THE TRAFFIC SAFETY PROBLEM IN URBAN AREAS

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As the number of people who reside and work in urban areas increases, so, too, do the needs and demands placed on the infrastructure. This has led to severe congestion in many European cities, a situation which affects not only the environment in terms of pollution, but most notably levels of traffic safety. In Europe, tens of thousands of people are killed in road traffic accidents, and more than 1 million are injured each year at a cost, which is estimated to exceed the total European Union budget by a factor of two. The majority of accidents involving injury occur within urban areas often at junctions, while the number of fatalities outside these areas is greater, largely as a result of higher speed. Traffic safety research has shown a biased interest in the problems associated with motorway and rural areas in the past. There are many reasons, which advocate a greater interest in urban areas, in particular, those related to the safety of unprotected road users. In urban areas the traffic system context is more complex, where a mixed road user environment prevails and greater perceptual and cognitive demands are placed on road users. In the past, many of the more successful safety countermeasures have focused on designing the roadway to meet the needs and limitations of road users. These solutions have, however, proved to be very costly. Today, new and relatively cheap technological solutions referred to as Intelligent Transport Systems (ITS) have been developed which have the capacity to reduce exposure, accident risk, and accident severity. While the long term effects of these systems are largely unknown, and problems associated with standardisation and legislation are in need of resolve, systems such as Intelligent Speed Adaptation and advanced traffic control systems have shown great potential with regard to the traffic safety problem in urban areas. In order to effectuate this potential, a great deal of integrated multi-disciplinary research is required.

1. INTRODUCTION

The last century of the second millennium has seen vast improvements in the living conditions and economic wealth of the industrialised nations of the world, and consequently a large growth in population, particularly in urban areas. The growth of cities and towns has also led to an increase in the need for mobility, and a consequent increase in the numbers and types of vehicles occupying the road infrastructure. The exponential increase in the number of vehicles during the twentieth century has far outweighed the projected capacities and adaptive capabilities of the existing road infrastructure systems, this has resulted in a situation of congestion and frustration among road users of all types and has had significant detrimental effects for traffic safety in terms of the unacceptable numbers of road accidents involving fatality and injury.

During 1997, there were approximately 45 000 fatalities, and 1.3 million injuries reported from road traffic accidents within the European OECD countries according to statistics taken from the International Road Traffic and Accident Database (IRTAD). The costs of such accidents within the European Union are estimated to be in the region of 160 billion ECU per year, thereby exceeding the total annual budget for the EU in 1997 (89 billion ECU). Statistics indicate that while approximately two-thirds of all fatalities occur outside urban areas, two-thirds of the total number of injuries occur inside urban areas. The outcomes of urban accidents are usually less severe in terms of the numbers of injuries and fatalities as a direct result of the greater limitations imposed on speed. Mainly for this reason, most of the international and national traffic safety research has focused on motorways and major roads that link towns and cities by traversing rural and suburban areas.
Why Focus on Traffic Problems in Urban Areas?

There are however, a number of very important reasons why the traffic system existing in urban areas should not be disregarded by prevailing research. Most importantly, there are a great number of people living in urban areas, and travel distances are generally shorter than in rural areas, which encourages people to use bicycles or to walk. According to the statistics for the European OECD countries, pedestrians amounted to 15 per cent, and cyclists 6 to per cent, of the total number of road-traffic fatalities during 1997, respectively. For other types of road users, such as vehicle drivers, there are significant differences in the types of accidents that occur in urban areas with a greater number of rear-end and turning collisions, and a larger percentage of collisions occurring at junctions. Generally, the urban environment can be regarded as more complex with many different types of road users with different needs, the physical and mental demands placed on road users are therefore much higher, and are reflected in the statistics by a comparatively greater number of accidents involving injury.

The Development of Traffic Safety in Urban Areas from a Historical Perspective

In the past, European traffic safety in urban areas has most typically focused on speed management and traffic calming. Kjemstrup and Herrstedt (1992), identified three specific periods of development. During the first period prior to 1968, the major growth in the number of vehicles was initially countered by expanding the infrastructure where possible. These measures soon proved insufficient, leading to the hazardous overuse of local roads that had previously catered for lighter traffic, cyclists and pedestrians. In the second period from 1969 to 1979, the traffic safety problem was approached by separating light and fast-moving heavy traffic, and by designing the traffic environment with an emphasis on uniformity and simplicity. “Traffic calming” initiatives became popular together with what became known as ‘Woonerf design’, which entailed physical speed-reducing measures (e.g. humps and narrowings), and rules to govern speeds and priorities within urban areas.

The third period from 1980 to 1990 saw increasing opposition to speed reducing measures by public and private interests. A new and less expensive solution was required, and eventually took the form of “environmentally adapted through-roads”, which took into consideration: flow-rates, composition of traffic, accident rates, pedestrian needs, and environmental sensitivity (in relation to noise levels air-pollution etc.). Research has shown considerable success in a number of European countries (e.g. Denmark, France, Germany), while others have neglected the potential offered by this concept. Kjemstrup and Herrstedt (1992) concluded at the time of writing, that automatic speed regulation devices were “a long way into the future” and that traffic calming through physical measures and the design of street space was the only currently available approach to achieving lower speeds and increased safety and security and an improved urban environment.

Despite safety countermeasures such as traffic calming techniques, various legislative measures, publicity campaigns, active police enforcement, improvements in vehicle safety standards, and local improvements in the infrastructure, the problems related to traffic safety in urban areas still prevail at an unacceptably high level. One area of research that has shown great promise is that concerning Intelligent Transport Systems (ITS) which exploit the latest information and communication technologies and integrate them into the traffic system. This approach enables the already congested infrastructure to be utilised with much greater efficiency, and to some extent can resolve problems associated with human limitations. The future appears to have arrived for automatic speed regulation devices such as “Intelligent Speed Adaptation” (ISA), which are perceived to have great safety potential (see e.g. SNRA, 1996). There is however, an irrefutable need for establishing sound scientific knowledge related to how effective countermeasures, with or without the aid of ITS, can be designed, developed, and implemented to resolve urban area traffic safety problems.

The Need for Traffic Safety Strategies

The World Health Organisation has referred to the existing traffic safety as a social and public health problem. In order to approach this problem, different European and world-wide traffic safety research programs have been initiated, which call for international co-operation between different institutions and establishments, and a conglomeration of different scientific disciplines in a major offensive to find ways to improve the present situation. At a national level some countries have developed specific traffic safety strategies in order to approach the traffic safety problem.
In Sweden, the “vision zero” has been sanctioned by the government in order that individuals and organisations can develop an operational energy and innovative thinking towards a new and radical future situation where the desired ultimate goal is to have zero road-traffic fatalities (Tingvall, 1995). This is to be achieved by emphasising for individuals that loss of health is completely unacceptable, and that traffic safety is ultimately their responsibility. The focus of attention is placed on active safety (i.e. the prevention of accidents), passive safety (i.e. reducing the severity of accidents upon occurrence), and improving the rescue services, health-care, and rehabilitation. Importantly, it is recognised that there are other interests in society in addition to the provision of safety (e.g. environmental issues and regional planning issues) which must be discussed in order to find a balance by authorities other than those in the road-transport sector in a social and political context. Thus, the “vision zero” concept involves a wide spectrum of interest at many different levels in order to provide an integrated and far reaching approach to the traffic safety problem in Sweden.

