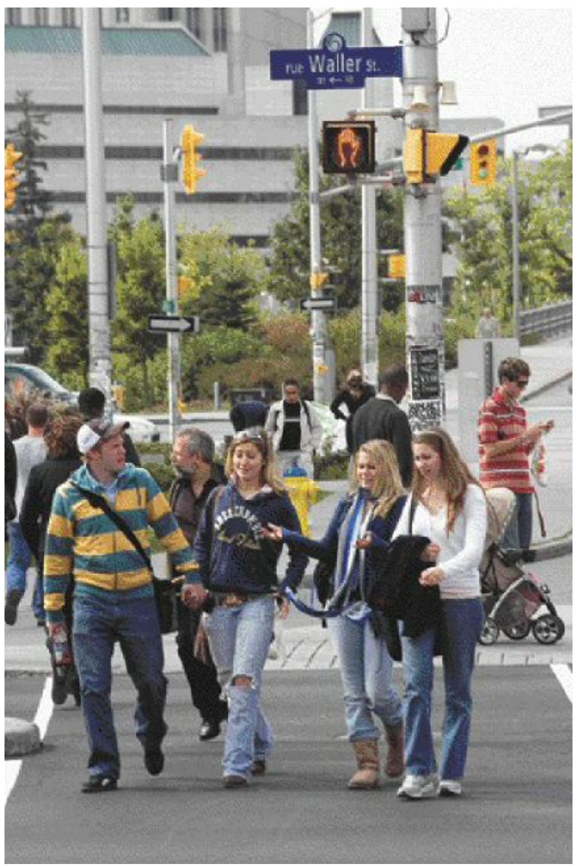
Human-centred Pedestrian Safety Evaluation Program: Technical Foundation



Technical foundation describing the knowledge & processes used for setting investment priorities in intersection pedestrian safety in the City of Ottawa.

January 2010

TABLE OF CONTENTS

LIST OF FIGURES

1 INTRODUCTION

1.1 Background

Pedestrians, and other vulnerable road users, represent an important part of the overall road safety picture. Vulnerable road user[1] fatalities in Canada claimed 567 lives in the year 2000 – a figure that represents almost 20% of all road fatalities in our country. Of these, 367 involved pedestrians. In addition, over 13,700 people suffered some level of personal injury.

Almost 70% of the pedestrian fatalities took place in urban areas, and two-thirds were killed at intersections. Even though crash involvement rates for persons 65 years of age and over are lower than for most other age groups, seniors are much more vulnerable to serious injury or death when struck by a motor vehicle than younger pedestrians[2]. In Canada, over one-third of all pedestrian fatalities involve a senior citizen. This constitutes a substantial over-representation of this group.

In its “Pedestrian Crossing Control Manual”, the Transportation Association of Canada (TAC) states:

> *Pedestrian crossings present one of the greatest challenges for the traffic and safety engineering communities.* [3]

Kenneth Ogden, in his seminal work on road safety engineering, further reinforces this view:

> *Pedestrians, bicyclists, and other vulnerable road users require specific consideration in traffic design and management, particularly from a road safety viewpoint.* [4]

1.2 The City of Ottawa Context

The walking mode of travel represents an important component of overall travel demand in the City of Ottawa. Estimates of walking trip activity prepared for the City as part of another project indicate that in 2001, pedestrians accounted for over 81 million person trips in the course of the year, or almost 12% of all travel demand in the City. The vast majority of these trips took place in the urbanized area of the City, with about 40%

[1] Vulnerable road users (VRU) include pedestrians, cyclists, and in-line skaters. In addition, within the pedestrian group, special consideration is usually necessary in dealing with the needs of seniors, persons with disabilities (including manual and motorized wheelchair users), and children.

[2] Zegeer, CV. Seiderman, C. Lagerwey, P. Cynecki, M. Ronkin, M. Schneider, R. “Pedestrian Facilities Users Guide: Providing Safety and Mobility”. Federal Highway Administration. McLean. VA. 2001. p.12.

[3] Transportation Association of Canada. “Pedestrian Crossing Control Manual”. Ottawa. Canada. 1998. p. 1.

[4] Ogden, KW. “Safer Roads: A Guide to Road Safety Engineering”. Avebury Technical. Aldershot, England. 1996. p. 365.

occurring in the peak periods and almost 58% happening in off-peak times.[5] This figure approaches the 15% daily mode share captured by public transit in the City. Given this fact, it is not surprising that community interest in pedestrian safety issues is significant in the City.

1.3 Goals and Objectives

The overall goal of this study is to help improve the ability of the City to deal with pedestrian road safety issues, and in particular, to enhance the process used for programming their pedestrian safety investments explicitly and proactively to account for pedestrian needs.

More specifically, the objectives of this project include the need to:

- Improve the understanding of the relationship of pedestrian needs and safety issues in the context of signalized and non-signalized intersection operations;
- Develop two key processes that include:
    - an overall approach to planning and programming road safety improvements oriented specifically to pedestrian needs at signalized and non-signalized intersections – that allows for community-based input and discussions that leads to the identification of intersections requiring detailed study, and
    - a robust technical analysis process to proactively prioritize sites and identify appropriate candidate countermeasures.

1.4 Organization of the report

This technical foundation report starts with this introductory section and is followed by a discussion of road safety prioritization principles in Section 2. Section 3 describes an overall programming process that focuses on the use of a collaborative process involving both City technical staff and community representatives to develop agreed-upon priorities for pedestrian-oriented intersection improvements across the City. In Section 4 we discuss road user needs and expectations at intersection crossings. This discussion helps set a strong human-factor foundation for various technical and analytical elements of the prioritization methodology. In Section 5 of the document, we focus on an assessment of current practices and emerging techniques that we subsequently use in various ways as the practical technical basis of our pedestrian safety evaluation program. Building on this work, Section 6 describes two key analytical tools that were developed in the course of our work. These are intended to be used for both the prioritization of pedestrian-oriented intersection safety improvements, and selection of candidate countermeasures. A number of concluding thoughts are offered in Section 7 of this document.

[5] Projections based on City of Ottawa data and prepared for the 2003 Cost of Travel update project.

2 THE NEED FOR PRIORITIZING ROAD SAFETY IMPROVEMENTS

2.1 Background

There is little doubt that the fundamental process of prioritizing road safety improvement investment options is undergoing rapid change.[6] Hauer provides an excellent definition and clarification of this process, which he dubs “network screening”:

> *Road network screening can be done at little cost because it relies on the computerized use of electronically stored accident, traffic data, and site data. The product of road network screening is a list of sites ranked in order of priority for the conduct of a more detailed and costly examination. The detailed and costly examination, often called a “Detailed Engineering Study” (DES) is applied only to the sites ranked near the top of the list. The purpose of a DES at a site is to formulate cost-effective projects for improved safety.* [7]

This kind of approach is analogous to the pavement management system technique of carrying out “network level pavement management” to define priorities for investment, and “project level pavement management” to select specific rehabilitation strategies from among a number of candidate alternatives for each priority project.

The increasing interest in, and development of, such quantified prioritization tools is part of a growing migration in the road safety area from what Hauer terms “The Pragmatic Style” to the “Rational Style” of safety management. He depicts this as shown in Figure 1, below.

Figure 1: Two ends of the road safety management spectrum[8]

- Based on Lay beliefs and on the self interest of organizations
- Does not require knowledge of fact
- Does not conduct evaluative research

- Based on expected consequences
- Needs factual information
- Learns from experience

---

[6] Hauer, E., Kononov, J., Allery, B., Griffith, M. “Screening the Road Network for Sites with Promise”. Paper prepared for the 2002 Conference of the Transportation Research Board. TRB. Washington, DC. 2002.

[7] Ibid. P. 1.

[8] Hauer, E., “Workforce for Road Safety Management”. Paper prepared for presentation at the Highway Safety Workforce Planning Workshop. San Antonio, TX. April 3-4, 2002.

2.2 A generalized road safety improvement prioritization structure

The preceding discussion set the groundwork for the specification of a generalized road safety improvement or pedestrian safety evaluation (PSE) program, whose aim is to identify opportunities for investment in appropriate and cost-effective road safety engineering treatments. Such programs usually include:

1. A prioritization or "network screening" phase: which is intended to identify high collision locations;

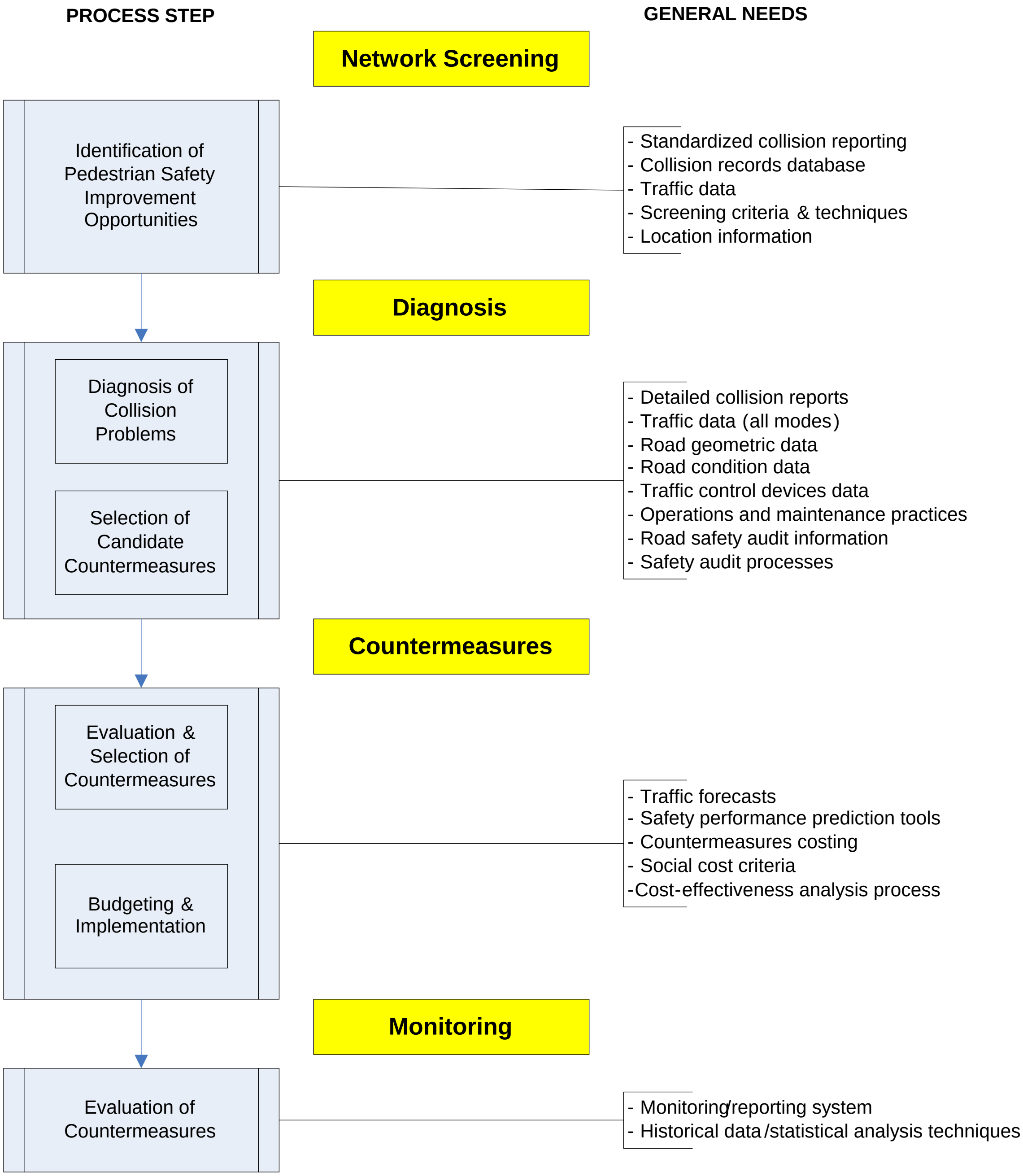
2. A diagnosis or investigation phase: in which possible causal factors are identified, and candidate countermeasures are selected for each high priority project selected for inclusion in the program. These investigations constitute part of the Detailed Engineering Study program (DES);

3. A countermeasures evaluation and programming phase: in which project specific recommendations are made, a prioritized program of work is finalized, and that program is implemented. The implementation phase must also include some provision for the monitoring and evaluation of various countermeasures.

