A model for star rating school walking routes

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Abstract

Walking is fundamental to mobility, but its perceived importance as a transport mode has fallen dramatically in past decades. The potential benefits of walking for society are numerous, including improved health, reduced traffic and congestion and enhanced social connections. It has become a community health priority to introduce some of these benefits to children by encouraging active transport to and from school. While walking should be encouraged, pedestrians are vulnerable road users, with one of the biggest potential injury threats being road crossing points and it is therefore vitally important to ensure that children can select safe locations to cross roads. To assist community members to select safe walking routes for children, a model and iPhone/iPad app to rate the safety of individual road crossings were devised, based on the 'star rating' concept familiar to many. The model considered the evidence-based key determinants of pedestrian crash and injury risk at individual road crossings. Based on established relationships and expert consensus, the variables were combined mathematically to generate a star rating between zero and five for each crossing point along a route. While the model is designed primarily in recognition of the abilities and limitations of children, it could also be adapted to other walking populations and road environments. This paper presents the methods undertaken to develop the resource, some sample results and discusses the implications and opportunities for its use to enhance the safety of all pedestrian groups.

Introduction

There is a clear and continuing tendency for Australians and other western populations to rely on motor vehicles as a primary mode of transport. Walking, however still forms a component of daily travel routine for most trips, with obvious health benefits to all. It is one of the main ways of increasing physical activity (Catford, 2003) and is strongly recommended by the public health sector because it has been shown to assist with weight control and reduce the risks of cardiovascular diseases, diabetes and arthritis (Cavill, Kahlmeier & Racioppi, 2006). Walking can also increase fitness, health and longevity, contribute to exercise and enjoyment, in addition to providing a sense of freedom, wellbeing and relaxation (Forward, 1998; Hydén, Nilsson & Risser, 1998; van der Heiden & Rooijers, 1994; Wigan, 1995). Meanwhile, it is associated with a range of other psychological health benefits including enhanced mental performance and concentration levels, improvements in self-concept, mood, sleep and energy levels, in addition to, tension and stress levels, while also decreasing feelings of anxiety, hostility and depression (Forward, 1998; Hydén et al., 1998; van der Heiden & Rooijers, 1994; Salmon, Breman, Fotheringham, Ball & Finch, 2000). It is clear that walking accompanies a range of major public health implications that in turn, warrants the need to incorporate it into everyday life, through recognising its fundamental contribution to overall health and wellbeing.

Walking also has associated environmental, social and economic benefits for individuals. This may include lower personal expenditure on vehicle fuel and maintenance, improved health status of populations, reductions in congestion and greenhouse gas emissions, as well as reduced environmental burden on the local area such as the costs of developing and maintaining the current road infrastructure (Salmon et al., 2000).

There are a number of factors likely to lead to increased participation in walking over the coming years, for both health and transport reasons (Catford, 2003; Salmon et al., 2000). The benefits of alternative modes of transport such as walking or cycling are increasingly recognised by governments and health professionals. In response, there has been a major push to promote safe walking and cycling in urban areas, particularly in Europe and Australia (Dijkstra et al., 1998; Victorian Government, 2006) in order to meet important goals in urban traffic policy (i.e., accessibility for all, safety, and a 'good' environment). Coupled with this, increases in traffic density, congestion and complexity will be mitigated by increased use of alternative transportation modes.

Pedestrians, however, are an extremely vulnerable road user group, largely due to their lack of protection and limited biomechanical tolerance to violent forces. Crashes involving pedestrians, particularly when impacted by a vehicle are, therefore, severe in nature, making pedestrian safety a serious community concern. Crashes involving pedestrians constitute a substantial proportion of all road deaths world-wide (Davies, 1999; Öström & Eriksson, 2001; NHTSA, 2001). In the most recent reported statistics, 2010 included 118 pedestrian deaths in Australia, representing approximately 13 percent of all road deaths (Department of Infrastructure and Transport, 2010). In terms of injury rates however, 2824 people within Australia sustained serious injuries as a pedestrian between July 2006 and June 2007 (Henley & Harrison, 2009).