**Delimiting and Defining Urban Areas for Traffic Safety Research**

In this report it is important to distinguish between those roads that can be regarded as part of an urban area road network, and those which are not. A reasonably straightforward definition of urban areas could be taken to include all types of roads provided that they fall within a town or city boundary. This distinction is, however, too general to be of value for research purposes. The definition that is adopted by the Swedish Institute for Transport and Communications Analysis (SIKA), and which will be used as a *de facto* definition in this report is:

- roads which most often are directly adjacent to large numbers of buildings where people live and work
- roads where there are many different types of road users (including cyclist and pedestrians) allowed to use the road
- roads where there is a high density of road junctions, roundabouts, pedestrian crossings etc. in order to allow for a reasonable level of accessibility for all road users
- roads where the maximum allowed speed is no greater than 50 km/h, or where a higher speed limit is posted, but the density of the surrounding buildings and the traffic conditions resemble those described above

Roads that lead through built-up areas, but do not have intersections and are separated from the environment (by a fence) or restricted to motor vehicles are not considered to lie in an urban area (SIKA, 1999). The Swedish National Road Authority makes a distinction between “central”, “intermediate”, and “suburban” roads (SNRA, 1989, p. 55). What are considered “urban” or “built-up” areas differs to some extent from country to country depending on the responsibilities and prevailing political climate of the local and central authorities with regard to different road categories, and environmental and traffic safety issues. The exact distinction remains therefore somewhat “fuzzy” at an international level.
2. SWEDISH AND INTERNATIONAL TRAFFIC SAFETY STATISTICS: THE DIFFERENCES BETWEEN URBAN AND NON-URBAN AREAS

The traffic safety situation in Sweden is described annually in an official publication entitled “Traffic Injuries” produced by the Swedish Institute for Transport and Communication Analysis (SIKA). This publication is based entirely on police reported accident data, and represents only those accidents, which involve personal injury. The problem of under-reporting is acknowledged, and it is believed that the statistics presented might represent only as much as 30 per cent of the lighter injuries and approximately 60 per cent of the more serious injuries. Most injuries in relation to the different road user groups are believed to be represented to a level of approximately 50 per cent (e.g. car-occupants, motorcyclists, pedestrians). The most notable exception is found in the statistics for cyclists which are only believed to be represented to a level of 15 per cent (SIKA, 1999).

Basic Swedish statistics and trends for the period 1960-1997

With 8.85 million inhabitants, Sweden has one of the smallest populations among the European OECD nations. The infrastructure consists of a 210 000 km road network that is populated by around 4.44 million motor vehicles. During the period between 1960 and 1997, the total number of accidents and the number of urban accidents has declined marginally (see Figure 1). The total number of fatalities and the number of fatalities in urban areas has, however, declined significantly (by more than 50 per cent since the mid-1960’s) during this time period (see Figure 2).

During the period from 1960 to 1997 the proportion of accidents involving fatality in urban areas has remained relatively constant, at an average of 32 per cent of the total number. Similarly, the proportion of accidents involving injury in urban areas has remained fairly constant during this time period at around 58 per cent of the total number.

Comparing Swedish Urban and Non-Urban Statistics

In 1997, 9 015 of the 15 752 reported road accidents involving fatality or injury occurred in urban areas. These urban area accidents resulted in 154 fatalities, 1 765 serious injuries, and 11 593 less serious injuries. The remaining 6 737 accidents occurring outside urban areas resulted in 387 fatalities, 2 152 serious injuries, and 7 689 less serious injuries. The majority of the accidents that are reported to the police authorities involve one or more motor vehicles. The main classes of accidents are single vehicle accidents, vehicle-vehicle accidents, and accidents where vehicles and unprotected road users are involved (i.e. moped riders, cyclists, and pedestrians).
Single vehicle accidents usually occur in situations where drivers lose control over their vehicle, often as a result of driving too fast for the situation and prevailing road conditions. Many of these accidents occur at night-time and involve collisions with parked vehicles. With regard to vehicle-vehicle accidents, a more in-depth look at the nature of the accident called for is in order to get a clearer picture of the different accident profiles occurring in Swedish urban and non-urban areas.

The main types of vehicle-vehicle accidents described by SIKA are:

- **Overtaking and Lane-Changing** – Accidents where the two primarily involved vehicles are on the same road travelling in the same direction without any planned turn and where one of the vehicle drivers intended to either change lanes or overtake.
- **Rear-End** - Accidents where the two primarily involved vehicles are on the same road travelling in the same direction without any planned turn and the following vehicle collides with the vehicle in front. No intended overtaking should be present in the situation.
- **Meeting** – Accidents in which both of the primarily involved vehicles collided while travelling in opposite directions with no planned turn.
- **Turning** – Accidents where the two primarily involved vehicles are originally travelling on the same road in the same or opposite direction, and where one or both of the vehicles has planned to turn.
- **Crossing** – Accidents where the two primarily involved vehicles are originally travelling on different roads, and where neither of the vehicles has planned to turn in a situation where the vehicles’ planned routes cross each other, or where one or both vehicles planned to turn.
- **Others** – Accidents that do not fit any of the above descriptions (e.g. reversing accidents and U-turn accidents).

The differences in the number of accident occurrences between urban and non-urban areas are depicted in Figure 3. The figure indicates that almost all accident types are more frequent in urban areas, with the exception of single-vehicle accidents, accidents involving overtaking or lane changing, and meeting accidents. Single vehicle accidents occur more often outside urban areas often as a result of loss of control at speeds, which are too high for the prevailing road conditions. Overtaking tends to occur less frequently within urban areas where a speed limit of 50 km/h or less is posted, and generally congested conditions restrict the opportunity for a manoeuvre of this type. Lane changing on the other hand occurs quite frequently within urban areas, but does not result in the same number of accidents most probably on account of lower speeds.

The number of rear-end accidents is greater within urban areas than in rural areas, there is a considerably larger number of situations per km of roadway which require vehicles to stop or yield. Similarly, there is a greater number of opportunities for turning and crossing accidents within urban areas due to higher levels of congestion and the higher number of traffic junctions. The most noticeable differences between urban and non-urban area accidents that are depicted in Figure 3, are those concerning motor vehicles and unprotected road users (i.e. mopeds, cycles, and pedestrians). There is a comparatively greater number of unprotected road users in urban areas, but the absolute number of these accidents in comparison to single vehicle and vehicle-vehicle accidents suggest that this is one area that should be given great attention in the field of traffic safety research. The “others” category shown in Figure 3, which is not vehicle-vehicle related refers to accidents involving a vehicle and another type of obstacle than those already mentioned. In rural areas and on motorways (and occasionally with urban areas) accidents occur that involve motor vehicles and wild animals that have strayed onto the road, larger animals such as moose can cause severe injury and sometimes fatality.

Other types of motor vehicle accidents resulting in injury can also involve other forms of transportation that occupy or cross the roadway (e.g. trains, trams, tractors and other more unusual vehicles). Accidents that result in injury also occur between forms of transportation that do not involve the more common motor vehicles category, and in some cases pedestrians (e.g. between cycles, mopeds, and/or pedestrians).
The fatality statistics reveal some interesting facts (see Figure 4). Most importantly, all types of vehicle-vehicle accidents result in a greater number of fatalities outside urban areas, despite the fact that some types occur more frequently within urban areas. This fact can be attributed largely to the higher speeds allowed on non-urban roads, and is exaggerated further by the number of fatalities in meeting accidents in non-urban areas where the collision speed is the sum of the two vehicles that are approaching in opposite directions.

The unprotected road users category is that which is of great concern to traffic researcher with regard to urban areas. The proportion of accidents involving motor vehicles and pedestrians or cyclists that result in fatality are considerably greater in non-urban areas as a result of the higher speed of the vehicles, but the absolute number of those accidents is considerably smaller outside urban areas. The traffic safety problems associated with unprotected road users are quite prominent. The fatality risk independent of the type of area where the fatality occurred for pedestrians in relation to vehicle occupants given the relative number of travelled kilometres is 11 to 1, for cyclists 4.5 to 1, and for moped riders 24 to 1.

Figure 3: The number of urban and non-urban accidents for different road user accidents categories (LCh/Ov = Lane Changing and Overtaking, Rear-E = Rear-End, Pedestr = Pedestrian).