A typical framework of a safety evaluation program is illustrated in Figure 3 on the page following.

Figure 2: A Barnes-Dance crossing in Toronto, ON

Figure 3: General form of a pedestrian safety evaluation program



2.3 Benefits of a Pedestrian Safety Evaluation Program

A PSE program is essentially a decision support system. Each of its four fundamental components (Network Screening, Diagnosis, Countermeasures Evaluation, and Monitoring) contributes to further refining of the information available to a decision maker attempting to reach a decision on where funding for road safety engineering improvements is best allocated. When such systems are formalized and implemented with value added tools in the form of software and processes, the resulting decision support system yields returns upon the investment made in creating it through two means:

- By improving the speed with which a decision can be reached (Efficiency);
- By improving the accuracy of the decision that is reached (Risk management and quality).

There are no strongly supported quantitative indicators of benefit/cost ratios associated with the implementation of safety management systems and their components such as a PSE. Experience in analogous technical decision support areas such as pavement management however does strongly suggest that while efficiency gains are important and very significant, it is through the improvements in the accuracy of road safety investment decisions and priorities that the greatest degree of benefit is returned to the road safety decision support system developer.

2.4 The next steps

In order to meet the objectives of this study within the context of the framework illustrated in Figure 3, we must address two key elements:

- What will the overall process look like? How do we collaborate with the various community groups and then produce a list of sites for planning/programming?; and
- What science and technical processes are required to produce a list of prioritized sites that require pedestrian safety countermeasures?

The first set of questions regarding the overall process is discussed in Section 3. Our response to the second question regarding specific science and technical analyses required to carry out the overall programming approach is discussed in Sections 4, 5, and 6.

3 DEVELOPING A COLLABORATIVE PROCESS

3.1 Background

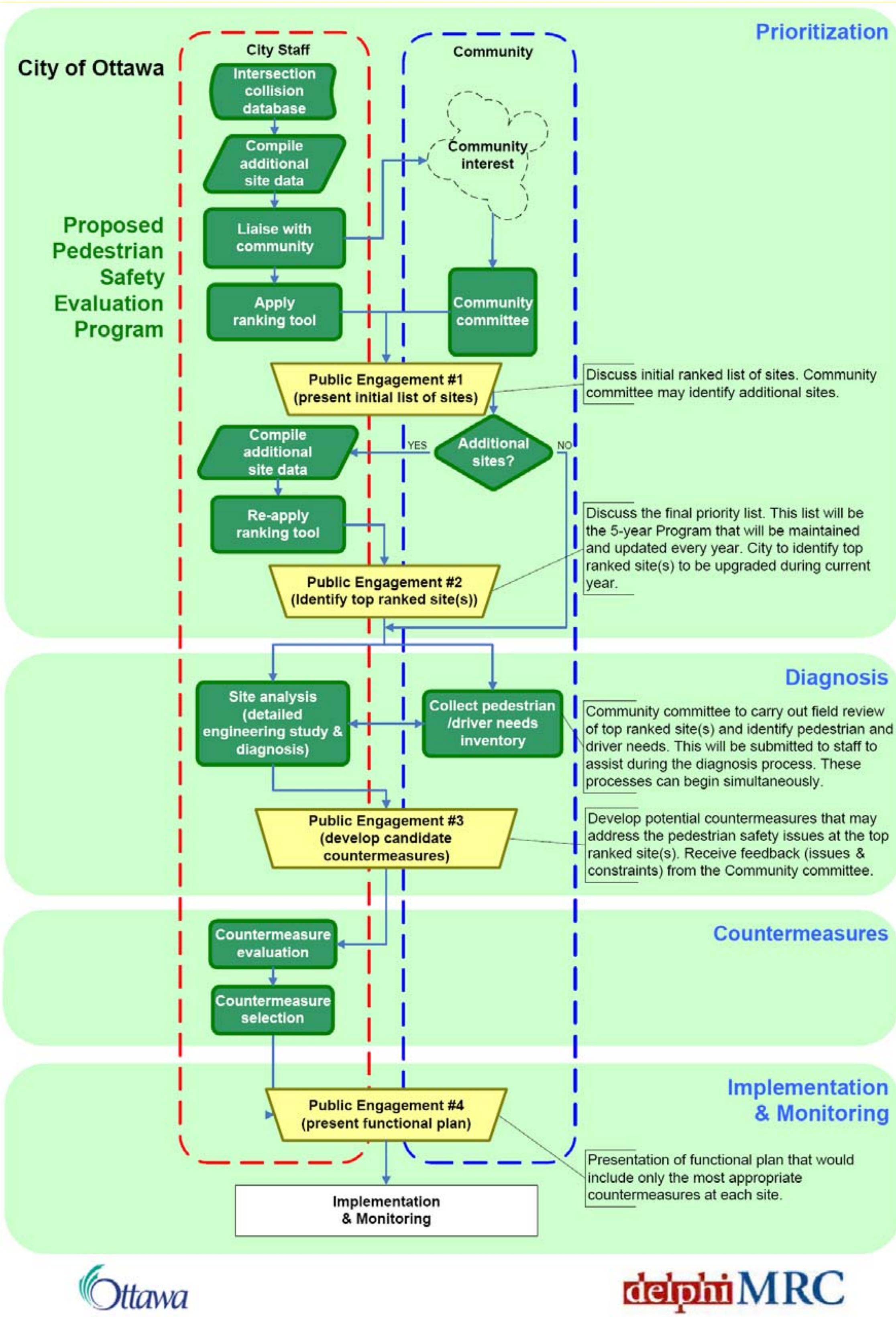
The City of Ottawa requires a process to address the pedestrian safety issues at intersections. This process needs to be consultative as there is a need to involve community groups in the data gathering and decision components of the process. Based on these requirements, and following the framework of a safety evaluation program discussed in Section 2, we developed a proposed programming process suited to the City of Ottawa context.

3.2 The proposed process

An illustration of the proposed process is provided in Figure 5.

Figure 4: A challenging pedestrian crossing environment

Figure 5: A proposed programming process



There are elements of the process that require input and analysis from City staff and there are elements that require data gathering and input from the various community groups. During the course of the entire programming process there are four consultation meetings – between staff and the community groups – to discuss the findings and results. This provides a collaborative opportunity to explain the decisions made (to that particular point in the process) as well as gather input for the next steps.

The timeline to carry out such a program is expected to require about 10 to 12 months from the point at which the initial data is gathered, through to the development of a 5-year program of sites for safety improvements.

Figure 6: Inappropriate vehicular intrusion into the pedestrian environment

4 ROAD USER NEEDS AT INTERSECTIONS

4.1 Background

This chapter was prepared on behalf of Delphi-MRC by Human Factors North Inc. (HFN) HFN is one of Canada's leading consulting firms specializing in human factors in transportation. The material presented in this chapter is reproduced verbatim from the material provided by HFN in order to preserve the integrity of the science and guidance provided therein. The primary authors of this material were Dr. Alison Smiley, CCPE and Mr. Tom Smahel

4.2 The objective of this Chapter

Human Factors North Inc. was asked by Delphi-MRC on behalf of the City of Ottawa to review the literature with the following objectives:

- The development of a concise and clearly expressed summary of the current state of knowledge of key pedestrian and driver human factors needs in respect of using both signalized and unsignalized intersections safely

- The identification of key design and operational features of signalized and unsignalized intersections that most directly affect the pedestrian's ability to use the intersection in a safe manner and the pedestrian's **perception** of the level of safety being offered by the intersection.

To meet these objectives, this document draws on earlier work written by the author (Chapter 2 of the U.S. Highway Safety Manual) and introduces the core elements of human factors that affect the interaction of drivers, pedestrians and intersections. With an understanding of how drivers and pedestrians interact with the roadway, there is more potential for intersections to be designed and constructed in a manner that minimizes human error and associated crashes.

Road users make frequent mistakes because of human physical, perceptual, and cognitive limitations. These errors seldom result in crashes because road users compensate for errors of others or because the circumstances are forgiving (e.g., there is room to manoeuvre and avoid a crash). Near misses, or conflicts, are vastly more frequent than crashes. One study found a conflict-to-crash ratio of about 2,000 to 1 at urban intersections (Older & Spicer, 1976).

Road user error is a significant contributing factor in most crashes (Treat, Tumbas, McDonald, Shinar, Hume, Mayer, Stansfin, & Castellen, 1977). Drivers can make errors of judgment concerning, for example, closing speed, gap acceptance and appropriate speeds to approach intersections. In-vehicle and roadway distractions, driver inattentiveness, and driver weariness can lead to errors. A driver can also be overloaded by the information processing required to carry out multiple tasks simultaneously, which may lead to error. To reduce their information load, drivers rely on a-priori knowledge, based on learned patterns of response; therefore, they are more likely to make mistakes when their expectations are violated. In addition to unintentional errors, drivers sometimes deliberately violate traffic control devices and laws. Similarly pedestrians can be inattentive, can judge gaps and speeds of traffic inaccurately and can deliberately violate traffic control devices and laws.

Road design and traffic control elements have a major impact on road safety at intersections, regardless of whether road user errors are intentional or unintentional. There is potential to reduce the probability of error when roadway designs account for drivers and pedestrians with varied visual, information processing, and motor skills. Similarly, if the roadside environment is forgiving, driver error may not be as likely to lead to serious consequences.

The next Section describes human characteristics and limitations which affect all road users. Driver limitations are emphasized simply because they are moving faster than other road users and consequently their information processing demands are higher. Section 4.4 concerns crash types that can occur at intersections due to road user limitations and potential countermeasures that address the precipitating human errors. Section 4.5 summarizes the report.

4.3 Road User Characteristics and Limitations

This section outlines basic driver capabilities and limitations in performing the driving tasks which can influence safety. Topics include attention and information processing ability, vision capability, perception-response time, and speed choice.

4.3.1 Attention and Information Processing

Human attention and ability to process information is limited. These limitations can create difficulties especially for drivers because driving requires the division of attention between control tasks, guidance tasks, and navigational tasks. Control tasks involve keeping the vehicle at a desired speed and heading within the lane. The guidance task involves interacting with other vehicles (following, passing, merging, etc.) by maintaining a safe following distance and by following markings, traffic control signs, and signals. Navigation: involves following a path from origin to destination by reading guide signs and using landmarks (Lunenfeld & Alexander, 1990).

A successful driving experience requires smooth integration of the three tasks, with driver attention being switched from one to another task as appropriate for the circumstances. This can be achieved by ensuring that high workloads in the sub-tasks of control, guidance, and navigation do not happen at the same time.

While attention can be switched rapidly from one information source to another, road users only attend well to one source at a time. Furthermore, road users can only extract a small proportion of the available information from the road scene. It has been estimated that more than one billion units of information, each equivalent to the answer to a single yes or no question, are directed at the sensory system in one second. On average, humans are expected to consciously recognize only 16 units of information in one second (McCormick, 1970). For this reason, drivers function best when roads and traffic control devices are designed as expected, and patterns are familiar, with the result that there is not a surfeit of information to process. Drivers are more likely to err when they are overloaded with information, for example when searching for street name signs while approaching a complex and unfamiliar intersection. Drivers are also more likely to err when they must make complex decisions quickly, for example, to stop or go on a yellow signal close to the stop bar.

Roadway design considerations for reducing driver workload are:

- Presenting information in a consistent manner to maintain appropriate workload

- Presenting information sequentially, rather than all at once
- Ensuring drivers are not overloaded in more than one of the control (e.g. navigating a sharp curve), guidance (e.g. sharing a bicycle path at a turn point) or navigation tasks (e.g. reading street name signs with small letter heights) at a given time.

