risk, to stimulate design and purchase of vehicles with high pedestrian protection ratings.

*Layers 3 and 4*

- The use of in-vehicle ITS applications such as intelligent speed adaptation (ISA). Other ITS applications that reduce driver perception-reaction-time, reduce vehicle "perception-reaction-time" (i.e., leading to more rapid and effective automated application of vehicle braking systems in the event of a pedestrian conflict), or both, should also be investigated;
- Demonstration projects of the overall effects of lower speed limits in hazardous pedestrian areas, supported by infrastructure that promotes low travel speeds, separation of vehicles and pedestrians, and meets aesthetic and environmental goals for urban settings;
- Investigation and countermeasure development aimed at ensuring pedestrians benefit fully from the intrinsically safer operation of roundabouts. Enhancements to roundabout design and operation for all vulnerable road users are envisaged.

*Layer 4*

- Investigation of ways of improving driver and rider compliance with speed limits through advances in effectiveness of enforcement strategies and technologies;
- Strengthening urban speed management/zoning practices, drawing upon the physical laws governing braking distances and impact speeds;
- Evaluating the effectiveness of full-time 50 km/h speed limits in provincial cities and towns, and part-time 40 km/h speed limits in metropolitan shopping strips.

*Layer 5*

- Investigation of the potential for the innovative use of traffic signal control/linking strategies to facilitate traffic use of low risk routes and discourage traffic from pedestrian-sensitive routes;
- A literature review of congestion pricing schemes and their effects on traffic volumes on roads in congested cities of the world. The potential for applying such a strategy and its potential to reduce pedestrian crash risk would be assessed;
- Assessment of the potential for innovative, alternative modes of transport in major city centres, to reduce private vehicle use in these high pedestrian activity centres.

It is clear from the systematic assessment of crash and injury risk promoted by the VRM that the travel speeds adopted by drivers and riders, the urban speed limits set by road authorities and the type of infrastructure and traffic engineering philosophies practised by road authorities are highly influential in setting the intrinsic level of safety for pedestrians. Research activities that focus on gaining a full understanding of the role of speed should, therefore, receive high priority.

The model has also identified countermeasures that could be implemented more or less immediately. For some measures, implementation could be preceded by a "first principles" assessment, with preference being given to countermeasures which:

- Fully separate pedestrians from vehicles, where the required infrastructure is feasible within, and appropriate for, the surrounding environment;

- Ensure drivers do not exceed 30 km/h in areas where pedestrians and vehicles mix;
- Provide comprehensive spatial coverage along roads with significant pedestrian crash risk;
- Deliver potential synergies through a compatible combination of speed moderation and infrastructure that "calms" vehicular traffic and increases pedestrian-vehicle separation.

## 5 SUMMARY OF FEATURES OF THE VRM

A unique aspect of the VRM is the absolute requirement that the human be protected from harmful levels of kinetic energy or mechanical force. Thus, the VRM has the potential to enable a *fundamental* reduction in the risk of serious or fatal injuries to pedestrians, in contrast to the incremental reductions that have resulted from traditional approaches. For this to be possible, innovation - one of the foremost strengths of the VRM - is essential.

A major challenge in further developing the VRM is to identify practical ways in which the model can be used to create safe pedestrian environments. The model has a number of general applications to pedestrian safety, as well as some site-specific and category-specific uses:

- Improved understanding of the factors that affect pedestrian crash and injury risk, the relative importance of these factors and how they might be moderated, or changed in a fundamental way, to enhance pedestrian safety;
- Assessment of the qualitative and quantitative effects of particular countermeasures and other interventions;
- Improved understanding of the overall effects of applying two or more countermeasures simultaneously, in terms of combined and interactive effects;
- Assessment of the effects of site-specific improvements before they are implemented, thereby raising the cost-effectiveness of treatment programs;
- Assessment of system-wide interventions in terms of their general or specific effects on high-risk categories of pedestrians, such the young, the elderly or the intoxicated;
- Identification of research ideas and priorities, and new countermeasure possibilities.

These benefits and others can be realised by ensuring that the VRM has an appropriate structure, including valid relationships between model elements. The model should also have both quantitative and qualitative capabilities, to estimate changes in crash risk and injury risk, as a consequence of pedestrian safety or other measures that may unintentionally affect safety.

As the main focus of the study was on the safety of pedestrians, some identified countermeasures may have unintended effects on the mobility of drivers and riders. Further research may be required to better understand such effects. The established processes of society and government can determine whether to adopt pedestrian safety measures that lead to a possible loss of driver mobility.

## 6 CONCLUSIONS

The VRM is highly relevant to pedestrian safety in Australasia and especially relevant in developing countries where pedestrian trauma is a major concern. The emphasis of research and countermeasures would vary according to the conditions in any particular jurisdiction. It is recommended that further development of the VRM take place, particularly with respect to its mathematical capability. Among the potentially valuable features of a fully developed model is its ability to predict the direction of changes in crash and injury risk, as a result of introducing a particular measure, as well as to quantify the likely magnitude of any effects. At this early stage of model development, these possibilities have been recognised but considerable further research and development is needed to operationalise the VRM. Providing a reliable mathematical capability appears feasible and may even permit synergistic effects to be estimated. Developing the VRM's mathematical capability would draw extensively on the large body of scientific evidence across the field of pedestrian safety research in particular and road safety in general. It is also recommended that the VRM be applied to other categories of serious road trauma. The highest priority categories of serious trauma would include vehicle-to-vehicle collisions at intersections, single-vehicle crashes with roadside hazards and motorcyclist crashes with cars.

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