Figure 4: The number of urban and non-urban fatalities for different road user accidents categories (LCh/Ov = Lane Changing and Overtaking, Rear-E = Rear-End, Pedestr = Pedestrian).
During 1997 almost 200 more accidents occurred per month within urban areas rather than outside. In the urban environment, more accidents than average occurred from May to October, with a local minimum in July. July is also the month in which the majority of accidents outside urban areas occur. This can be explained by the fact that a large percentage of the Swedish population take their holidays in July, resulting in a lower number of road users within urban areas and a greater number on rural roads and motorways. A look at the distribution of accidents occurring within urban areas according to the days of the week also shows a different pattern when compared to accidents occurring in non-urban areas. In urban areas, the number of accidents is above average on workdays, rising marginally towards Friday. A sharp decline in the number of accidents can be noticed during weekends. For times of day, the patterns are similar for accidents occurring within and outside urban areas. The main difference lies in the larger quantity of urban accidents. Most accidents occur in the afternoon between 16:00 and 18:00. Few accidents occur during early morning hours before 6:00.

Comparing Swedish and International Urban and Non-Urban Statistics

In the 1999 summer edition of the European Transport Safety Council (ETSC) newsletter “Safety Monitor” it was stated that the fatality rates expressed in 100 million person/kilometres travelled were significantly greater for cyclists (6.3), pedestrians (7.5), and moped/motorcyclists (16) than all other modes of travel. This situation remained unchanged even when the fatality rates were expressed in terms of 100 million hours of relative exposure. The ETSC also pointed out that there is a considerable difference (by a factor of 7) between the country with the most adverse fatality rate and the country with the least number of fatalities, and recommended that priority should be given to the traffic safety problems associated with unprotected road users. The European fatality statistics suggest that car travel is ten times safer than walking (although car travel is in itself ten times less safe than bus travel).

The majority of international statistics in this report are extracted from the OECD IRTAD database. This data is presented with due consideration to the problems of under-reporting and a general lack of exposure data. Currently twenty European nations (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and United Kingdom) report data to IRTAD each year. Some of the more standard detailed data is, however, not available for some countries (most notably Greece, Luxembourg, and Portugal). Besides these European countries there are data for Canada, USA, Australia, New Zealand, Japan, and South Korea. Table 1 indicates some of the basic demographic and traffic safety data for Europe (with Sweden shown separately), and other IRTAD countries for 1997.

<table>
<thead>
<tr>
<th>Country/Continent</th>
<th>Population (x 1000)</th>
<th>Road Network (km)</th>
<th>Land Area (sqkm)</th>
<th>Motor Vehicles (x 1000)</th>
<th>Reported Accidents involving Injury</th>
<th>Reported Accidents involving Injury in Urban Areas</th>
<th>Reported Fatalities</th>
<th>Reported Fatalities in Urban Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>8 844</td>
<td>210 000</td>
<td>449 760</td>
<td>4 428</td>
<td>15 752</td>
<td>9 015</td>
<td>541</td>
<td>154</td>
</tr>
<tr>
<td>OECD Eur Average</td>
<td>20 281</td>
<td>183 568</td>
<td>194 134</td>
<td>10 767</td>
<td>72 393</td>
<td>50 015</td>
<td>2 485</td>
<td>790</td>
</tr>
<tr>
<td>OECD Eur Total</td>
<td>405 610</td>
<td>3 304 227</td>
<td>3 882 684</td>
<td>215 347</td>
<td>1 303 074</td>
<td>850 258</td>
<td>44 728</td>
<td>13 427</td>
</tr>
<tr>
<td>USA</td>
<td>267 636</td>
<td>6 346 857</td>
<td>9 363 353</td>
<td>203 568</td>
<td>2 455 118</td>
<td>1 564 411</td>
<td>41 967</td>
<td>14 864</td>
</tr>
<tr>
<td>Canada</td>
<td>30 286</td>
<td>895 562</td>
<td>9 360 527</td>
<td>17 576</td>
<td>152 765</td>
<td>107 019</td>
<td>3 064</td>
<td>1 043</td>
</tr>
<tr>
<td>Australia</td>
<td>18 532</td>
<td>810 000</td>
<td>7 686 844</td>
<td>11 238</td>
<td>--</td>
<td>--</td>
<td>1 767</td>
<td>--</td>
</tr>
<tr>
<td>New Zealand</td>
<td>3 743</td>
<td>91 864</td>
<td>269 122</td>
<td>2 393</td>
<td>9 482</td>
<td>5 944</td>
<td>540</td>
<td>146</td>
</tr>
<tr>
<td>Japan</td>
<td>126 166</td>
<td>1 152 207</td>
<td>377 837</td>
<td>75 713</td>
<td>780 399</td>
<td>566 169</td>
<td>11 254</td>
<td>5 512</td>
</tr>
<tr>
<td>South Korea</td>
<td>45 545</td>
<td>82 342</td>
<td>99 266</td>
<td>11 991</td>
<td>246 452</td>
<td>162 320</td>
<td>13 343</td>
<td>5 378</td>
</tr>
</tbody>
</table>

The statistics presented in Table 1 show that Sweden is smaller in terms of population than the average OECD European country, yet larger in terms of the land area and the size of the road network. The number of accidents involving injury and the number of fatalities (regardless of whether they occurred within or outside urban areas) are also considerably smaller than the average.
An interesting comparison can be made between OECD Europe and the USA. The population of OECD Europe is approximately one-third larger than USA and the number of motor vehicles is only 5.5 per cent higher. However, the road network in the USA is 48 per cent larger in terms of the number of kilometres, and the total number of reported accidents involving injuries is 47 per cent higher than in OECD Europe.

The total number of fatalities for the USA is only 6 per cent smaller than for the OECD European countries despite the smaller population and larger road network. The higher number of vehicles relative to the population could partly explain these differences. Before any more solid conclusions can be drawn important exposure data are required. The problem of under-reporting as previously mentioned, and the actual reporting method may also have confounding effects on the data. The rates for all accidents that resulted in injury per 10 000 population, and fatality rates per 100 000 population, for the different OECD countries and continents mentioned above are shown in Figure 5. The number of accidents that resulted in injury was not available for Australia. The average rates for the OECD European countries were calculated individually on the data that were available (some data was not available for Greece, Luxembourg, and Portugal). The data presented in Figure 5 show that Sweden (and other Scandinavian countries) has a lower fatality rate and accident rate than other OECD European and non-European countries that reported data to the IRTAD database.

![Figure 5](image_url)

Figure 5: Accident rates for all accidents that resulted in injury per 10 000 population, and fatality rates per 100 000 population, for the different OECD countries and continents.

Looking at the international statistics in relation to urban and non-urban areas it can be noticed that all of the OECD countries, with the exception of Norway, had a higher proportion of accidents involving injury occurring within urban rather than outside. Sweden (57 per cent) came a close second to Norway (47 per cent), with the OECD European average matching very closely that of USA (63 and 64 per cent respectively). Japan had the highest proportion of accidents involving injury occurring within urban areas (73 per cent). This might well be attributable to the high level of urbanisation in Japan and the resulting high proportion of urban roads.

In Sweden, 28 per cent of all road-traffic fatalities occur in urban areas. This figure is lower than the OECD European country average (33 per cent) and lower than most of the countries and continents outside Europe with the exception of New Zealand (27 per cent). Japan has the highest urban area fatality rates (49 per cent) perhaps for the same reasons as mentioned above. Within OECD Europe, Spain has the lowest recorded fatality rate in urban areas (20 per cent), closely followed by Norway (21 per cent), Austria (23 per cent), and Germany (24 per cent). Unfortunately, the IRTAD database is not so detailed concerning the exact types and involvement of different categories of road users concerning urban area accidents that involve injury and urban area fatalities.