In addition to information processing limitations, drivers' attention is not fully under their conscious control. For drivers with some degree of experience, driving is a highly automated task. That is, driving can be, and often is, performed while the driver is engaged in thinking about other matters. Most drivers, especially on a familiar route, have experienced the phenomenon of becoming aware that they have not been paying attention during the last few miles of driving. The less demanding the driving task, the more likely it is that the driver's attention will wander, either through internal preoccupation or through engaging in non-driving tasks. Factors such as increased traffic congestion and increased societal pressure to be productive could also contribute to distracted drivers and inattention. Inattention may result in failing to respond to a vehicle suddenly slowing ahead or to a traffic signal, or a vehicle or pedestrian on a conflicting path at an intersection.

One way to address human information processing limitations is to design roadway environments in accordance with road user expectations. When road users can rely on past experience to assist with their tasks they only need to process information that is new or was not previously known. Drivers develop both long- and short-term expectancies. Examples of long-term expectancies that an unfamiliar driver will bring to a new section of roadway include:

- When a minor and a major road cross, the stop control will be on the road that appears to be the minor road
- When approaching an intersection, drivers must be in the left lane to make a left turn at the cross street

Examples of short-term expectancies include:

- After driving along a corridor with four way stops, drivers may not anticipate a two way stop, especially if the major road is not noticeably different from the previous crossroads.

4.3.2 Vision

Approximately 90% of the information that road users use is visual (Hills, 1980). While visual acuity is the most familiar aspect of vision related to driving, numerous other aspects are equally important. The following aspects of driver vision are described in this section:

- Visual acuity – the ability to see details at a distance
- Contrast sensitivity – the ability to detect slight differences in luminance (level of light) between an object and its background
- Peripheral vision – the ability to detect objects that are not in the primary focus of the eye

- Movement in depth – the ability to estimate the speed of another vehicle by changes in the visual angle of that vehicle subtended at the eye

- Visual search – the ability to search the rapidly changing road scene to collect road information

4.3.2.1 Visual Acuity

Visual acuity determines how well drivers can see details at a distance. It is important for guidance and navigation tasks, which require reading signs and identifying potential hazards ahead.

Under ideal conditions, in daylight, with high contrast text (black on white), with unlimited time, a person with a visual acuity of 20/20, considered "normal vision," can just read letters that subtend an angle of 5 minutes of arc. A person with 20/40 vision needs letters that subtend twice this angle, or 10 minutes of arc. With respect to traffic signs, a person with 20/20 vision can just barely read letters that are 5 cm tall at 34 m, and letters that are 10 cm tall at 68 m and so on. A person with 20/40 vision would need letters of twice this height to read them at the same distances. To encompass a broad range of driving conditions, and more than 95% of young drivers and 75-85% of older drivers, it should be assumed that driver acuity is 4.8 m/cm of letter height for fonts used on guide signs (Mace, Garvey, & Heckard, 1994).

4.3.2.2 Contrast Sensitivity

With respect to safety, contrast sensitivity is often thought of as more important than visual acuity. Contrast sensitivity is the ability to detect small differences in luminance (brightness of light) between an object and the background. The lower the level of ambient light, the more contrast is required to see a target such as a curb, debris on the road, or a pedestrian against its background.

Good visual acuity does not necessarily imply good contrast sensitivity. For people with standard visual acuity of 20/20, the distance at which non-reflective objects are detected at night can vary by a factor of 5 to 1 (Olson & Sivak, 1983).

Drivers with normal visual acuity but poor contrast sensitivity may have to get very close to a low-contrast target before detecting it. Experimental studies show that even alerted subjects can come as close as 8 m before detecting a pedestrian in dark clothing standing on the left side of the road (Olson and Sivak 1983). In general, pedestrians tend to overestimate their own visibility to drivers at night. On average, drivers see pedestrians at half the distance at which pedestrians think they can be seen (Allen, Hazlett, Tacker, & Graham, 1970). This may result in pedestrians stepping out and assuming that drivers have seen them, surprising drivers and leading to a crash or near-miss event.

4.3.2.3 Peripheral Vision

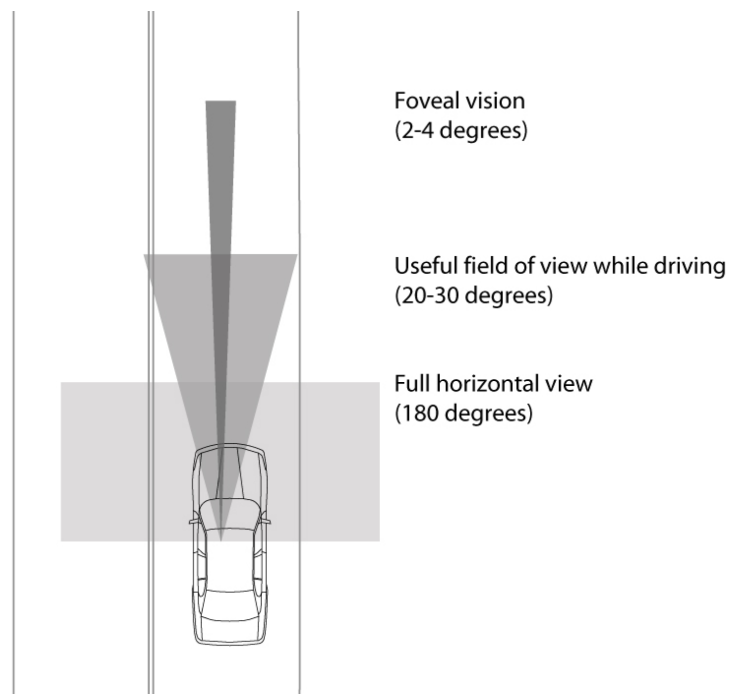
The visual field of human eyes is large: approximately 55 degrees above the horizontal, 70 degrees below the horizontal, 90 degrees to the left and 90 degrees to the right. However, only a small area of the visual field allows accurate vision. This area of accurate vision includes a cone of about two to four degrees from the focal point. The lower-resolution visual field outside the area of accurate vision is referred to as peripheral vision. Although acuity is reduced, targets of interest can be detected in the low-resolution peripheral vision. Once detected, the eyes shift so that the target is seen using the area of the eye with the most accurate vision.

Targets that road users need to detect in their peripheral vision include vehicles on an intersecting path, pedestrians, signs, and signals. In general, targets best detected by peripheral vision are objects that are closest to the focal point; that differ greatly from their backgrounds in terms of brightness, colour, and texture; that are large; and that are moving. Studies show that for drivers the majority of targets are noticed when located less than 10 to 15 degrees from the focal point and that even when targets are conspicuous, glances at angles over 30 degrees are rare (Cole & Hughes, 1984; Smiley, Smahel, & Eizenman, 2004).

Target detection in peripheral vision is also dependent on demands placed on the driver. The more demanding the task, the narrower the "visual cone of awareness" or the "useful field of view," and the less likely the driver is to detect peripheral targets.

Figure 7 summarizes the driver's view and awareness of information as the field of view increases from the focal point. Targets are seen in high resolution within the central 2 to 4 degrees of the field of view. While carrying out the driving task, the driver is aware of information seen peripherally, within the central 20 to 30 degrees. The driver can physically see information over a 180-degree area, but is not aware of it while driving, unless motivated to direct his or her attention there.

Figure 7: Visibility of Target Object as Viewed with Peripheral Vision

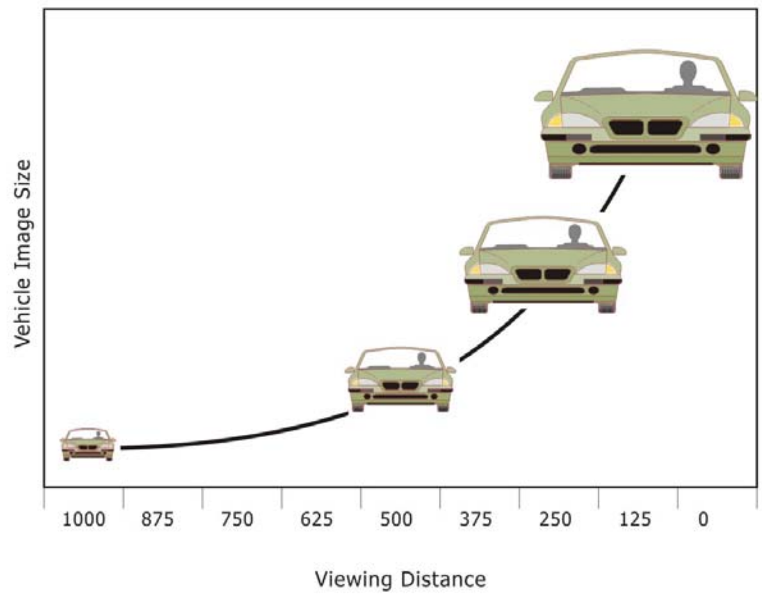


4.3.2.4 Movement in Depth

Numerous driving situations require drivers to estimate movement of vehicles based on the rate of change of visual angle created at the eye by the vehicle. These situations include safe following of a vehicle in traffic, selecting a safe gap on a two-way stop-controlled approach, and passing another vehicle with oncoming traffic and no passing lane.

The primary cue that drivers use to determine their closing speed to another vehicle is the rate of change of the image size. Figure 8 illustrates the relative change of the size of an image at different distances from a viewer. As shown in Figure 8, the relationship between viewing distance and image size is not a linear relationship. The fact that it is a non-linear relationship is likely one source of the difficulty drivers have in making accurate estimates of closing speed.

Figure 8: Relationship between viewing distance and image size



Drivers use the observed change in the size of a distant vehicle, measured by the rate of change of the visual angle occupied by the vehicle, to estimate the vehicle's travel speed. Another source of difficulty in detecting changes in vehicle speed over a long distance is due to the relatively small amount of change in the size of the vehicle that occurs per second. This is particularly important when drivers make left turns on a green ball traffic signal at an intersection with a posted speed above 60 km/h. In order to complete the turn in time, drivers must initiate the turning movement before the oncoming vehicle is close enough to judge whether it is moving faster or slower than the traffic stream.

Limitations in driver perception of closing speed may also lead to increased potential for rear-end crashes when drivers travelling at high speeds approach stopped or slowing vehicles and misjudge the stopping distance available. This safety concern is compounded when drivers are not expecting this situation. One example is on a two-lane roadway where a left-turning driver must stop in the through lane to wait for an acceptable gap in opposing traffic. An approaching driver may not realize that the vehicle is stopped until it is too late. In this circumstance the use of turn signals or visibility of brake lights may prove to be a crucial cue for determining that the vehicle is stopped and waiting to turn.

4.3.2.5 Visual Search

By understanding drivers' visual search patterns and where they tend to fix their eyes in varying circumstances, information can be placed in the most effective location and format. The driving task requires active search of the rapidly changing road scene, which results in little time to collect and absorb road information. The length of an eye fixation on a particular subject varies from 1/10 of a second for a simple task such as checking lane position, and up to 2 seconds for reading a complex guide sign. By understanding where drivers fixate and their visual search patterns while performing a particular driving task, information can be placed in the most effective location and format (Rockwell, 1988).

Studies using specialized cameras that record driver-eye movements have revealed how drivers distribute their attention amongst the various driving sub-tasks, and the very brief periods of time (fixations) drivers can allocate to any one target while moving. On an open road drivers were shown to fixate approximately 90% of the time within a 4-degree region vertically and horizontally from a point directly ahead of the driver (Mourant, Rockwell, & Rackoff, 1969). Of this 90%, slightly more eye fixations occurred to the right side of the road where traffic signs are found. This indicates that driver visual search is fairly concentrated.