Children under the age of 16 years are considered one of the high risk sub-groups of pedestrians and constitute a substantial proportion of pedestrian deaths (9%) (Department of Infrastructure and Transport 2010) and serious injuries (22%) (Congiu, Whelan, Oxley, Charlton, D'Elia & Muir, 2008). Moreover, research suggests that younger children (between the ages of six and 10) are at highest risk of death and injury, with an estimated minimum four times the risk of collision compared with adult pedestrians (Struik, Alexander, Cave, Fleming, Lyttle & Stone, 1998; Thomson, 1996). Almost half these children were killed between the hours of 8:00 am to 9:00 am and 3:00 pm to 4:00 pm, the times during which children are travelling to and from school (Logan, 2008). Given the vulnerability of child pedestrians, coupled with the potential for increased exposure and general growth in traffic, it is paramount that low risk and comfortable walking environments are provided.

The notion of a Walking School Bus (WSB) has evolved to encourage children to walk to and from school in supervised safety and therefore enjoy the health and well-being benefits of physical activity. The concept has been implemented, in one form or another, in many Western countries, including New Zealand, Canada, the USA and the UK, as well as in Australia (e.g. Kearns, Collins & Neuwelt, 2003; Kong, Sussman, Negrete, Patterson, Mittleman & Hough, 2009). Children walk in a group along a designated route under the supervision of adult volunteers, picking up or dropping off children along the way at designated 'bus stops'. The benefits of the program include assisting children to become more active, encouraging social and community connections and a reduction in the number of cars on the road, bringing health, environmental, safety and social benefits to communities. Given children are particularly vulnerable in traffic however, it is important that efforts to promote walking among school age children are undertaken without increasing their levels of crash and injury risk. Limited evaluations of WSB programs have been undertaken (e.g. Wong, Patterson, Fill, & Richards, 2004), with the majority of these focusing on the health benefits of increased walking, while minimal consideration of the safety implications have been explored. Moreover, for those schools wanting to implement WSBs and choosing WSB routes, there is no objective guidance in the form of readily usable, evidence-based techniques, to assist them in assessing the safety performance of candidate routes that can provide the lowest risk and most practical routes available.

This paper describes the development and application of a risk-based star-rating system to achieve the safest possible walking routes to and from schools. It discusses the implications of the use of this system by traffic engineers and school communities involved in ensuring safe school walking routes. It also considers the potential for the concept to be more broadly applied to pedestrian safety in general.

It should be noted that there are a number of other factors, including UV exposure, air and noise pollution and personal safety that could influence the choice to increase levels of walking. The model documented in this paper, however, considered only road safety issues during this study phase.

Model description

A concept for rating the safety of individual road crossing points forming a walk-to-school route was developed. The rating method was based on the familiar 'star-rating' concept used in a wide variety of situations, such as to rate the amenity of hotel accommodation (e.g. STAR Ratings Australia), energy efficiency of electrical appliances and the safety performance of motor vehicles. This section describes the fundamental risk relationships underpinning the model, the structure of the model and the means by which the risk relationships were translated into a star-rating system.

Defining risk factors

The model has been designed to take into account five main factors considered the most influential in determining the risk of both crash and injury to pedestrians based on a number of previous national and international research (e.g. Jensen, 1999; Oxley, Corben, Fildes, O'Hare & Rothengatter, 2004).

Factor 1: the speed limit applicable to vehicles at the crossing point during the periods when children walk to and from school;

The evidence has clearly established the relationship between pedestrian fatality risk and impact speed (e.g. Anderson, McLean, Farmer, Lee & Brooks, 1997; Ministry of Transport and Communications, 1997). The basic relationship determined by Anderson et al. (1997) is shown in Figure 1 (after Corben, D'Elia & Healy, 2006).