With regard to the fact that many accidents in urban areas involve unprotected road users it is worthwhile to take a look at the available IRTAD data concerning these categories despite the fact that
the proportions of accidents involving injury and fatalities in urban and non-urban areas are not available. The data indicates that Sweden has one of the lowest overall pedestrian fatality rates per 1 million population, and also a low cyclist fatality rate per 1 million population within (but not outside) the OECD European countries (see Figure 6). Obviously the proportional number of cyclists needs to be taken into account for the different countries in order to allow statements about their relative safety.

Figure 6: Fatality rates for pedestrians and cyclists per 1 million inhabitants for the different OECD countries and continents.

A Closer Look at Accidents that Occur at Junctions in Sweden

Having identified the fact that the majority of accidents in urban areas occur at junctions it is interesting to look more closely at the nature of these accidents and the differences between existing types of junctions. Figure 7 below indicates the main differences between road-links (i.e. the roads stretching between junctions), T-junctions, crossroad junctions, roundabouts, and other categories, in relation to the different types of road users involved. Unfortunately, no urban and non-urban breakdown of the statistics is available.

Figure 7: Number of accidents on road-links and different junction types shown in accordance with the different types of road users involved.

Figure 7 shows that the majority of all single accidents occur on link roads. The accident statistics also show that accidents occurring on road-links have a higher frequency of fatalities and more serious injuries than those occurring at junctions. Of the 493 accidents involving fatality in Sweden during 1997, 329 occurred on link roads (i.e. 67 per cent), 69 at T-junctions (14 per cent), 68 at crossroad-junctions (14 per cent), and 4 at roundabouts (1 per cent). It is important to note that roundabouts are relatively uncommon in Sweden, between 3.5 and 10 times less in number than other types of crossing (Englund et.al, 1998).
Before discussing the vehicle-vehicle accidents, it is important to note that the majority of vehicle-cycle and also the vehicle-moped accidents occur at T-junctions and crossroad-junctions. A far greater number of accidents occur at these types of junctions than on link roads. For pedestrians an almost equal number of accidents occur on road-links (523) and at T-junctions and crossroad-junctions taken together (498). There is little difference between the accident and fatality rates for T-junctions and crossroad-junctions, and the data for roundabouts is not comparable on account of the relatively low number existing in the traffic infrastructure. The statistics show a larger number of vehicle-vehicle accidents occurring at T-junctions and crossroad-junctions taken together (3 436) in comparison with the number of accidents on road-links (2 216). It is interesting to examine the vehicle-vehicle accidents in relation to the different categories of accidents that occur (see Figure 8).

Figure 8: Number of accidents on road-links and different junction types shown in accordance with the different types of vehicle-vehicle accidents (Overt/L Ch = Overtaking and Lane Changing).

Figure 8 shows that very few ‘overtaking and lane changing’ accidents and very few ‘meeting’ accidents occur at junctions (these are more likely to fall into the ‘crossing’ and ‘turning’ categories when they occur at junctions). It can also be noticed that a similar number of ‘rear-end’ accidents occur at T-junctions and crossroad-junctions, but these are far exceeded by the quantity occurring on road-links (this may reflect the way these accidents are coded with regard to distance in relation to a junction). Differences can be noticed at T-junctions and crossroad-junctions regarding the number of ‘turning’ and ‘crossing’ accidents. ‘Turning’ accidents occur with much greater frequency at T-junctions (690) than at crossroad-junctions (381), whereas ‘crossing’ accidents are more likely to occur at crossroad-junctions (1030) than at T-junctions (481). These statistics reflect differences in the frequencies of ‘turning’ and ‘crossing’ manoeuvres and possible conflict situations that occur at these two sites. These findings concur with those of the Swedish researcher Brüde (1991) who points out that more than half of the accidents in urban areas occur at junctions. He also states that 4-legged junctions are 1.5 to 2 times more accident-prone than 3-legged junctions, and consequently that redesigning 4-legged to three-legged junctions can enhance safety.
3. THE MAIN CAUSES OF ACCIDENTS IN URBAN AREAS

In the majority of traffic accidents, urban or otherwise, the cause cannot usually be traced to a single factor but rather to a combination of circumstances in a chain of events that are best described by the interactions between: a) the road user, b) the vehicle, and c) the roadway and prevailing environment. Any attempts to explain and improve traffic safety in urban areas must ideally adopt a “systems approach” in order to consider the contributions and interactions of all important factors, and to capture the dynamics and complexity of the traffic system (Hydén, 1994; Leveson, 1995).

The concept of traffic safety can ultimately be regarded as an emergent property of the actions and interactions of the main elements of the traffic system. This suggests that any systems analysis aimed at examining existing traffic safety problems must be performed at an appropriate contextual level in order to gain appropriate knowledge and insight into the existing complexities and dynamics of the system and its constituent elements at a given time. However, even if a systems approach is adopted, the subject of how and why accidents in urban areas actually occur presents a number of problems for researchers.

The main difficulties appear to lie in establishing the exact chain of events leading up to the accident. This information is of some relevance to the police authorities and insurance companies for the purposes of determining responsibility, but is often neglected with regard to important details that might provide a more in-depth systematic description of what actually occurred. Often, post crash interviews are susceptible to distortion as a result of trauma or fear of the consequences of being assigned responsibility. Describing the conditions leading up to an accident is also made more difficult as they are often not monitored consciously by the driver who is often performing skills in what is best described as “automated” mode (Wickens, 1992).

In the remainder of this section three important and relevant studies from different countries, which focus specifically on the reasons behind urban accidents, are described and discussed, and related to the traffic safety problem in urban areas in Sweden.

The English Study

One of the most comprehensive and most interesting studies in relation to the causes of urban area accidents was carried out in the Leeds area in England at the end of the 1980’s (Carsten, Tight, Southwell & Plows, 1989). During a one year period, Carsten and colleagues investigated 1,254 injury accidents reported to five different police sub-divisions that involved 2,454 participants (1,863 drivers, 463 pedestrians, and 128 cyclists) that occurred in the Leeds area on roads that had a speed limit of 40 mph (approx. 60 km/h) or less. The accident data showed that 2 per cent of the accidents involved fatalities, and as many as 20 per cent involved serious injury. Nearly 70 per cent of all accidents occurred at junctions, and of these junctions 12 per cent were controlled by traffic-lights or stop signs, and 72 per cent by give-way signs, the remaining 16 per cent were uncontrolled. Besides the official police accident reports, questionnaires were administered by interview or post, and a visit was made to the accident site prior to a case conference that was convened to determine and classify the circumstances surrounding the accident.

An innovative method for describing accident causation was adopted in which four different levels could be combined in accordance with a multi-level coding scheme comprised of 150 different items in order to form what was described as a “chain of factors” approach. According to Carsten and colleagues (1989) a contributory factor behind an accident could be defined as “a road user or traffic systems failure without which the accident would not have happened”, the immediate failure that precipitated the accident. The results of this study indicated that, of the first level factors (i.e. immediate failures that precipitated an accident), ‘unable to anticipate’ accounted for 29 per cent, ‘failure to yield’ for 16 per cent, and ‘failure to anticipate’ 10 per cent of the factors coded. ‘Unable to anticipate’ implies that the road user in question had the right of way, and a “reasonable road user” would also have been unable to anticipate the faulty behaviour of the other person, while ‘failure to yield’ implies that a “reasonable road user” would have perceived the upcoming danger earlier. Results also show that as many as 44 per cent of drivers were “innocent victims of others’ mistakes”. Failure to yield was also a factor for adult and child pedestrians (66 and 78 per cent, respectively).
At the second level (i.e. failure that increased the likelihood of an accident), findings suggested that 62 per cent of the factors determined were situational problems. For the drivers the most important factors were ‘driving too fast for the situation’ (29 per cent) and ‘following too close’ (8 per cent). On the third level (i.e. road user behaviour or lack of skill that led to failure) different road user skills are considered. It is found that especially pedestrians, and mostly children, “fail to look”, while the main problem of motor vehicle drivers usually is the misinterpretation of other road users’ intentions. Both groups also show “lack of judgement”, which includes a wrong estimation of the speed or the path of other road users. The most common problem on the fourth level (i.e. the explanation for the failure or behaviour) for drivers is their view being obstructed by something, either inside the car or outside. “Impairment”, which mainly means the influence of alcohol, is much more common among adult pedestrians than among drivers.