The visual search pattern changes when a driver is negotiating a horizontal curve as opposed to driving on a tangent. On tangent sections, drivers can gather both path and lateral position information by looking ahead. During curve negotiation, visual demand is essentially doubled, as the location of information is displaced (to the left or to the right) from information about lane position. Eye movement studies show that drivers change their search behaviour several seconds prior to the start of the curve. These findings may suggest that advisory curve signs be placed just prior to the beginning of the approach zone in order to consider visual search limitations (Shinar, McDowell, & Rockwell, 1977).

Other road users, such as pedestrians and cyclists, also have a visual search task. Visual search is of particular importance at intersection conflict points. Pedestrians can be observed to conduct a visual search if the head is turned toward the direction from which the vehicle is coming prior to entering the vehicle path and within three seconds of entering the vehicle path. A study of pedestrians at signalized downtown intersections (discussed in more detail later) showed that between 8% and 25% did not look for threats (Van Houten, Malenfant, Van Houten, & Retting, 1997).

4.3.3 Perception-Reaction Time

Perception-reaction time includes time to detect a target, process the information, decide on a response, and initiate a response. Although values such as 1.5 or 2.5 seconds are commonly used, it is important to note that perception-reaction time is not fixed; it depends on human elements discussed in previous sections, including information processing, driver alertness, driver expectations, and vision.

The following sections describe the components of perception-reaction time: detection, decision, and response.

4.3.3.1 Detection

The initiation of perception-reaction time begins with detection of an object, hazard, or obstacle. At this stage, the driver does not know whether the object seen is truly something to be concerned with, and if so, what it is.

Detection can be a fraction of a second for an expected object or a highly conspicuous object placed where the driver is looking. At the other extreme, at night, an object which is located several degrees from the line of sight, and which is of low contrast compared to the background, may not be seen for many seconds. The object cannot be seen until the contrast of the object exceeds the threshold contrast sensitivity of the driver viewing it.

Failures in detection are most likely for objects that are:

- More than a few degrees from the driver's line of sight
- Minimally contrasted with the background
- Small in size
- Seen in the presence of glare
- Not moving
- Unexpected and not being actively searched for by the driver

Once an object or obstacle has been detected, the details of the object or obstacle must be determined in order to have enough information to make a decision. As discussed in the next section, identification will be delayed when the object being detected is unfamiliar and unexpected. For example, a parked trailer with inadequate reflectors blocking a lane at night will be unexpected and hard to identify.

4.3.3.2 Decision

Once an object or obstacle has been detected and enough information has been collected to identify it, a decision can be made as to what action to take. The decision does not involve any action, but rather is a mental process that takes what is known about the situation and determines how the driver will respond.

Decision time is highly dependent on circumstances that either make a decision difficult or require it be made immediately. Many decisions are made quickly when the response is obvious. For example, when the driver is a substantial distance from the intersection and the traffic light turns red, minimal time is needed to make the decision. If, on the other hand, the driver is close to the intersection and the traffic light turns yellow, there is a dilemma: is it possible to stop comfortably without risking being rear-ended by a following vehicle, or is it better to proceed through the intersection? The time to make this stop-or-go decision will be longer given that there are two reasonable options and more information to process.

Decision-making also takes more time when the information the driver is looking for is difficult to find (e.g., street name signs seen against visual clutter of commercial signs) or complex (e.g., turning restrictions for different vehicle types). Decision-making also takes more time when drivers have to determine the nature of unclear information, such as bits of reflection on a road at night. The bits of reflection may result from various sources, such as harmless debris or a stopped vehicle.

4.3.3.3 Response

When the information has been collected, processed, and a decision has been made, time is needed to respond physically. Response can range from simple to complex. A simple response would be to stop in the presence of a red light, while a complex response could be making a left turn across several lanes of high speed, heavy traffic. The more complex the response, the more time will be required for the driver to initiate it.

4.3.3.4 Perception-Reaction Times in Various Conditions

Given the various factors affecting driver perception-reaction time, it is clearly not a fixed value, but is dependent on the particulars of each situation. Guidance on values appropriate for a straight-forward detection situation, in which a hazard is clearly visible in the middle of the roadway, comes from a study of perception-reaction times in a “stopping sight distance” situation, in which drivers without warning encountered a obstacle partially blocking the lane. The majority of drivers (85%) reacted within 1.3 seconds, and 95% of drivers reacted within 1.6 seconds (Olson, Cleveland, Fancher, & Schneider, 1984). The experimental situation in this study was relatively straightforward. It was daylight and the driver was cresting a hill and therefore looking at the road at the very moment an object blocking the road came into view. In a more recent study which also examined drivers’ response to unexpected objects entering the roadway, it was concluded that a perception-reaction time of approximately 2.0 seconds seems to be inclusive of nearly all the subjects’ responses under all conditions tested (Fambro, Fitzpatrick, & Koppa, 1997).

The 2.0 second perception-reaction time is inappropriate for application to a low contrast object seen at night. Although an object can be within the driver’s line of sight for hundreds of meters, there may be insufficient light from low beam headlights, and insufficient contrast between the object and the background for a driver to see it. Perception-reaction time cannot be considered to start until the object has reached the level of visibility necessary for detection, which varies from driver to driver and is influenced by the driver’s state of expectation. A driving simulator study found that drivers who were anticipating having to respond to pedestrian targets on the road edge took an average of 1.4 seconds to respond to a high contrast pedestrian, and 2.8 seconds to respond to a low contrast pedestrian, indicating a substantial impact of contrast on perception-reaction time (Ranney, Masalonis, & Simmons, 1996). Glare lengthened these perception-reaction times even further. It should be noted that subjects in experiments are abnormally alert, and real-world reaction times could be expected to be longer.

As is clear from this discussion, perception-reaction time is not a fixed value. It is dependent on the visibility of the hazard, the complexity of the response required, and the urgency of that response. The value of 2.5 seconds used by highway designers covers most situations in which clearly visible hazards are presented to drivers.

4.3.4 Speed Choice

A central aspect of traffic safety is driver speed choice. Higher speeds increase the risk of injury and fatality when crashes occur. While speed limits influence driver speed choice, these are not the only or the most important influences. Drivers select speed using perceptual and "road message" cues.

4.3.4.1 Perceptual Cues

A driver's main cue for speed choice comes from peripheral vision. In experiments where drivers are asked to estimate their travel speed with their peripheral vision blocked (only the central field of view can be used to determine speed), the ability to estimate speed is poor. This is because the view changes very slowly in the center of a road scene. If, on the other hand, the central portion of the road scene is blocked out, and drivers are asked to estimate speed based on the peripheral view, drivers do much better (Salvatore, 1968).

Streaming (or "optical flow") of information in peripheral vision is one of the greatest influences on drivers' estimates of speed. Consequently, if peripheral stimuli are close by, then drivers will feel they are going faster than if they encounter a wide-open situation. In one study, drivers were asked to drive at 60 mph (96 km/h) with the speedometer covered. In an open-road situation, the average speed was 57 mph (91 km/h). After the same instructions, but along a tree-lined route, the average speed was 53 mph (85 km/h) (Shinar et al. 1977). The trees near the road provided peripheral stimulation, giving a sense of higher speed.

Noise level is also an important cue for speed choice. Several studies in which drivers wore earmuffs examined how removing noise cues impacts speed. Noise also was reduced in other ways. The result is that when drivers are asked to travel at a particular speed, they underestimate how fast they are going and drive 6 to 9 km/h faster than when the usual sound cues are present (Evans, 1970b; Evans, 1970a). With respect to lowering speeds, it has been counter-productive to progressively quiet the ride in cars and to provide smoother pavements. These factors decrease drivers' sensitivity to their own speed.

Another aspect of speed choice is speed adaptation. This is the experience of leaving a freeway after a long period of driving and having difficulty conforming to the speed limit on an arterial road. One study required subjects to drive for 32 km on a freeway and then drop their speeds to 65 km/h on an arterial road. The average speed obtained on the arterial road was 80 km/h (Schmidt & Tiffin, 1969). This speed was higher than the requested speed despite the fact that these drivers were perfectly aware of the adaptation effect, told the researchers they knew this effect was happening, and tried to bring their speed down. The adaptation effect was shown to last up to five or six minutes after leaving a freeway, and to occur even after very short periods of high speed (Schmidt and Tiffin 1969). Various access management techniques, sign placement, and traffic calming devices may help to reduce speed adaptation effects.

4.3.4.2 Road Message Cues

Drivers may interpret the roadway environment as a whole to encourage fast or slow speeds depending on the effects of the geometry, terrain, or other roadway elements. Drivers tend to drive faster on a straight, wide road with several lanes, wide shoulders, and a wide clear zone, than drivers on a narrow, winding road with no shoulders or a cliff on the side. Speeds on rural highway tangents are related to cross-section and other variables, such as the radius of the curve before and after the tangent, available sight distance, and general terrain (Polus, Fitzpatrick, & Fambro, 2000).

Evidence of the power of the road message and the effect of task difficulty on speed also comes from a Canadian report on non-enforcement methods of speed control. The research study involved 30 sites, all of which had a 50 km/h speed limit. Ten of the sites had considerable "side friction," or activity on the side of the road, such as parking and heavy pedestrian and bicycle activity. At these sites, the 85th percentile speed was 50 km/h, which is the posted speed limit. The other 20 sites were uncluttered, open-road situations. At these sites, the 85th percentile speed was 62 km/h. Given the fact that the speed limits were identical, the 12 km/h difference is substantial (Persaud, Parker, Knowles, Wilde, & IBI Group, 1997).

Speed advisory plaques on curve warning signs appear to have little effect on curve approach speed, probably because drivers feel they have enough information from the roadway itself and select speed according to the appearance of the curve and its geometry. One study recorded the speeds of 40 drivers, unfamiliar with the route, on curves with and without speed plaques. Although driver eye movements were recorded and drivers were found to look at the warning sign, the presence of a speed plaque had no effect on drivers' selected speed (Zwahlen, 1987).

In contrast, one study of 36 arterial tangent sections found some influence of speed limit, but no influence of road design variables. The sections studied had speed limits that ranged from 25 to 55 mph (40 to 90 km/h). Speed limit accounted for 53% of the variance in speed, but factors such as alignment, cross-section, median presence, and roadside variables were not found to be statistically significantly related to operating speed (Fitzpatrick, Carlson, Wooldridge, & Brewer, 2000).

4.3.5 Pedestrian Walking Speed

Sample average walking speeds for males and females are: 1.4 m/sec (age 5), 1.8 m/sec (age 12), 1.6 m/sec (40's) to 1.3 m/sec (60+). (Eubanks & Hill, 1998) cited in (Dewar & Olson, 2007) (p. 433). A study in Sweden found that for pedestrians aged 70 and older, a "fast" speed was less than the 1.3 m/sec typically used to set pedestrian walk signals ((Dewar and Olson 2007) (p. 432). A "comfortable speed" for the 15th percentile in this age group was 0.67 m/sec.

4.3.6 Positive Guidance

Knowledge of human limitations in information processing and human reliance on previous experience (i.e., driver expectation) to compensate for those limitations in information processing, led to the "positive guidance" approach to highway design. This approach is based on a combination of human factors and traffic engineering (Lunenfeld and Alexander 1990). Its central principle is that road design that corresponds with driver limitations and expectations increases the likelihood of drivers responding to situations and information correctly and quickly. Conversely, when drivers are not provided with information in a timely fashion, when they are overloaded with information, or when their expectations are violated, slowed responses and errors may occur.

With respect to road design, the positive guidance approach emphasizes:

- Predictability: Design roadway configurations, geometrics, and traffic operations in accordance with driver expectations. Design that conforms to expectations reduces the chance of driver error (e.g., there will not be a STOP controlled intersections in the midst of a string of signalized intersections).