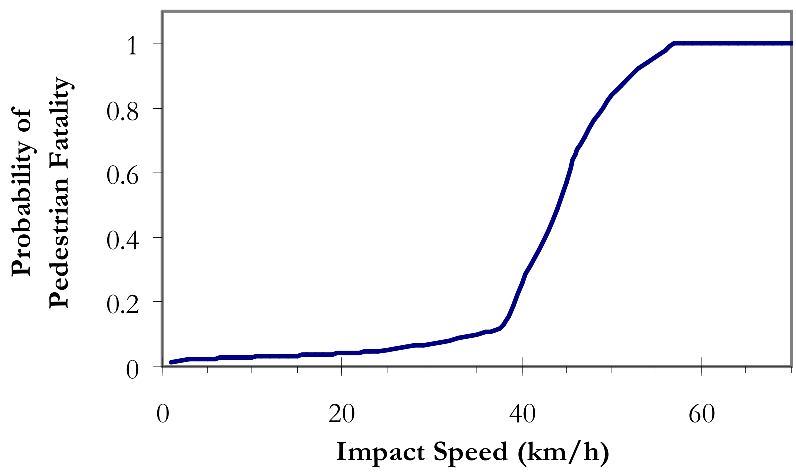

Figure 1 Relationship between probability of a pedestrian fatality and impact speed.

Factor 2: the average number of vehicles per hour at the crossing point during the periods when children walk to and from school;

Traffic volume is defined as the number of vehicles passing the crossing point during school trips. A larger number of vehicles passing a crossing point leads directly to increased crash risk through increased exposure. With more vehicles, there are more opportunities within a given time period for a collision to occur with a pedestrian crossing during this period.

Factor 3: the width of road to be traversed to complete an individual crossing movement;

In general, wider roads make it more difficult for a pedestrian to select a safe gap in traffic. This is believed to be due, at least in part, to the greater difficulty for the pedestrian in calibrating walking speed in conjunction with available gaps in the traffic. Wider roads add uncertainty to this critical judgement and also mean that:

- The pedestrian needs to spend more time on the roadway and hence is exposed to crash risk for a longer period;
- Higher mean travel speeds occur due to environmental cues (see Oxley & Corben, 2001);
- There can be greater uncertainty about the lateral positioning of an approaching vehicle, especially where there are no marked traffic lanes or where drivers can change lanes during their approach to the crossing point;
- There will often be higher traffic volumes, an effect that is captured by the traffic volume factor above.

Factor 4: the number of directions of conflicting traffic that must be assessed by a pedestrian crossing at this point;

Factor 5: whether there is a formal crossing facility provided, such as traffic signals, a school crossing or a zebra crossing, for example, to facilitate the crossing manoeuvre.

In addition to being major determinants of pedestrian safety, the selection of these easily measured factors means that data can be readily collected by all potential users of the system, including traffic engineering practitioners, school co-ordinators and local government authorities.

Quantifying risk relationships

Subsequent to the identification of the five pedestrian risk factors, it was essential to quantify these in such a way that they could be incorporated into a model. Each risk factor needed to be individually addressed, given the fundamental differences in risk among the factors. The quantification of risk relationships for each factor follows.

Speed limit

Given the compelling evidence about the role of speed in pedestrian crash and injury risk, this risk relationship was designated the core risk measure controlling the model, with the remaining risk factors serving to moderate the effects of speed.

Corben et al. (2006) combined information on the probability of a fatal crash, given that a crash occurred, with the overall probability of crash occurrence, to derive a relationship between relative risk of a fatal pedestrian crash and driver speed choice, as shown in Table 1. A speed of 30 km/h was used as the reference against which to scale risk for higher speed choices, since studies of the biomechanical tolerance of humans to violent forces have shown that an impact at this speed equates to a low risk (less than 10%) of death to a pedestrian and that this risk increases rapidly as impact speed increases (Anderson et al., 1997; Davis, 2001).