Some other points of interest to emerge from this study concerned the fact that 75 per cent of all accidents occurred within the first 5 kilometres of travel, and also that 93 per cent of the respondents had knowledge of the road where the accident occurred. Also, it is noteworthy that as many as 16 per cent of all pedestrians involved in accidents admitted consuming alcohol within a three hour period prior to the accident, compared to 4.5 percent of drivers. Some important differences were also found regarding different age groups, more specifically, the problems of younger drivers (most notably males) such as driving too fast for the situation differ from those of elderly drivers associated with deteriorating perceptual and cognitive abilities with increasing age.

Perhaps one of the most important points concerns the fact that almost 50 per cent of the second most common level 1 factor, ‘failure to yield’, could be explained by lower level perceptual and cognitive factors (e.g. ‘failure to look’ and ‘failure to see’). On the basis of the important knowledge gained from their study, the authors were able to make a number of recommendations concerning road user issues for drivers (and riders), and pedestrians, and suggests ways in which traffic management and engineering issues might be brought to bear on traffic safety problems along with counter measures that involve improvements in publicity, education, and training.

The French Study

Another major study which looked at some of the reasons behind accidents in urban areas, and the differences between these accidents and those occurring outside urban areas, was conducted by the French traffic researchers Malaterre and Fontaine (1993). This investigation was primarily aimed at identifying the safety needs of drivers, and the possibility of satisfying these needs by using the different Intelligent Transport Systems (ITS) functions suggested in the European PROMETHEUS programme. The authors identified 17 different basic needs in relation to the driving task: “For each user the accident could have been avoided, if the need had been satisfied”. 3179 accidents involving 6049 road users were examined according to these needs. For approximately 20 % of the road users no needs were identified – they are considered the passive victims of the accident. The needs were grouped into the road user skills of: “control”, “prediction”, “estimates”, “detection”, and “status”.

The results of this study show an overriding need for detection in urban areas (mainly at junctions), followed by the need for prediction (i.e. predicting the manoeuvre of a road user who has already been detected). Detection problems were advocated in 61 per cent of the accidents analysed, and within this particular grouping of identified needs ‘transversal detection’ problems (i.e. detecting the approach of another road user on an intersecting lane at a junction, or similarly for a pedestrian, detecting the approach of a vehicle on the roadway he/she is preparing to cross) occurred most frequently (19 per cent of all accidents).

Outside urban areas detection problems were still predominant over the other types of identified needs (45 per cent of all accidents). However, the second most important need was identified as status-related diagnostic needs (i.e. mainly driver-related problems in relation to alcohol or fatigue, and space-time assessment needs) rather than prediction needs which were found to be somewhat less important in non-urban areas. The authors suggest that a large number of junction-related accidents in urban areas (i.e. meeting and turning accidents) could be avoided by the introduction of suitable Intelligent Transportation systems (ITS) which support driver needs such as ‘critical course determination’, ‘obstacle detection’, ‘vision enhancement’, and ‘safety margin determination’.
The American Study

The North American researchers Retting, Williams, Preusser, and Weinstein (1995) have conducted another major study focusing specifically on traffic safety problems in urban areas. According to the authors, efforts to reduce the number and severity of accidents have been seriously inhibited by a general lack of important information with regard to the specific types of accidents that predominate in urban areas. The primary purpose of their study was to develop a classification system based on pre-accident driver/vehicle behaviour in order that planners and policy makers could develop suitable countermeasures aimed at reducing the most prevalent types of urban accidents. The investigation conducted by Retting and colleagues was based on police reported accident data from three cities and one urban county, each from different states. The data were collected between August 1990 and July 1991 and included records from 4 526 accidents, many of these included property damage only in contrast to European police accident reporting.

The results of this study show that 56 per cent of all accidents occurred at intersections, and only 31 per cent of accidents resulted in injury. Pedestrian and cycle accidents were not included in the accident statistics, although it is reported that these would otherwise have accounted for 5 and 3 per cent of the total number of accidents, respectively. Five of the thirteen different types of accidents accounted for 76 per cent of the total number that occurred in the four urban areas, these included: ‘ran traffic control’ (i.e. a situation where a vehicle that is required to stop, remain stopped, or yield disregards the requirement and collides with some other vehicle) with 22 per cent, ‘stopped or stopping’ (i.e. a situation where a vehicle that has stopped, or is stopping or just starting up in a travel lane is hit from the rear) with 18 per cent, ‘ran-off road’ (i.e. a situation where a vehicle leaves the travel lane(s) striking an object such as a parked cars) with 14 per cent, ‘lane-change’ (i.e. a situation where a vehicle in a travel lane swerves or moves into another in the same direction that is already occupied) with 13 per cent, and ‘left-turn oncoming’ (i.e. a situation where a vehicle in the process of making a left turn in front of oncoming traffic is struck by or strikes a vehicle which is both coming from the opposite direction and which has a superior right of way) with 9 per cent.

These five accident types also accounted for 83 per cent of the total number of accidents involving injury. The rank order among these five accident types differed between areas. Also, the ‘ran traffic control’ and ‘left-turn oncoming’ accidents occurred most frequently at intersections. A closer look at the ‘ran traffic control’ category showed that 41 per cent of the intersections where the accidents occurred were controlled by stop signs, and that 31 per cent were controlled by traffic lights. It was also noticed that the ‘left-turn oncoming’ accidents generally occurred in the presence of traffic lights and were most often the result of a failure to yield to a right-of-way. The ‘stopped or stopping’ accidents, involving mostly rear-end collisions, were found to be the result of inattention.

It was proposed that the most common types of accidents, described as ‘ran traffic control’, could be resolved by better signal timing, the increased visibility of signals and signs, reduced speeds near intersections, red-light cameras, or redesigning the intersection in terms of traffic signals and signs. It is also recognised by the authors that different intersections are likely to have different accident type distributions depending on (e.g. road geometry, population density, traffic density, methods of traffic control, and police enforcement strategies). Similarly, ‘stopped or stopping’ accidents might be reduced by better signal timing and reducing the number of stops. The ‘ran-off road’ category of accidents might be reduced by better roadway design including the use of one-way systems, better lane delineation, and better lighting. Suggestions are also made regarding other possible solutions including changes in roadway design to reduce the possibility for conflict between different road users.

Comparison of the Swedish, American, English and French Data

It is problematic to compare the four different countries directly because of the many differences in data collection methods, the grouping and inclusion of different road-users, and the many differences in the traffic systems. The most important differences that are noted include the fact that the French study does not consistently distinguish between accidents in rural and in urban areas, and the fact that the American data also includes property damage accidents and excludes other important accident types (e.g. accidents with unprotected road users). Also, both the English and the French study give only sparse information as to the accident location.
One of the main conclusions that can be drawn concerns the fact that urban area junctions are accident-prone. In the USA 56 per cent of the accidents occurred at junctions, for England this number lies at 70 per cent, and in Sweden at least 46 per cent of the accidents that involve only motor vehicles occurred at junctions. This figure is probably larger, because it is likely that part of the rear-end accidents (21 per cent of all urban motor vehicle accidents in Sweden) also occurred at junctions. In the English study it is stated that the majority of accidents for drivers occur as a result of an inability to anticipate, a failure to yield or a failure to anticipate (29, 16 and 10 per cent of all accidents respectively), the Swedish data suggests that 13 per cent of all urban area accidents are crossing accidents between two vehicles (i.e. suggesting a failure to yield or to anticipate), and also that 8 per cent of all urban area accidents are turning accidents (i.e. suggesting an inability or a failure to anticipate). Also of importance in this comparison is the finding that 50 per cent of the accidents resulting from a failure to yield (which is the second most common form of accident) were attributed to perceptual factors for all road-user categories and a further 14 per cent to cognitive factors. The Swedish traffic researcher Brüde (1993) arrives at nearly the same figure – he suggests that 61 per cent of all urban area accidents are attributable to detection related (i.e. perception and cognition) failures.