With respect to traffic control devices, the positive guidance approach emphasizes assisting the driver with processing information accurately and quickly by considering:

- Primacy: Determine the placements of signs according to the importance of information, and avoid presenting the driver with information when and where the information is not essential

- Spreading: Where all the information required by the driver cannot be placed on one sign or on a number of signs at one location, spread the signage along the road so that information is given in small chunks to reduce information load

- Coding: Where possible, organize pieces of information into larger units. Colour and shape coding of traffic signs accomplishes this organization by representing specific information about the message based on the colour of the sign background and the shape of the sign panel (e.g., warning signs are yellow, regulatory signs are white).

- Redundancy: Say the same thing in more than one way. For example, the stop sign in North America has a unique shape and message, both of which convey the message to stop. A second example of redundancy is to give the same information by using two devices (e.g., “no passing” indicated with both signs and pavement markings).

In addition, information must be legible at a distance that allows the driver to read the sign, make a decision and carry out any required manoeuvres (e.g., lane change to turn right or left at an intersection) before reaching the decision point.

4.4 INTERSECTION CRASH TYPES: ERRORS AND COUNTERMEASURES

This section considers human errors associated with common intersection crash types: rear-end and side-swipe, turning, angle and vulnerable road user crashes. Countermeasures related to the precipitating human errors are suggested.

4.4.1 Road User Tasks in Intersections

As discussed above, the driving task involves control, guidance, and navigation elements. At intersections, each of these elements presents challenges:

- Control: The path through the intersection is typically unmarked and may involve turning

- Guidance: There are numerous potential conflicts with other vehicles, pedestrians, and cyclists on conflicting paths

- Navigation: Changes in direction are usually made at intersections, and road name signing can be difficult to locate and read in time to accomplish any required lane changes

In the process of negotiating any intersection, all road users are required to:

- Detect the intersection

- Identify signalization and appropriate paths

- Search for vehicles, pedestrians, and bicyclists on a conflicting path
- Assess adequacy of gaps for crossing/turning movements
- Successfully complete through or crossing/turning manoeuvres

In addition to these tasks, at signalized intersections, the driver must rapidly make a stop/go decision in the dilemma zone.

Thus, intersections place high demands on road users in terms of visual search, gap estimation, and decision-making requirements that increase the potential for error. Road crash statistics show that although intersections constitute a small portion of the highway network, about 50% of all urban crashes and 25% of rural crashes are related to intersections (Kuciemba & Cirillo, 1992). A study of the human factors contributing causes to crashes found that the most frequent type of error was "improper lookout," and that 74% of these errors occurred at intersections. In about half of the cases, drivers failed to look, and in about half of the cases, drivers "looked but did not see." (Treat et al. 1977; National Highway Traffic Safety Administration, 2003).

4.4.2 Rear-End and Side-swipe Crashes

4.4.2.1 Precipitating Errors

Errors leading to rear-end and side-swipe crashes include the following:

- Incorrect assumptions about the intentions of the driver ahead
- Inattention

A following driver generally assumes that the lead driver, once moving forward, will continue through the stop sign. However, the lead driver may suddenly stop due to late recognition that there is a vehicle or pedestrian on a conflicting path. Similarly the following driver may assume that the lead driver will go through a green or yellow light, but the lead driver stops due to greater caution. Drivers following one another can make differing decisions in this "dilemma zone". The higher the speed, the longer the dilemma zone, the higher the deceleration required to stop, and the greater the chance of a rear-end collision. The lead driver may also slow or stop due to a vehicle ahead slowing to enter an access point just prior to the intersection, or a vehicle exiting an access point suddenly intruding into the lane, or a pedestrian crossing against a red light.

Following drivers may be inattentive or distracted (because of preoccupation with internal thoughts, attention directed to non-driving tasks within the vehicle, distractions on the roadside, nearby downstream traffic light). As a result the following driver may belatedly search for street name signs or landmarks, resulting in a late lane change to access a turning lane. A following driver may fail to detect slowing or stopping vehicle ahead.

4.4.2.2 Countermeasures

Countermeasures to rear-end and side-swipe crashes include:

- Optimized caution interval so that drivers are neither given too little nor too much time to make the stop or go decision when they are close to the stop bar

- Eliminating driveways within the “influence area” of the intersection so that drivers are not surprised by the vehicle ahead suddenly slowing just before or just after a signalized intersection

- Clear lane designation in advance of the intersection so that drivers do not make last second lane changes

- Street name signs that are legible at a sufficient distance that drivers have time to make a lane change if necessary before reaching the intersection

4.4.3 Turning Crashes

4.4.3.1 Precipitating Errors

Turning movements are more demanding with respect to visual search, gap judgment, and path control than are through movements. Turning movements can lead to crashes at intersections or access points due to the following:

- Perceptual limitations

- Visual blockage

- Dilemma zone

- Inadequate visual search

Perceptual limitations in estimating closing vehicle speeds could lead to left-turning drivers selecting an inappropriate gap in oncoming traffic. Drivers turning left during a permissive green light may not realize that an oncoming vehicle is moving at high speed.

A visual blockage may limit visibility of an oncoming vehicle when making a turn at an intersection. About 40% of intersection crashes involve a view blockage (Treat et al. 1977). Windshield pillars inside the vehicle, utility poles, commercial signs, and parked vehicles may block a driver’s view of a pedestrian, bicyclist, or motorcycle on a conflicting path at a critical point during the brief glance that a driver may make in that direction. Visual blockages also occur where the offset of left-turn bays results in vehicles in the opposing left-turn lane blocking a left-turning driver’s view of an oncoming through vehicle.

In high-volume traffic, drivers turning left on a permissive green light may be forced to wait for a yellow light to make their turn, at which time they come into conflict with oncoming drivers who continue through into a red light. The higher the speed of the oncoming driver, the longer the dilemma zone, the higher the deceleration required to stop, and the greater the chance the oncoming driver will continue through the intersection and conflict with left-turning drivers.

Drivers turning right may concentrate their visual search only on vehicles coming from the left and fail to detect a bicyclist or pedestrian crossing from the right (Summala, Päsänen, Räsänen, & Sievänen, 1996). This is especially likely if drivers do not stop before turning right on red, and as a result give themselves less time to search both to the left and right.

4.4.3.2 Countermeasures

Countermeasures to turning crashes are:

- Protected left turns at high speed and/or wide cross-section intersections which eliminate the need for drivers to judge whether there is an adequate gap where the speed of the oncoming vehicle is difficult to judge or where the speeds and distances to several oncoming vehicles must be considered
- Neutral or positive offsets for left-turn bays to improve visibility of through traffic
- Adequate sight distance (on the order of 10 seconds at operating speeds) to crossing traffic
- Roundabouts which eliminate gap judgments involving high speed oncoming vehicles

4.4.4 Angle Crashes

4.4.4.1 Precipitating Errors

Angle crashes can occur due to:

- Delayed detection of an intersection (sign or signal) at which a stop is required
- Delayed detection of crossing traffic by a driver who deliberately violates the sign or signal
- Inadequate search for crossing traffic or appropriate gaps

Drivers may miss seeing a signal or stop sign because of inattention, or a combination of inattention and a lack of road message elements that would lead drivers to expect the need to stop. For example, visibility of the intersection pavement or the crossing traffic may be poor, or drivers may have had the right of way for some distance and the upcoming intersection does not look like a major road requiring a stop. In an urban area where signals are closely spaced, drivers may inadvertently attend to the signal beyond the signal they face. Drivers approaching at high speeds may become caught in the dilemma zone and continue through a red light.

4.4.4.2 Countermeasures

Countermeasures to angle crashes include:

- Adequate sight distance (on the order of 10 seconds at operating speeds) to the paved area of the intersection
- Stop signs that are large, equipped with flashing lights, placed near the driver’s line of sight
- Coordinated traffic signals to create a “green wave” and reduce the need for drivers to stop
- Roundabouts which, through geometry, force drivers to slow on entry and at the same time eliminate vehicle movements at right angles, the crash configuration in which vehicle occupants have least protection

4.4.5 Crashes with Vulnerable Road Users

4.4.5.1 Precipitating Errors

One of the most frequently identified causes of pedestrian crashes is improper crossing of the roadway or intersection (NHTSA, 2003, p. 132). Pedestrians who dart out in mid-block, who cross against traffic signals, or who attempt to cross freeways, are engaged in behaviours that do not comply with traffic laws. As noted by Dewar, "pedestrians often consider themselves outside the law, and enforcement typically is low. They get to destinations by the shortest distance, so they jay-walk and avoid both overpasses and underpasses" (Dewar & Olson, 2002).

Pedestrians may cross improperly due to inadequate search. In a Florida study at signalized downtown intersections, researchers observed pedestrian search behaviour, with and without various auditory signals (Van Houten et al. 1997). To be scored as checking for a particular threat, the pedestrian had to orient his or her head toward the direction the vehicle would be coming from prior to entering the vehicle path and within 3 seconds of entering the vehicle path.

Results showed that in the baseline condition, without auditory signals, which is typical of most signalized intersections, depending on the observation period, between 8 and 25% of pedestrians did not look for threats. Search varied with respect to the three types of threats: vehicles coming from behind require the greatest head movement and were searched for least – approximately 30% of pedestrians looked for such vehicles. Search for vehicles coming from the side and from ahead, was more frequent – approximately 50% and 60% of pedestrians respectively.

In right-turning crashes, pedestrians and drivers have been found to be equally guilty of failure to search. In left-turning crashes, drivers are more frequently found at fault, likely because the left-turn task is more visually demanding than the right-turn task for the driver (Habib, 1980).

Pedestrians may cross improperly due to insufficient gaps in traffic. Hamed analyzed pedestrian behaviour at pedestrian crossings, examining a broad range of road user and roadway factors (Hamed, 2001). Hamed found that the time that a pedestrian must wait to cross the first half of a divided street is positively correlated with the risk that they will cross the second half when it is potentially unsafe (i.e, when there is a smaller than normally acceptable gap in traffic, or illegally).

A field study found that the crossing gap varied with crossing distance and walking speed (Fitzpatrick, Turner, Brewer, & Carlson, 2006). For a walking speed of 1.1 m/sec, the 85th percentile gap accepted varied from 8.5 seconds for a crossing distance of 9 m to 14.5 seconds for a crossing distance of 15 m. For a four lane road, the 85th percentile gap accepted would be equivalent to 10 seconds. These gaps are shorter than those required based on assumptions about perception reaction time, walking speed and safety margin, and likely reflect pedestrian expectations that, given enough notice, vehicle operators will slow if necessary to allow them to complete their crossing.

Pedestrians who make improper crossings can easily surprise drivers and put drivers in the position of being unable to respond in time. When a clearly visible pedestrian standing at the edge of the roadway, suddenly steps into the lane, drivers will need about 1.0 to 1.6 seconds to perceive that the pedestrian has moved into the lane and initiate a braking response. At night, when visibility is poor, drivers may take considerably longer to detect the pedestrian.

A pedestrian who is "dashing" across the roadway moves at 3 to 4 m/s, and so can move across one and a half lanes in the time it takes a driver to get his or her foot on the brake. At 50 km/h drivers will travel 13 to 21 m during a perception-reaction time of 1.0 to 1.6 sec. If the driver makes an emergency stop on dry pavement, a deceleration in the range of 0.6 to 0.75 g can be expected. The total distance required for perception, reaction and braking is a minimum of 25 m. A pedestrian who steps out when a vehicle travelling at 50 km/h is closer than this distance is highly likely to be hit and, in triggering an emergency stop, potentially also cause a rear-end crash. Stopping distances are substantial, especially from high speeds, and pedestrians may over-estimate a driver's ability to stop.

Even when pedestrians have the right of way at a marked crosswalk, they can put drivers in an impossible situation. Drivers are legally required to stop when a pedestrian signal at a crosswalk is activated or the pedestrian makes clear his or her intention to cross. While some drivers do not stop even if they can, others may simply not be able to. The demands on a driver at a marked crosswalk are much more difficult than at a traffic signal. A traffic light provides a yellow warning signal of several seconds to warn drivers before the light turns red. This allows drivers who are too close to the intersection at the light change to continue through the intersection, while drivers further away have sufficient time to decelerate comfortably, and without risking a rear-end crash. There is no warning interval at a crosswalk. A pedestrian who steps out when the vehicle is too close can precipitate a crash.