Table 1. Relationship between driver speed choice and relative risk of fatal pedestrian crash

Speed choice (speed limit) (km/h)	Relative risk of a fatal pedestrian crash (compared to 30 km/h)
20 and below	0.2
30	1.0
40	4.5
50	18.6
60	30.7
70 and above	40.9

Note: Risk values quoted to 3 significant figures.

Traffic volume

The increase in crash risk due to increased traffic volume has been represented in the model by a direct linear relationship; that is doubling the traffic volume doubles the crash risk. This relationship has been operationalised in the model by defining six discrete intervals, as shown in Table 2. The interval 101-300 vehicles per hour was nominally set to a relative risk of 1, as this volume was thought to represent a typical traffic volume range in residential streets not affected by significant levels of through traffic. Fewer 'risky' crossing movements would be expected on roads with lower traffic volumes.

Table 2. Relationship between traffic volume and relative risk of fatal pedestrian crash

Traffic volume range (vehicles/hour)	Relative risk of a fatal pedestrian crash (compared to 101-300 vehicles/hour)
<100	<0.4
101-300	1
301-1000	3.3
1001-3000	10.0
3001-10000	32.5
>10001	>50.0

Note: Risk values quoted to one decimal place.

Road width

An attempt was made to combine the factors influencing crash risk (listed in Section 1.1) as a function of road width. In order to develop a realistic mathematical relationship, individual sub factors were separately addressed from first principles:

1. Increased time on the road through increased road width was considered to take a linear relationship;

2. Pedestrian crash risk has been shown to vary with speed according to a second power relationship based on stopping distances. When reaction time is taken into account in estimating overall stopping distance, the resultant exponent would lie somewhere between 1 and 2;

3. The uncertainty for the pedestrian of vehicle lateral position was assumed to follow a nonlinear relationship, with an exponent between 1 and 2. In the absence of sound empirical evidence, an exponent of 1.5 was used.

Combining the above sub factors resulted in the following mathematical relationship:

$$crash\ risk \propto (road\ width)^{1.5}$$

Similar to the relationship between traffic volume and crash risk, a base level of risk was assumed, as shown in Table 3. The road width categories corresponded to typical road widths in Australia. This level of precision was considered appropriate given the desired ease of use of the model and the absence of a robust mathematical relationship justifying greater precision.

Table 3. Relationship between road width and relative risk of fatal pedestrian crash

Road crossing width (m)	Relative risk of a fatal pedestrian crash (compared to 7m road width)
3.5 (~1 lane)	0.4
7.0 (~2 lanes)	1
10.5 (~3 lanes)	1.8
14.0 (~4 lanes)	2.8
17.5 (~5 lanes)	4.0
>17.5	>4.0

Note: Risk values quoted to one decimal place.

Number of directions of conflicting traffic

A pedestrian crossing a road is required to assess the approach of vehicles, often from a number of different directions. In the simplest case, on a one-way street or a divided road where a median or refuge island exists to enable a staged crossing movement, the pedestrian need attend to only one direction at a time. On two-way undivided roads, there is a substantial increase in the difficulty of safe gap choice because of the need to select coincident gaps from two directions of traffic. At common cross intersections, pedestrians can encounter conflict from vehicles approaching from four or more directions, depending upon the geometric layout and complexity of the intersection.

The effect of a number of conflicting traffic directions on crash risk is represented mathematically in the star rating system by:

$$crash\ risk \propto (no.\ of\ \ conflicting\ directions)^2$$

As for the risk-road width relationship, the current project proposes a mathematical relationship based upon expert judgement and would need to be reviewed in any further development of the model.

Table 4. Relative pedestrian crash risk and star rating versus number of conflicting road directions. Reference risk: 2 conflicting directions = 1

Number of conflicting directions	Approx. relative risk
1	0.5
2	1
3	2.3
4	4.0
5	6.3
>6	>9.0

Note: risk values rounded to one decimal place.