A more detailed comparison can be made for certain types of accidents in Sweden and in the USA. It has to be kept in mind, though, that the Swedish data does not include damage only accidents, and there is no information given if damage only accidents in the US show a different pattern of occurrence than injury accidents. Only accidents in urban areas that involve motor vehicles are considered. The percentages with which different accident types occur are quite similar in Swedish and American urban areas. The most common type in the US is ‘ran traffic control’ with 22 per cent, which might be matched against crossing accidents in the Swedish data (26 per cent). Rear-end accidents make up 18 per cent in the US and 16 per cent in Sweden, single accidents in the US account for 14 per cent, but for 22 per cent in Sweden. The next common category in the US is lane-changing accidents with 13 per cent, which (including overtaking) account for only 3 per cent in Sweden. ‘Left turn oncoming’ accidents in the US make up 9 per cent of the urban accidents, while the figure for Sweden lies at 12 per cent, ‘left turn waiting’ accidents make up 3 per cent in both countries. It can be seen that the distribution of accident types is quite similar for both countries, with the exception of single accidents and lane changing accidents. This last difference might be due to the fact that roads with more than one lane in each direction are much more common in American urban areas than in Swedish cities, which makes the occurrence of lane changes more likely in the US.
4. SAFETY ENHANCEMENT MEASURES IN THE TRAFFIC SYSTEM

Road accidents are the result of a potentially large number of causal factors that exert their influence at approximately the same location and time. In order to be able to propose, evaluate, and compare safety enhancement measures within the context of the traffic system, a suitable model is required. There are a number of models that can be applied for road safety management in order to describe the safety situation at a national or communal level. While many models tend to focus on the events surrounding the accident occurrence, or human error mechanisms, one of the more useful and more comprehensive models that is recognised internationally focuses on three dimensions related to: exposure in traffic; the risk of an accident given the exposure; and the consequences (i.e. severity) of accidents (see e.g. Thulin & Nilsson, 1994; Rumar, 1996; and OECD, 1997). Other models also aim at predictability or effectiveness evaluation, perhaps using econometric modelling. There are also models that exist at the micro-level in order to describe safety problems at an individual level. These models are usually associated with the evaluation of subjective risk and are predisposed to problems associated with the fact that accidents are random and essentially unpredictable at the micro-level, requiring the use of other less valid proxy measures or safety indicators. Many of these micro-models are not comprehensive enough to be of any great value in assessing risk within a systems context. Researchers in the field usually advocate a multi-disciplinary approach, although presently there are no known models that can bridge the macro-micro gap (see OECD, 1997 for a more complete description of different models).

The three dimensions suggested in above model are adopted for a description of the more traditional approaches taken when dealing with the traffic safety problem. Emphasis is given to urban area safety although many countermeasures may also have value in other areas. One of the advantages of this model is that it can be applied to the three primary elements of the traffic system (i.e. road users, vehicles, and the roadway environment), in order to form a 3 by 3 classification matrix for the many different traffic safety countermeasures (see Table 2 below).

Table 2: Classification matrix for different types of traffic safety countermeasures related to the three main elements of the traffic system.

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Accident Risk</th>
<th>Accident Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road-User</td>
<td>Vehicle</td>
<td>Roadway</td>
</tr>
<tr>
<td>E.g. improvements in attractiveness of alternative (safer) modes of transport to relieve congestion and reduce travel time, etc.</td>
<td>E.g. better use of other safer forms of (public) transport, ITS-functions which aid driver perception and decision-making, better driver training, etc.</td>
<td>E.g. better use of in-vehicle injury prevention devices such as seat belts, better use of protective clothing by unprotected road users, etc.</td>
</tr>
<tr>
<td>E.g. more effective use of road-system through route-guidance, increases in parking costs, annual vehicle/road taxation, fuel taxation, etc.</td>
<td>E.g. use of improved technology to provide better handling, ABS brakes, high-mounted brake lights, better man-machine, interface, warning systems, etc.</td>
<td>E.g. better vehicle design and use of materials that can absorb energy on impact, provision of injury prevention devices such as air-bags, etc.</td>
</tr>
<tr>
<td>E.g. better infrastructure design, differential toll-systems, improved traffic management strategies for better flow and capacity etc.</td>
<td>E.g. improvements in roadway design, better visibility and lighting, separation of different types of road users to reduce possibility for conflicts etc.</td>
<td>E.g. Greater speed restrictions, Limited access to urban roads, Removal of dangerous roadside objects, etc.</td>
</tr>
</tbody>
</table>

Safety Improvements Aimed at Individual Road Users

For the different categories of road users, changing levels of exposure is very rarely stated as a primary goal for the purposes of improving the traffic safety situation. This may be related to the fact that accurate exposure data are very difficult to collect and are rarely presented in conjunction with accident statistics, thereby making exposure related improvements difficult to measure. There are also problems associated with making comparisons between different modes of transport owing to the fact that exposure can be measured in terms of travel time or travel distance. In Sweden travel habit surveys that focus of establishing reliable exposure data have been performed on several occasions, and related to accident data (e.g. Thulin & Nilsson, 1994).
Factors, which tend to reduce road user exposure in general, are usually associated with the attractiveness of alternative modes of transportation. For example, reductions in the use of private vehicles in favour of public transportation (e.g. buses and commuter trains) usually occur as a result of more competitive pricing combined with good levels of service, where the change of one transportation mode to another can also result in lower levels of congestion and a reduced exposure level in the traffic system in general. Careful regional planning is required to find a balance in the system that reflects the demands of the users in relation to the different forms of transportation and their perceived costs and benefits (i.e. attractiveness), and the effects that such changes might have for the community at large. Another important factor regarding changes in modes of transportation is that many forms of public transport are safer by comparison than the use of private vehicles, and cycling and walking, thereby reducing not only exposure but also accident risk (ETSC, 1999a).

Safety countermeasures that reduce the accident risk for road users are now commonly provided by the many different in-vehicle systems that enhance perceptual abilities and aid cognitive decision-making (see e.g. Malaterre & Fontaine, 1993; ETSC, 1999b). Many of these types of systems that have to do with the way information from the environment is interpreted, manipulated and acted upon, are discussed in the following chapter concerning Intelligent Transportation Systems (ITS). The quality of driver education training is also an important factor, and has resulted in a number of new approaches such as ‘graduated licensing’, which is built upon the concept that driving tasks become gradually more difficult and unrestricted. Generally, the majority of systems include three levels of tests, an initial provisional license, a preliminary licence, and a full licence (Englund et al., 1998). This form of graduated licensing has been shown to have a number of beneficial effects including a reduced risk for accident involvement (Smith, 1994). Inverted licensing, which encourages drivers to understand and accept responsibility for their actions has also been suggested (Klyve, 1998). Attempts to reduce accident risk through public safety campaigns and education programmes (e.g. for school children) have often had a limited long-term effect on traffic safety (see e.g. OECD, 1986; Järmara, 1992; Linderoth & Gregersen; 1994; Englund, Nyberg & Thiseus, 1997).