Pedestrians are at risk because of the time required for drivers to respond and because of the energy involved in collisions, even at low speeds. Relatively small changes in speed can have a large impact on the severity of a pedestrian crash. A pedestrian hit at 80 km/h has an 80% chance of being killed; at 60 km/h the risk is reduced to 45%; at 30 km/h the risk is reduced to 5% (Pasanen, 1992).

Poor conspicuity, especially at night, greatly increases the risk of a pedestrian or bicyclist crash. Clothing is often dark, providing little contrast to the background. Although streetlighting helps drivers see pedestrians, streetlighting can create uneven patches of light and dark, and pedestrians can be difficult to see at any distance from the streetlight.

4.4.5.2 Countermeasures

A Federal Highway Administration study provides an approach to the safety assessment of intersections from the pedestrians' and bicyclists' perspective (Vanasse Hangen Brustlin, 2007). The primary objective of the study was to develop safety indices to allow engineers, planners, and other practitioners to proactively prioritize intersection crosswalks and intersection approaches with respect to pedestrian and cycling safety. The prioritization models developed are based on expert safety ratings and behavioural data.

The study's initial list of factors that may impact the safety of an intersection was as follows:

- Traffic control (presence and type)

- Traffic speed
- Number of intersection legs
- One-way or two-way
- Number of lanes
- Crossing width
- Crosswalk (presence and type)
- Median islands (presence and width)
- Pedestrian signals (presence and type)
- Pedestrian-related signs
- Right turn curb radii
- On street parking
- Right turn on red allowance
- Street lighting
- Surrounding development type

A sample of 68 sites was videotaped and analyzed by engineers, planners, pedestrian coordinators, advocates for the blind, pedestrian advocates, pedestrian professionals, and researchers. The number of conflicts and avoidance manoeuvres (objective measures) were noted, and an individual safety rating (subjective measures) was created and attached to each location. Every approach/crossing was analysed separately.

The suggested model has the following form:

Ped Intersection Safety Index = 2.372 - 1.867 **SIGNAL** - 1.807 **STOP** + 0.335 **THRULNS** + 0.018 **SPEED** + 0.006 (**MAINADT*SIGNAL**) + 0.238 **COMM**

Where:

SIGNAL – Signal-controlled crossing (0 – no, 1 – yes)
STOP – Stop-sign controlled crossing (0 – no, 1 – yes)
THRULNS – Number of through lanes
SPEED – 85% speed (miles per hour)
MAINADT – Main street volume (ADT in thousands)
COMM – Land use (0 - not predominantly commercial, 1 - predominantly commercial)

Increasing Ped ISI is related to less safety. As can be seen, the presence of a signal or stop control has the largest impact on safety. More lanes, higher traffic volume and greater speeds all decrease safety.

When major destinations (e.g., malls, bus stops, school or university buildings) are located far from traffic signals or marked crosswalks, it can be assumed that pedestrians will cross near the destination point. Locating crosswalks near these destination points, and locating bus stops near safe crossing points (i.e., traffic signals, crosswalks, or at a minimum, areas with good sight distance) is one way of reducing the risk of pedestrian crashes.

Drivers are more likely to notice pedestrians when they are at well-marked crossings. The more visible the crossing, the more likely the driver is to expect, search for, and detect pedestrians. Well-maintained delineation of the crosswalk and signing help improve crosswalk conspicuity. Flashing lights overhead or on the road edge are particularly effective at night, where there is a high contrast between the light and the background. Streetlighting at the crosswalk will also assist in making the pedestrian more visible.

One exception to the use of marked crossings is sites with no signal or sign to stop traffic. A case-control study of intersections was carried out to examine the impact of markings on older pedestrian safety. The cases were intersections at which an older pedestrian (65+) had been struck. The controls were nearby crossings matched to case sites on road classification. Crosswalk markings were associated with increased risk of pedestrian collisions involving older pedestrians at sites where no signal or stop sign was present to halt traffic.

Pedestrian countdown signals have shown mixed effects on safety. In a study of three control sites with traditional pedestrian signals and two test intersections with countdown pedestrian signals, average compliance rate was better at the former than at the latter (59% versus 47%) (Huang & Zegeer, 2000) cited in (Schattler, Wakim, Datta, & McAvoy, 2007). However, a larger study involving thirteen intersections found improved pedestrian compliance with the “walk” phase at intersections with countdown signals (71% versus 62%) and fewer signal violations (15% versus 24%). Furthermore, there was no difference in red or yellow light running behaviour associated with the countdown signals (Schattler et al. 2007).

Where there is a substantial amount of pedestrian traffic, road design and posted speed limits should be used to reduce speeds. Distance travelled during perception-reaction time and stopping is over twice as great at 70 km/h as compared to 40 km/h. The “complete street” movement focuses on designing roads that are safe for all users (Laplante & McCann, 2008). Speeds much over 50 km/h are incompatible with pedestrians and bicyclists and thus techniques to reduce driver speed are a major aspect of this approach. These techniques include narrower lanes, which will cause drivers to be more cautious, road diets (converting 4-lane road to 3-lane road with bicycle paths and shared turning lanes), tightening corner curb radii will slow down turning vehicle speeds, elimination of free-flow right turn lanes to discourage freeway speeds onto or off urban arterial streets, raised medians which visually narrow the roadway and provide refuge, median/parkway landscaping further visually narrow the road and curb parking and curb bulb-outs. The authors note that if signal lights could be properly coordinated to permit steady two-way progression down a road, the travel time at 50 km/h would be the same as the travel time at 70 km/h with the existing stops caused by traffic lights.

A moving pedestrian is more likely to be detected in peripheral vision if there is a clear view for drivers. Care should be taken to ensure that pedestrians are not blocked from view by parked vehicles, newspaper boxes, commercial signs, planters or trees in the vicinity of crosswalks, signals or common crossing points to buses, malls, high school or college buildings.

Innovative auditory and visual signals have been used to encourage more active search. A voice prompt to pedestrians to wait for the walk signal and to look for turning vehicles was successful in increasing pedestrian search and reducing pedestrian conflicts (Van Houten et al. 1997). An animated display of two eyes, which look left and right, and have been incorporated into a pedestrian signal, have been shown to increase visual search in adult pedestrians (Van Houten, Retting, Van Houten, & Farmer, 1999). While both displays show promise, it may be that pedestrians would become less responsive to such signals over a period of months. This has not yet been tested.

Countermeasures to poor conspicuity include street lighting and slower speeds in areas pedestrians are likely to be encountered.

4.5 Summary

Road users are limited in their attention and information processing, visual and perception-reaction skills. Based on an understanding of the road user tasks in an intersection, in combination with knowledge of road user limitations, it is possible to identify ways in which intersection design can lead to error, and to identify countermeasures likely to reduce these errors.

4.6 References for this report chapter

Allen, M.J., Hazlett, R.D., Tacker, H.L., and Graham, B.V. Actual pedestrian visibility and the pedestrian's estimate of his own visibility. *American Journal of Optometry and Archives of the American Academy of Optometry, 47,* 44-49. 1970.

Cole, B.L. and Hughes, P.K. A field trial of attention and search conspicuity. *Human Factors, 26*(3), 299-313. 1984.

Dewar, R.E. and Olson, P.L. *Human Factors in Traffic Safety*. ISBN 0913 875473. Lawyers & Judges Publishing Company, Tucson, Arizona. 2002.

Dewar, R.E. and Olson, P.L. *Human Factors in Traffic Safety (2nd Ed.)*. ISBN 1-933264-24-1. Lawyers & Judges Publishing Company, Tucson, Arizona. 2007.

Eubanks, J.J., & Hill, P.L. (1998) *Pedestrian Accident Reconstruction and Litigation*: Lawyers & Judges Publishing Co., Tucson, AZ.

Evans, L. Automobile speed estimation using movie-film simulation. *Ergonomics, 13,* 231-235. 1970a.

Evans, L. Speed estimation from a moving automobile. *Ergonomics, 13,* 219-230. 1970b.

Fambro, D.B., Fitzpatrick, K., and Koppa, R.J. *Determination of stopping sight distances*. Transportation Research Board NCHRP Report 400. 1997.

Fitzpatrick, K., Carlson, P.J., Wooldridge, M.D., and Brewer, M.A. *Design factors that affect driver speed on suburban arterials*. Rep. No. FHWA Report No. FHWA/TX-001/1769-3, Federal Highway Administration, Washington, D.C. 2000.

Fitzpatrick, K., Turner, S., Brewer, M.A., and Carlson, P.J. *Improving pedestrian safety at unsignalized crossings*. National Cooperative Highway Research Program Report No. 562 and Transit Cooperative Research Program Report No. 112, Washington, DC. 2006.

Habib, P. Pedestrian Safety: The hazards of left-turning vehicles. *ITE Journal, 50*(4), 33-37. 1980.

Hamed, M.M. Analysis of pedestrians' behavior at pedestrian crossings. *Safety Science, 38*(1), 63-82. 2001.

Hills, B.B. Visions, visibility and perception in driving. *Perception*, *9*, 183-216. 1980.

Huang, H. and Zegeer, C.V. *The effects of countdown pedestrian signals in Lake Buena Vista*. Florida Department of Transportation. 2000.

Kuciemba, S.R. and Cirillo, J.A. *Safety effectiveness of highway design features: Volume V - Intersections*. Report No. FHWA-RD-91-048, Federal Highway Administration, Washington, DC. 1992.

Laplante, J. and McCann, B. Complete streets: We can get there from here. *ITE Journal*, *78*(5), 24-28. 2008.

Lunenfeld, H. and Alexander, G. *A user's guide to positive guidance (3rd edition)*. FHWA SA-90-017, Washington, DC. 1990.

Mace, D.J., Garvey, P.M., and Heckard, R.F. *Relative visibility of increased legend size vs. brighter materials for traffic signs*. Rep. No. FHWA-RD-94-035, U.S. Department of Transportation. 1994.

McCormick, E.J. *Human Factors in Engineering*. 3rd edition. McGraw Hill Book Company, New York. 1970.

Mourant, R.R., Rockwell, T.H., and Rackoff, N.J. Drivers' eye movements and visual workload. *Highway Research Record*, *292*, 1-10. 1969.

National Highway Traffic Safety Administration. *Fatality Analysis Reporting System (FARS)*. National Center for Statistics and Analysis. 2003.

Older, J.S. and Spicer, B. Traffic conflicts - a development in accident research. *Human Factors, 18*(4) 1976.

Olson, P.L., Cleveland, D.E., Fancher, P.S., and Schneider, L.W. *Parameters affecting stopping sight distance*. Rep. No. UMTRI-84-15, University of Michigan Transportation Research Institute, NCHRP Project 1508. 1984.

Olson, P.L. and Sivak, M. *Improved low-beam photometrics*. Rep. No. UMTRI-83-9, University of Michigan Transportation Research Institute, Ann Arbor, MI. 1983.

Pasanen, E. *Driving speed and pedestrian safety: A mathematical model*. Report No. 77. Helsinki University of Technology. 1992.

Persaud, B., Parker, M.R., Knowles, V., Wilde, G., and IBI Group. *Safety, speed and speed management: A Canadian review*. File No. ASF 3261-280, Road Safety and Motor Vehicle Regulation, Transport Canada, Ottawa, Ontario, Canada. 1997.

Polus, A., Fitzpatrick, K., and Fambro, D.B. Predicting operating speeds on tangent sections of two-lane rural highways. *Transportation Research Record*, *1737*, 50-57. 2000.

Ranney, T., Masalonis, A.J., and Simmons, L.A. Immediate and long-term effects of glare from following vehicles on target detection in driving simulator. *Transportation Research Record*, *1550*, 16-22. 1996.

Rockwell, T.H. *Spare visual capacity in driving - revisited. Vision in Vehicles II*. A.G. Gale et al., Elsevier Science Publishers B.V. (North Holland). 1988.