Crossing type

There have been few studies investigating safety differences between the different types of crossing facilities. Even when traffic signals or other types of crossing facilities are present, the safety of a pedestrian is never assured; it is common for pedestrians to be struck at formal pedestrian crossing facilities (Zegeer, Stewart, Huang & Lagerwey, 2001), though for children this is rare, especially as it is common practice in Australia for crossings around schools to be supervised during school hours. An iterative expert consensus approach was used to develop the model, where a number of different sites were selected with a panel of pedestrian safety experts rating each. An initial correction factor was determined using one crossing point, then applied to various other crossings, iterating until ratings were consistent and plausible both between similar roads with different crossing facilities and similar crossing facilities across roads with different characteristics

Table 5. Star rating corrections by crossing type

Crossing type	Star rating correction
No crossing facility	0
Pedestrian crossing	+1.0

Pedestrian-operated signals	+2.0
School crossing (always supervised)	+1.25
Intersection signals	+1.5
Intersection signals with fully controlled right turns	+2.0

The presence of a crossing supervisor increases the star rating of all of the above facilities (except for the supervised school crossing) by 0.5 stars (equating to a 25% reduction in risk – see following section).

The star rating concept

Based on the assumption that the model was intended for field assessments of intersections and for use by community members, rather than for research purposes, it was necessary to develop a simple system to rate the safety of individual intersections. Given the current broad use of star rating scales generally operating over a five star range, (e.g., Alton-Scheidl, Schumutzer, Sint, & Tscherteu, 1997), the same format was adopted to rate the safety of pedestrian road crossings. A purely objective system was proposed, to eliminate the biases inherent in subjectively-derived scales (Nichols, 1997).

The star rating system was structured around a 'base' star rating, derived from speed choice, which was then modified by star rating corrections computed from the other four factors plus crossing facility type. The base rating scale shown in Table 6 was developed, with 40 km/h nominated as 4.5 stars and 50 km/h as 2 stars, with the ratings for the remaining speeds derived from the risk relationships in Table 1. The calibration factor that resulted was a -4.05 star rating change for each 10 times increase in relative risk. Therefore, if the risk increased by a factor of 10 with all other factors remaining constant, the star rating would decrease by four, with an increase of four stars awarded for a ten times reduction in risk.

Table 6. Base star ratings by speed choice (speed limit)

Speed choice (speed limit) (km/h)	Base crossing star rating
20 and below	9.9
30	7.2
40	4.5
50	2.0
60	1.1
70 and above	0.6

The base rating was then modified as necessary by star rating corrections derived from the relative risk relationships defined earlier for each of the four factors considered, along with the crossing facility type. For each of these, the star rating correction was determined from the change in relative risk in accordance with the calibration factor, as shown below:

$$[\text{Star rating change}] = -4.05\log_{10}[\text{Relative risk}]$$

Star ratings outside the range of zero to five stars were set to zero or five stars respectively for usability reasons. Thus, a crossing that was sufficiently unsafe to calculate to -0.5 stars, for example, would be rounded to zero stars.

Model application

The Star Rating Tool was designed to be used within the community to assist in determining the level of safety at road crossings, with the safety of children foremost to help promote safe walking to and from school. It follows that the Star Rating model should be implemented in a form that is both easily accessible and user-friendly. Based on these specifications, a smart phone application for iPhone and iPad, called "Walk this Way" was developed in conjunction with Outware Mobile in Windsor, Melbourne and is currently available for free download in the Apple Store. Guidelines for using the software are available online[1].

Discussion

This paper documents the development of a prototype method for assessing and comparing the safety performance of pedestrian road crossing points along a route used for walking to and from school. The model utilises the common star rating concept which assigns between zero and five stars for individual crossing points, based on factors known to contribute to pedestrian crash and injury risk. The factor of prime importance is driver speed choice, as reflected by speed limit and this is modified by other factors, namely traffic volume, road width, number of directions of conflicting traffic and the type of pedestrian crossing facility present. These factors have been combined mathematically to reflect known relationships connecting speed with fatal pedestrian crash risk, and for other factors, relationships derived from expert judgement of relative risk of a crash resulting in death or serious injury to a pedestrian. Although the model presents an opportunity for further enhancement, it is believed to be sufficiently developed to be used to assess the safety performance of individual crossing points, as well as to gain valuable practical experience with its use. This experience will inform future improvements to the model.