Attempts to reduce accident severity for road users, particularly drivers and passengers of motor vehicles, has been the subject of a great deal of research by different vehicle manufacturers, particularly those who use the safety concept as an argument for marketing campaigns. The actual road user injury protection that has been developed as a result of large investments in in-vehicle design and research is discussed below in relation to vehicle engineering. For the safety of drivers and their passengers, the most important factor often concerns the use of injury protection measures rather than their provision. This is especially important with regard to the fact that many drivers consider themselves better than the average (Svenson, 1981; Williams, Peak & Lund, 1995). In many European countries, seat-belt use is relatively low resulting in an unnecessary number of fatalities and serious injuries. Many also fail to realise that the effectiveness of air bags is dependent on the use of seat belts (ETSC, 1999b). For unprotected road users the risk for (and consequences of) an accident can be reduced by ensuring easy detection by other road users through the use of suitably coloured clothing, reflexes, and cycle lights (OECD, 1998).

Safety Improvements Through Vehicle Engineering

Vehicle engineering has come a long way during the past century, a fact that is reflected by the relatively small number of accidents that are directly attributable to vehicle failure. Modern vehicles undergo rigorous testing in order to ensure stability and handling, adequate steering characteristics and braking capacity, a high level of driver visibility, warning and control systems, low levels of maintenance, and most importantly a high level of injury protection. A vast number of improvements have been made in most of these areas in modern vehicles, and international and national legislation exists to ensure that safety standards are upheld to a minimum level (see e.g. Evans, 1991; Englund, et al., 1998, Neilsen & Condon, 1998). Reducing levels of vehicle exposure (i.e. the use and need of vehicles) is contrary to the interests of vehicle manufacturers. However, new technology in the form of navigation and dynamic route-guidance systems is now largely recognised as an important in-vehicle attribute, where the main aim is to find destinations easily while avoiding congested areas, thereby also reducing exposure. Levels of exposure can also be affected (both negatively and positively) through changes in vehicle/road taxation and fuel taxation, although this is not their primary intention.
Accident risk has also been reduced as result of the introduction of devices such as high-mounted brake lights, daytime running lights, anti-locking braking systems (ABS), and more advanced Intelligent Transportation Systems (ITS) that involve driver monitoring and support in perception and decision-making tasks. Vehicle safety trends combined with the safety awareness of the public and recognised international safety standards has resulted in significantly improved safety even in smaller vehicles. Injury protection (i.e. the reduction of accident severity) has one of the major concerns for many leading car manufacturers. This has resulted in improved protection for vehicle impact with a better internal structure to reduce injury, the provision of air-bags to complement safety-belt use, and the provision of child-seat straps (Englund et.al. 1998). One of the more interesting developments within European Union concerns provision for the protection of pedestrians and cyclists in the event of being struck by the front-end of vehicles (Neilson & Condon, 1998).

Safety Improvements Through Traffic Engineering

Traffic engineering focuses specifically on research and design developments in relation to the roadway in order to increase existing levels of traffic safety for all categories of road users. Different countermeasures to specifically reduce exposure are relatively uncommon although the dynamic traffic management and control systems that exist in the cities of some countries attempt to optimise traffic flow and increase capacity, thereby reducing exposure in terms of travel time (see e.g. OECD, 1990; Maher, Hughes, Smith & Ghali, 1993). The use of toll-systems to reduce exposure in the traffic network has also been recognised as a result of new technology, which greatly simplifies the methods of payment and collection with a minimum of inconvenience. These systems can, for example, be used control the flow and capacity of traffic into major urban areas at specific times and on particular days. Toll-systems designed specifically for what has been termed ‘urban road pricing’ are presently receiving a great deal of attention throughout the world (CEC, 1998).

Making improvements in the design of the roadway to reduce the risk of accident involvement is a common and widely recognised approach to improving traffic safety in traffic engineering. Typical solutions in many countries, including Sweden, involve policies of road user separation and differentiation (Englund et.al., 1998). Traffic engineering solutions aimed at safety improvement often focus on redesigning the roadway to meet the needs of the many different road users and prevailing levels of traffic. In many countries, the road authorities have developed special rules, which can be used for the purposes of determining a roadway design for a particular site. The Swedish National Road Authority maintains a capacity calculation manual and computer program (“CAPCAL”) which is used to determine the best traffic engineering solution given the traffic flow and other environmental conditions. Another expert computer program also exists to aid traffic engineers in the design of the roadway in smaller towns and communities in Sweden (the “Klots” system developed by the Swedish National Road and Transport Research Institute).

There are still relatively few theories and models that take into consideration both behavioural and engineering aspects in relation to roadway design. Towliat (1997) has formulated a number of fundamental principles based specifically on road user behaviour and knowledge concerning the effects of different safety countermeasures applicable to urban areas in Sweden. The main principles include: the correct adjustment to prevailing speed limits, no implicit yielding, sufficiently unrestricted vision, simplicity and clarity, and the integration of unprotected and protected road users. A national traffic safety program has also been introduced in Sweden, aimed at developing a safer traffic environment in urban areas. The reform program has been developed jointly by the police authorities, the Swedish National Road Authority, and community representatives as part of the “vision-zero” strategy mentioned earlier, in order to clarify, initiate, and stimulate more effective traffic safety countermeasures at general and detailed levels in urban areas (Englund et.al., 1998).

In Sweden, as in most countries, the majority of accidents in urban areas occur at junctions, where there is a relatively high level of exposure for many different types of road user. The most common principle used to ensure safe passage through a junction is that it should be simple and unambiguous. This can be achieved through, for example, the use of different types of traffic regulation, dividing vehicle flow into turning and non-turning, separating vehicle flows, changing four-way junctions into two three-way junctions, changing three-way or four-way junctions into roundabouts, improving visibility, changing the angle of adjoining roads in three-way junctions, and other design details.
Careful consideration must also be given to the needs of cyclists and pedestrians at junctions and roundabouts, and the design characteristics and placing of crossings. The use of low speeds is generally not designated in Sweden as a primary principle to ensure safe passage through a junction. However, speed reduction is achieved to some extent through the deployment of physical measures, such as speed-dips or humps, raised pedestrian crossings, and more commonly through different types of regulation involving the use of stop-signs, give-way signs, and traffic lights. Many design changes can reduce the number of accidents involving personal injury significantly. The use of roundabouts instead of three-way or four-way junctions are, for example, estimated to reduce the number of accidents involving personal injury by between 30 and 40 per cent (Englund et al., 1998). Other more simple solutions, such as road narrowings and painted cycle lanes have also been estimated to have great effects on reducing safety risks (Thulin & Obrenovic, 1999).

From a roadway and traffic engineering perspective, methods of reducing the severity of accidents in terms of injuries and fatalities largely involve the introduction of different measures which are intended to control the speed of vehicles, and making the roadway environment more ‘forgiving’ through careful consideration to the type of equipment placed at the roadside (Englund et al., 1998). The relationship between speed (including differential speed), accident risk, and severity has received a great deal of attention in traffic safety research (e.g. Salusjärvi, 1981). The problem of speeding in relation to accident severity is a particular problem in urban areas owing to the greater numbers of different road user categories and therefore the higher probability for conflicts between protected and unprotected road users.

A study by Spolander, Laurell, Nilsson, and Pettersson (1979) identified a large number of factors which were believed to influence the drivers choice of speed in a given traffic situation including amongst others: weather and visibility, time of day, subjective risk assessment, risk of being caught and punished for speeding, evaluation of costs associated with travel, desired level of comfort, and personal characteristics such as experience and desired speed. Exactly which of these variables are applicable for a particular person and situation are difficult to establish in a general model of driver behaviour. However, research has shown that vehicle characteristics, roadway geometry and quality, prevailing roadway conditions, and posted speed limits do have a significant influence on the choice of speed (Haglund and Åberg, 1990).