Salvatore, S. The estimation of vehicle velocity as a function of visual stimulation. *Human Factors*, *10*, 27-32. 1968.

Schattler, K.L., Wakim, J.G., Datta, T.K., and McAvoy, D. *Evaluation of pedestrians and driver behavior at countdown pedestrian signals in Peoria, Illinois*. Presented at the 86th Annual Meeting of the Transportation Research Board, Washington, DC. 2007.

Schmidt, F. and Tiffin, J. Distortion of drivers' estimates of automobile speed as a function of speed adaptation. *Journal of Applied Psychology*, *53*, 536-539. 1969.

Shinar, D., McDowell, E., and Rockwell, T.H. Eye movements in curve negotiation. *Human Factors*, *19*(1), 63-71. 1977.

Smiley, A., Smahel, T., and Eizenman, M. Impact of video advertising on driver fixation patterns. *Transportation Research Record*, *1899*, 76-83. 2004.

Summala, H., Päsänen, E., Räsänen, M., and Sievänen, J. Bicycle accidents and drivers' visual search at left and right turns. *Accident Analysis & Prevention*, *28*(2), 147-153. 1996.

Treat, J.R., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.E., Stansfin, R.L., and Castellen, N.J. *Tri-level study of the causes of traffic accidents*. Rep. No. DOT-HS-034-535-77-TAC, Institute for Research in Public Safety, Indiana University, Bloomington, Indiana. 1977.

Van Houten, R., Malenfant, J., Van Houten, J., and Retting, R. Using auditory pedestrian signals to reduce pedestrian and vehicle conflicts. *Transportation Research Record*, *1578*, 20-22. 1997.

Van Houten, R., Retting, R., Van Houten, J., and Farmer, C.M. Use of animation in LED pedestrian signals to improve pedestrian safety. *ITE Journal*, *69*, 30-38. 1999.

Vanasse Hangen Brustlin, I. *Pedestrian road safety audit guidelines and prompt lists*. Vol. FHWA-SA-07-007, Federal Highway Administration, Vienna, VA, U.S.A. 2007.

Zwahlen, H.T. Advisory speed signs and curve signs and their effect on driver eye scanning and driving performance. *Transportation Research Record*, *1111*, 110-120. 1987.

Figure 9: A pedestrian-oriented street

5 THE PEDESTRIAN SAFETY LITERATURE

5.1 Background

In addition to having to build a strong understanding of road user needs when developing a pedestrian safety evaluation program (PSE), it is also necessary to rely on well-founded and accepted literature and practices that will lead to a robust and technically defensible process that is in keeping with the duty of care expected of a public road agency.

The technical research and development elements of this study followed a logical series of steps including a detailed and carefully focused literature and research-in-progress review that was intended to provide much of the technical groundwork for our efforts in addition to the City of Ottawa reports on pedestrian safety and the Pedestrian Plan. In this regard, recent research on pedestrian safety in the United States, includes: efforts by the Federal Highway Administration (FHWA) on PEDSAFE (a pedestrian safety guide and countermeasures selection system); the development of pedestrian safety prediction models as part of the soon-to-be-released Highway Safety Manual; the American Association of State Highway and Transportation Officials (AASHTO) guidelines in their work on the planning, design, and operation of pedestrian facilities; the National Cooperative Highway Research Program (NCHRP Report 500 - Volume 10 of the AASHTO Strategic Highway Safety Plan (A guide for reducing collisions involving pedestrians); and new publications issued by the Institute of Transportation Engineers (ITE). Findings of our review are summarized in the following Section.

5.2 A word on pedestrian collision history

During an operational safety review process, the collision history is one of the key indicators of site safety performance. However, when dealing with pedestrian safety issues, typically the frequency of pedestrian-related collisions is sparse. The FHWA[9] states that this can lead to two problems:

- A site with only one or two collisions may be ranked with an abnormally high priority (as other sites may not have any collision history), and

- Due to the known randomness of collision frequencies, a high-risk site may have several years of no pedestrian-related collision events at all, leading to a site with an abnormally low priority.

This is not to say that practitioners should ignore the collision history information that is available at a site, but they should use caution in its use as part of a ranking and site prioritization process.

5.3 The relationship between safety and site characteristics

Zegeer et al. (1985)[10] carried out a study of vehicle-pedestrian collisions at signal-controlled intersections. Using a statistical regression analysis, it was found that the pedestrian volume and traffic volume variables demonstrated a positive correlation with the frequency of pedestrian collisions. Other key variables included: wide streets, public transit operations, two-way versus one-way flow, and higher volumes of turning traffic.

[9] Pedestrian and Bicyclist Intersection Safety Indices – Final Report. Federal Highway Administration Publication No. FHWA-HRT-06-125. November 2006.

[10] Zegeer, C.V., Opiela, K.S., and Cynecki, M.J. Pedestrian Signalization Alternatives. Federal Highway Administration Report No. FHWA/RD-83/102. July 1985.

In another study, Zegeer et al. (2001)[11] studied the relationships between pedestrian collisions and site-specific characteristics. It was found that high pedestrian volumes, high traffic volumes, and more lanes had a strong relationship. In addition, marked versus unmarked crosswalks were evaluated and it was found that there was no change in pedestrian risk for two-lane, two-way roadways or multi-lane roads with fewer than 12,000 vehicles per day (vpd). However, both multi-lane roads without a raised centre median, volumes higher than 12,000 vpd, and a marked crosswalk; and multi-lane roads with raised centre medians, volumes higher than 15,000 vpd and a marked crosswalk experienced higher pedestrian risks.

In 2003, King et al.[12] carried out an evaluation of intersection upgrades and its impact on pedestrian collisions. The upgrades were made to a suburban 4-lane roadway and included a raised median, narrowing of the roadway width, signal timing modifications, added bicycle lanes, intersection redesigns and added sidewalks. Using the well-known relationship between speed and collisions it was determined that the pedestrian exposure and risk decreased by 28%. The measured change in operating speeds was a drop of 3km/h.

5.4 FHWA Research

The FHWA has a large body of pedestrian safety research that has been carried out in recent years. The following documents were relevant to this study.

5.4.1 PEDSAFE Expert System

The FHWA began studying pedestrian safety countermeasures in 2002 and produced an initial document called the Pedestrian Facility User Guide: Providing Safety and Mobility[13]. This work was updated in 2004 by Zegeer and Harkey and out of these efforts came an expert system entitled PEDSAFE. This tool facilitates the countermeasure selection process which is part of the diagnosis phase of a safety evaluation program. The PEDSAFE expert system is packaged with 49 pedestrian safety countermeasure descriptions and 71 case studies to demonstrate ways in which to apply the tool. The tool requires the user to identify the key safety risks (from a list of 8 risk types) and predominant collision types that are occurring at a given site (from a list of 12 collision types).

The countermeasures identified in the PEDSAFE tool are based on past research efforts and these treatments have been shown to improve pedestrian safety at crosswalks.

5.4.2 Pedestrian and Bicyclist Intersection Safety Indices

Following the efforts in producing the PEDSAFE tool, the FHWA determined that there was a need to develop a technical process to proactively identify and rank sites for safety upgrades. The subsequent study collected data at 68 intersection crosswalks in

[11] Zegeer, C.V., Stewart, J.R., Huang, H.F., and Lagerwey, P. Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations – Executive Summary and Recommended Guidelines. Federal Highway Administration Report No. FHWA-RD-01-075. April 2001.
[12] King, M.R., Carnegie, J.A., Ewing, R. Pedestrian Safety Through a Raised Median and Redesigned Intersections. Transportation Research Board's Transportation Research Record
[13] Zegeer, C.V., Seiderman, C., Lagerwey, P., Cynecki, M., Ronkin, M., and Schneider, B. Pedestrian Facilities Users Guide: Providing Safety and Mobility. Federal Highway Administration Report No. FHWA-RD-01-102. March 2002.

major urban centers in Pennsylvania, California, and Florida. Specific data at each crosswalk location included the collision history, pedestrian-vehicle conflict observations, observations of avoidance maneuvers between pedestrians and vehicles as well as subjective ratings of the intersection environment by experts.

The data was compiled and a statistical regression analysis was carried out to determine which site-specific characteristics demonstrated the strongest relationship to pedestrian safety. The final variables used in the index equation included type of intersection control, number of through lanes, the operating speed, traffic volume, and type of surrounding land use. Once the data is entered for each crosswalk location the index values are calculated and the user can then rank the sites.

5.5 NCHRP Research

5.5.1 NCHRP Report 500 Volume 10

The NCHRP Report 500 series provides guidance to practitioners when implementing the AASHTO Strategic Highway Safety Plan. The focus of the Report 500 series is to identify potential safety countermeasure strategies, classify them, provide an indication on implementation timeframes, and the relative cost of implementing the strategy. Volume 10 of this series provides guidance on reducing collisions involving pedestrians.

The researchers identified 4 key strategies that address potential safety risks and include:

- Reducing pedestrian exposure to vehicles;
- Improving sight distance and visibility between vehicles and pedestrians;
- Reducing vehicle speeds;
- Improving pedestrian and driver awareness and behaviour.

Several safety countermeasures were identified under each strategy. For each countermeasure a discussion is provided that identifies policy implications, data needs, potential implementation issues and so forth.

5.5.2 NCHRP Pedestrian Safety Prediction Methodology

As part of the development of the Highway Safety Manual (HSM) the NCHRP undertook research efforts to develop a pedestrian collision prediction algorithm and the findings of which are documented in the NCHRP Project 17-26[14]. The objective of the study was to quantify the pedestrian safety effects related to site characteristics as well as the proposed improvements on urban and suburban arterials. This research did not include unsignalized intersections.

A statistical regression analysis was carried out to determine the regression coefficients and over-dispersion factors for each variable under study. The research was taken one step further to determine accident modification factors for bus stops, presence of

[14] Harwood, D. et al. Pedestrian Safety Prediction Methodology. National Cooperative Highway Research Program Project 17-26: Phase III. March 2008.

schools, presence of parks, number of alcohol establishments and neighbourhood per capita income.

We concluded that although this research is valuable, it was not appropriate for use in our study – particularly since unsignalized intersections were not included in the research.

5.6 Summary of findings

Based on our literature review process we concluded the following:

- There is a strong and well documented relationship between pedestrian safety risks and site-specific characteristics such as the width of an intersection and the volume of pedestrians or vehicles.

- It was determined that the FHWA processes for prioritization[15] and selecting candidate countermeasures[16] are appropriate for use in the context of the City of Ottawa. The prioritization tool (Ped ISI) was developed using statistical analysis of data gathered from relevant pedestrian crosswalk sites. In addition, both the Ped ISI and PEDSAFE tools use readily available site-specific data, and do not require onerous amounts of effort or resources to carry out the analyses. In addition, the simplicity of the tools add to their user-friendliness and our ability to develop customized versions in a spreadsheet environment specific to the City of Ottawa.

- It appears that the use of pedestrian collision history is not well suited to the prioritization process. However, it would be prudent to provide flexibility in a prioritization tool to access collision history data if necessary.

- Although there are issues with the use of pedestrian collision history – that are associated with small sample sizes and so forth – it is still a valuable piece of evidence during the diagnostic stage of a pedestrian safety evaluation program as the patterns and trends gleaned from the data help identify the key safety risks at a given site.

[15] Pedestrian and Bicyclist Intersection Safety Indices – User Guide. Federal Highway Administration Publication No. FHWA-HRT-06-130. April 2007.

[16] PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System. Federal Highway Administration Publication No. FHWA-SA-04-003. September 2004.

6 DEVELOPING THE ANALYSIS TOOLS

6.1 Background

There is a substantial body of research in the areas of prioritization and safety countermeasures. These two particular areas are fundamental to the safety evaluation process. Therefore, developing user-friendly tools for these steps – as part of an overall safety evaluation program – would benefit the City of Ottawa.