The relationship between speed limit and crash risk has been used to define a somewhat arbitrary base scale for assigning star ratings to selected levels of risk. Consequently, the assignment of alternative base scales could be considered in order to reflect more or less conservative stances on acceptable safety levels for child or other categories of pedestrians.

In its current form, the model can be used to assign star ratings to each of the road crossing points along a proposed or existing walking route in order to identify crossing points with a low star rating that should therefore receive priority attention. Attached to such crossing points is additional information on the factors leading to their ratings. This information can be used to guide the responsible agencies in identifying opportunities for raising safety to levels that are at least acceptable, but preferably commensurate with best-practice standards.

The goal should be to have all crossing points achieving four or five stars, with three star crossings defined as acceptable but with room for improvement. It is proposed that crossings with star ratings of two or less would be unacceptable for inclusion on a walk-to-school route and would need to be

[1] See: https://sites.google.com/site/walkthiswayhelp/

either improved to at least three, and ideally four or five, star level or a new route defined to exclude these high risk crossing points.

Road crossings were selected as the subject of the modelling exercise since they constitute a significant proportion of the risk to which children walking to and from school are exposed. However, due to the constraints of the development process, there are some limitations of the model. For example, the evaluation of a route involves navigating a number of hazards in addition to road crossings, however the model does not attempt to rate hazards such as driveway crossings, some of which provide access to schools or kindergartens, for example, and have the potential to carry sufficient – albeit generally low speed – traffic to constitute a significant risk during before and after school times. Furthermore, with regard to road crossings, only the core factors documented have been taken into account, excluding other factors such as sight distance, auditory information or potential distractions.

This study has demonstrated that it is feasible to objectively rate the safety performance of individual road crossings along routes used for walking to and from school as well as indications of overall route safety. Additional opportunities have been identified during the course of the study to improve the reliability of risk estimates as well as mathematical methods of combining their effects, beyond those currently available within Victoria. Moreover, although crash data are sparse in many of the areas where school walking trips are made, future work will also investigate validating the model against recorded crash history.

Conclusions

Walking is the most fundamental means of mobility for humans, but with the advent of the motor vehicle in particular, its importance as a transport mode has fallen dramatically. However, there are many compelling reasons, including health, energy conservation and climate change, for walking to be afforded a much higher priority than it has for the past fifty years or so. While undoubtedly valuable for adults, the benefits of walking for children are possibly even greater, encouraging them to become more active, encouraging social and community connections and reducing vehicular traffic. One of the biggest threats to walking safety is the potential for injury at road crossing points where pedestrians are more likely to be exposed to conflicts with motor vehicles.

This study developed a general method for rating the safety of individual road crossing points, based on the familiar ‘star rating’ concept used in a variety of areas to provide consumers with easily understood means for ranking the efficacy of products and services. A model was developed that considered the main determinants of pedestrian crash and injury risk at a road crossing and combined these characteristics mathematically to generate a star rating between zero and five for each crossing point along a route. While the model was designed primarily to generate star ratings which recognise the abilities and limitations of children, it is intended to be generic in its application, subject to the modification of internal weightings to suit other groups, including older people or the general population.

The study has demonstrated that it is feasible to objectively rate the safety performance of individual road crossing points, as well as provide indications of overall route safety. The model may be effectively used without the requirement for specific road safety expertise and is aimed at those personnel involved in evaluating or designing routes suitable for children to use to walk to and from school. Further work would be desirable to improve both the robustness of the mathematical risk relationships utilised, as well as to broaden the applicability of the model to other walking populations.

Acknowledgements

Caulfield Community Health Service, as part of its suite of health promotion programs, initiated this study in collaboration with the Monash University Accident Research Centre.

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