6.2 The Prioritization Tool

6.2.1 Introduction

As we determined from our literature review, the FHWA has developed a robust and technically defensible analytical process for prioritizing pedestrian crosswalks and in our opinion is suitable for application in the City of Ottawa context. Therefore, we have taken the analytical elements of this tool and developed a customized, spreadsheet-based version for use by City staff – and called it Ottawa Ped ISI.

The Ottawa pedestrian intersection safety index (Ped ISI) process calculates a safety index (PSI) value for each crosswalk at an intersection and then an overall intersection safety index based on the average of all crosswalks. Once the PSI values are calculated, they can be sorted (either by the intersection PSI value, by community, or both) to provide practitioners with a list of intersections having a high priority for undergoing pedestrian-oriented safety improvements.

6.2.2 The algorithm

The technical foundation for the Ped ISI process is based upon well-documented and clear relationships between pedestrian safety and general site-specific characteristics. All of the characteristics were processed in a rigorous statistical analysis that ultimately identified only the most significant characteristics to apply in the final algorithm. The FHWA research revealed that site-specific characteristics having the strongest relationship with pedestrian safety included:

- Intersection traffic signal control or stop control;
- The number of through lanes (an indicator of roadway width);
- Vehicle operating speeds;
- The volume of traffic (an indicator of exposure); and
- The type of land use (an indicator of pedestrian activity).

The final algorithm is contained in Figure 10.

Figure 10: The prioritization algorithm

$$PedISI = 2.372 - 1.867 * Signal - 1.807 * Stop + 0.335 * Lanes + 0.018 * Speed + 0.006(Volume * Signal) + 0.238 * LandUse$$

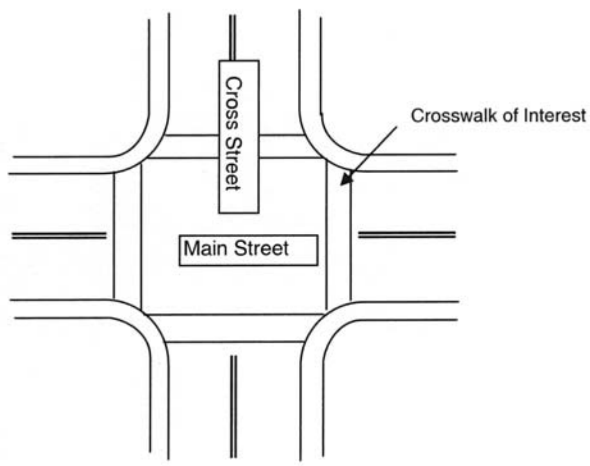
(Speed in miles per hour, volume in thousands of vehicles per day)

6.2.3 Data needs

One of the greatest benefits of the Ped ISI process is that it requires a limited amount of data that is readily available. If some of the required data is not available, it can be easily collected by one individual during a short field visit.

Users of the Ottawa Ped ISI tool will need to gather data on geometric and operational characteristics of each crosswalk at an intersection. This can be done by reviewing historical databases, GIS or digital mapping, or by conducting brief field visits. Roadway-specific information (i.e. vehicle speed, number of lanes, etc.) relates to the roadway that is crossed by the crosswalk of interest. This roadway is referred to as the “main street” and its location is illustrated in Figure 11.

Figure 11: The location of a crosswalk of interest



6.2.4 Limitations of the process

As with any technical process, this model is subject to certain limitations. During the development of the FHWA’s Ped ISI process, the FHWA dataset included urban and suburban intersections with the following characteristics:

- 3-leg and 4-leg intersections
- Signalized, 4-way stop and 2-way stop controlled intersections
- Traffic volumes that range from 600 to 50,000 vehicles per day
- One-way and two-way roadways
- One to four through lanes
- Speed limits between 24.1 and 72.4 km/h

As such, the Ottawa Ped ISI tool is applied most appropriately at intersections that meet the above criteria. Safety index values that are produced for intersections with characteristics outside of these ranges should only be used with the understanding that the models were not developed using intersections of that type.

6.2.5 Incorporating the collision history

One of the inputs to the Ped ISI prioritization tool is a 5-year collision history for each site. This data is not applied to the mathematical prioritization and ranking process. However, it can be used by the practitioner to help identify sites of interest. We recommend that the City of Ottawa adopt a policy whereby a preliminary investigation is carried out at any intersection following a fatal pedestrian collision in order to determine if there is a need to rank that particular intersection as a site of interest in the prioritization process – triggering a detailed engineering study. The purpose of such a policy is to incorporate an element of flexibility in how the practitioner applies the technical process when discordance arises between the public, media or politicians.

6.3 The Countermeasure Selection Tool

6.3.1 Introduction

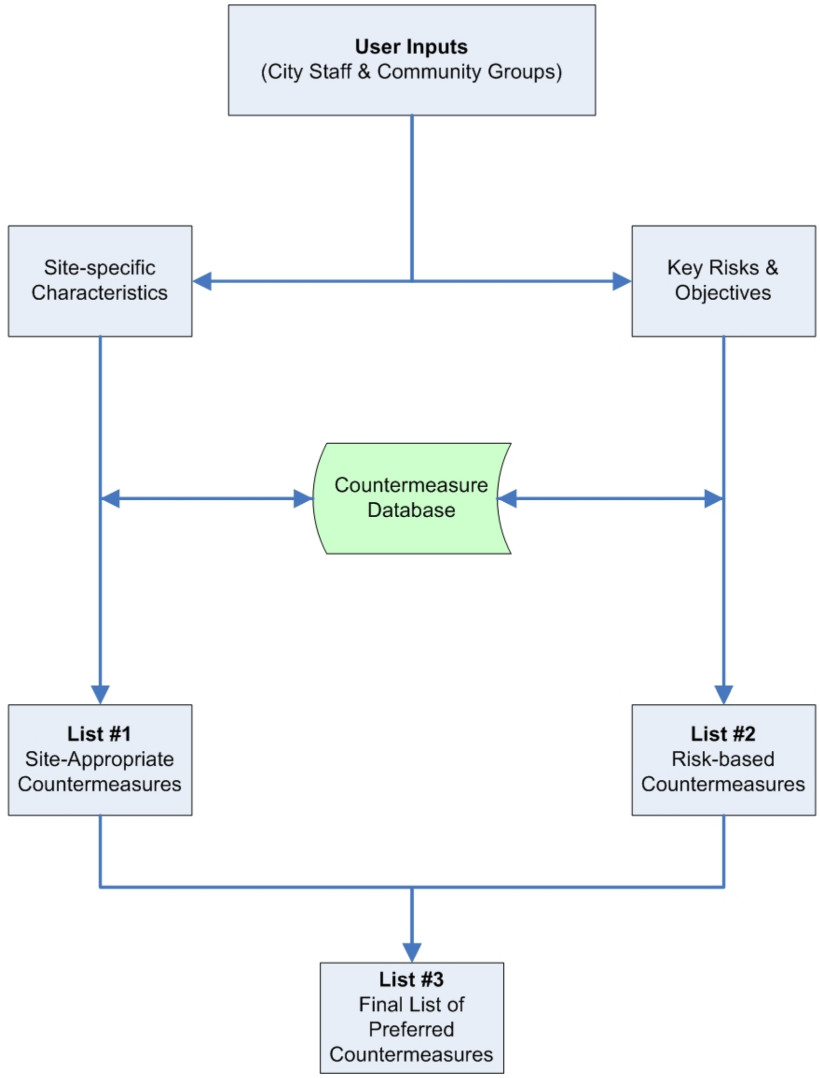
Once a practitioner has carried out a detailed engineering study, reviewed information submitted by the community group (based on the pedestrian and driver needs assessment), and diagnosed the issues, there is a need to identify candidate pedestrian safety countermeasures. From the literature review in Section 5 we determined that the FHWA countermeasure selection tool PEDSAFE was technically robust, used readily available data and was user friendly. Therefore, we have applied some elements of this expert system, added additional safety countermeasures and developed a customized, spreadsheet-based version for use by City staff – and called it Ottawa PEDSAFE. In total, there are over 60 pedestrian-oriented countermeasures to choose from in the new tool.

6.3.2 Key steps

The countermeasure selection process is outlined in Figure 13 (next page).

This space intentionally left blank

Figure 12: A process to select countermeasures



Users of the countermeasure selection tool will need to gather data in two areas: site characteristic information, and the key safety risks that need to be addressed. The majority of the input data for the tool will likely have been gathered as part of the detailed engineering study (DES) and the community group's pedestrian and driver needs assessment. A list of specific data requirements is provided in Section 5.3.3, below.

Once users enter the data, the tool will search the countermeasure database of over 60 countermeasures and generate two lists of candidate treatments – one list with countermeasures appropriate for the site characteristics (list #1) and another list with countermeasures appropriate for the safety risks (list #2). The tool then will generate a third and final list of candidate countermeasures from the common treatments that address both site characteristics and safety risks.

6.3.3 Data needs

The countermeasure selection tool requires user inputs from two perspectives: the site-specific characteristics (i.e. high or low traffic volumes) and site-specific safety risks that need to be addressed (i.e. the need to reduce vehicle speeds). The 10 user inputs related to site characteristics include:

- Type of traffic control;
- Pedestrian volume;
- Vehicle volume;
- Operating speed;
- Number of lanes;
- Presence of on-street parking;
- Presence of illumination;
- Type of land use in the immediate area;
- Predominant pedestrian type;
- Presence of a school.

The second set of user inputs will flow from the detailed engineering study and driver needs assessment. The result is a list of key safety risks. We have developed key safety risk categories and included them in the Ped ISI tool. The following 7 choices are presented to the user:

- Reduce vehicle operating speeds;
- Improve sightlines and visibility;
- Reduce the traffic volume;
- Reduce pedestrian exposure;
- Improve pedestrian access and mobility;
- Improve pedestrian and vehicle right-of-way compliance;
- Reduce high-risk behaviours

6.3.4 Output and results

The Ottawa PEDSAFE tool has been programmed to produce only the pedestrian safety countermeasures that are common to both the site characteristic criteria and risk objective criteria.

6.3.5 Limitations

As with any expert system, there is a limited amount of guidance that can be provided to the user and it is up to the practitioner to evaluate each candidate countermeasure based on its appropriateness and applicability to each site. It is strongly suggested that users of the tool refer to the countermeasure sheets provided in the Countermeasure Handbook as they provide valuable guidance and considerations at the planning and design stages of implementation.

7 CONCLUDING THOUGHTS

The goal of this study is to improve the ability of the City to deal with pedestrian road safety issues. Statistics tell us that more and more people are walking to their destinations in the urban areas of the City. In order to properly prioritize and deal with the infrastructure improvements required to accommodate this growing mode of travel, the City requires a process and methodology to proactively cope with their pedestrian road safety risks.

We were asked to develop such a process and it required a two-part solution. The first step was the development of an overall programming process that enabled proactive consultation and collaboration with the various community groups. The programming process is continuous on a once per year cycle. Each year, the basic process is expected to span 10-12 months, and will include four public consultations with a given community group. Each subsequent program will build on the previous year's work. Candidate intersections that have been dealt with will be taken off the list, new ones added, and a new set of priorities will be developed for each budget year. In this respect, the program of work will be analogous to the City's normal 5-year capital works program in that it provides a 5-year envelope of projected activity that is modified each year in response to change, need, and financial capacity.

The second part of our work involved the development of technically defensible, affordable, and user-friendly analytical tools that city staff – and for some elements of the work – community participants in the collaborative program - could use at the key stages of the overall programming process.

In all of this, the following points are worth noting:

- Both the prioritization/ranking and the candidate countermeasure selection processes are based on extensive research conducted by the United States Federal Highway Administration. The research demonstrates the technical strength of the relationships between urban intersection design characteristics and their impact on pedestrian safety risk.

- The processes are user-friendly and require data that is available and is already being collected on a regular and recurring basis.

- The analytical tools were developed and provided in a spreadsheet environment and as such are easy to use, flexible, and customizable.

Ottawa

delphiMRC