For the traffic engineer, there are a variety of different ways that speed can be influenced by roadway design. Wider roads and additional lanes are known to encourage higher speed (e.g. Fildes, Rumbold, & Leening, 1991), and speed bumps and other physical measures can be used in city centres and residential areas to reduce speed (e.g. OECD, 1998). It has been found that simply posting reduced speed limits, e.g. from 50 km/h to 30 km/h, in urban areas often does not have the intended effect unless it is combined with information campaigns and police monitoring (Wernsperger & Sammer 1995). The urban study by Wernsperger and Sammer showed a significant reduction in the number of serious injuries (24 per cent) mostly for pedestrians, and a large reduction in the number of accidents occurring at crossroad junctions (27 per cent) as a result of the reduction to 30 km/h.

The technical design of the traffic system requires knowledge from many disciplines including behavioural science. It is important to be able to predict to some extent the effect that changes in the roadway environment will have on road users in terms of safety. In Sweden it has been found that increasing the width of road lanes which should make overtaking manoeuvres safer, not only increases speed but also increases the number of single vehicle accidents. Thus, although many other types of accidents, for example rear-end, turning, and crossing accidents are reduced, the net safety gain can be much smaller than anticipated (Englund et al., 1998). Other behavioural adaptation problems that reduce the net safety gain of traffic safety countermeasures have also been identified in relation to the vehicle and emphasise the need for multi-disciplinary research based on sound theories and models which take into consideration all of the main elements of the dynamic and complex traffic system and the way in which these elements interact with one another.
5. INTELLIGENT TRANSPORT SYSTEMS IN URBAN AREAS

The use of “Intelligent Transport Systems” (ITS) can be traced back to the 1950’s, when the first serious attempts were made by private and public enterprises to implement route-guidance systems in the United States. However, the real explosion of ITS research and development did not occur until the early 1980’s when ITS became a technologically and economically viable prospect. Since the 1980’s there has been an overwhelming amount of research and development devoted specifically to ITS, particularly in Europe and Japan. ITS is no longer concerned with only in-vehicle systems, but also various other systems placed, for example on the roadside where they form part of a complex traffic control system. Essentially, “ITS” is an umbrella-term that incorporates virtually any system within the field of transportation that utilises the latest developments from information technology, computer science, telecommunications, and systems control.

A closer scrutiny of ITS applications commonly reveals an integration of research from many scientific disciplines (e.g. artificial intelligence, human factors, traffic engineering, etc.) that together have the capacity to provide many solutions to existing traffic safety problems. ITS is expected to have an highly beneficial impact in most countries throughout the world by:

- increasing the overall efficiency of the traffic system - the impact of ITS on efficiency can be noticed through, for example, improvements in capacity, accessibility, and customer service, etc.
- improving traffic safety – the impact of ITS on traffic safety can be identified primarily through changes in risk-levels and the severity (or outcomes) of accidents.
- making significant contributions to environmental quality and energy savings – the impact of ITS on environmental quality can be seen, for example, by reductions in emission rates, noise levels, and levels of pollution in the ground and air. Energy savings are reflected by reduced consumption rates.
- increasing the productivity of transport systems – the impact of ITS on productivity can be measured economically in terms of, for example, operational costs, and also by other measures such as, for example, travel time delays.

In order to achieve the full potential of ITS, a careful systematic approach is required in the design and planning, development, and implementation, which addresses the problems of user needs and benefits, system architecture and integration issues, and various institutional and political barriers, while at the same time giving due attention to other national and international medium and long-term objectives related to such issues as land use and regional planning, infrastructure design, transportation system management, and many other important areas that are directly or indirectly influenced as a result of ITS implementation. The great potential offered by technologically and economically viable ITS was quickly recognised as an efficient way to resolve many simple and complex transportation problems. Recent expectations in relation to this potential have suggested, for example, that ITS will lead to a 50 per cent reduction in road fatalities; a 25 per cent reduction in travel time; a 50 per cent reduction in traffic delays; and a 50 per cent reduction in city pollution (ERTICO, 1997).

Currently, there are countless projects and activities in progress at the international and national level that are related specifically to ITS and traffic safety both within Europe (including a number of significant projects initiated by the European Commission), and throughout the rest of the world. These involve, amongst others, PIARC (The World Road Association), ISO (International Standards Organisation), ESV (Enhanced Safety of Vehicles an organisation for automobile manufacturing countries), OECD (Organisation for Economic Co-operation and Development). Given the extent of the world market for ITS, and the probability that market forces will continue to be the main driving force behind ITS, there are important issues regarding consumer acceptance and the cost effectiveness of ITS introduction which must be given consideration in the near future. Most probably, some of the safety potential of vehicle-related ITS will only be realised through compulsory introduction by vehicle manufacturers and usage by road users, in accordance with international standards, guidelines, and legislation (ETSC, 1999).
**ITS User-Services and Areas of Application**

New areas of ITS application have regularly emerged during the relatively short history of ITS, and a large number of different comprehensive classification systems have been proposed by different organisations in different parts of the world. More recently ERTICO adopted the “ITS user services” and application area “bundles”, that originated from the United States (ITS America) and Japan (VERTIS). The concept of ITS user services has now been recognised by the International Standards Organisation (ISO) and is now largely accepted over the world as a *de facto* standard for classifying the many different existing ITS applications. ISO’s classification covers 8 application areas and presently around 33 different technologically independent user services (ETSC, 1999). The ISO classification is adopted in this report and presented subsequently in Table 3 in relation to safety issues and the intended area of use (see e.g. PIARC, 1999, ERTICO, 1999; for a more detailed description of the application areas and user services that are available).

Table 3: Classification of ITS applications in accordance with ISO together with their impact in accordance with the three safety dimensions (i.e. exposure, risk, and severity), and their intended area of use (i.e. urban or non-urban).

<table>
<thead>
<tr>
<th>Application Areas and User Services</th>
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ITS and Traffic Safety

In the descriptive model that is often adopted to describe the prevailing national traffic safety situation, ITS-applications can be seen to have the potential to influence each of the main three safety dimensions (i.e. exposure, risk and severity) suggested by the OECD (1997) and be of significant use in both urban and non-urban areas. In the following section the potential of ITS is discussed in relation to each of these three safety related dimensions.

The Exposure Dimension and ITS

A reduction in exposure is often considered to be an environmental objective rather than one, which is directly related to road user safety. Reducing the need or demand for transport generally reduces exposure. In terms of ITS, this can be achieved through two primary methods: access control which allows only authorised vehicles to enter restricted areas, and electronic road pricing schemes (i.e. toll-systems) based on distance and/or time. Many of the exposure reducing ITS functions are sanctioned for use in urban-areas. In particular, the use of advanced traveller information, which includes on-trip information to drivers, and users of public transport and route-guidance systems, is believed to have great potential for the future. This type of information has the capability to bring about modal shifts from private vehicles toward other safer forms of transport (i.e. buses and commuter trains), and to reduce travel time in general. Other applications that make public transport more attractive to car drivers include priority schemes for public transport, park-and-ride schemes, and other general operational improvements.

Travel planning and route-guidance and navigation systems (including Variable Message Signs) also have the potential to optimise (i.e. reduce) individual travel time and/or distance and also relieve performance reducing stress to some extent. However, the exact effects that some of these in-vehicle systems have on driver behaviour are not fully understood, and the redirection of vehicles through other less congested areas may not always be desirable (ETSC, 1999). Exposure can also be reduced with a significant safety effect by preventing unauthorised or unqualified drivers from using vehicles. This may be achieved through, for example, the use of electronic driving licences and the use of the “alcho-lock” system. Both of these systems have been tested in Sweden with some success, and are considered promising for the future at an international level (Myhrberg, 1997).

The Accident Risk Dimension and ITS

There are a number of ITS applications that have been developed with a view to reducing crash risk. The majority of such applications are in-vehicle systems that assist the driver by providing useful and timely information. These types of systems are often of equal value both within and outside urban areas. The type of information that is usually conveyed refers to the status of the vehicle, the driver, or the roadway situation, when potential hazards are detected in order to avoid an imminent collision. Some of the more advanced systems intervene and assume control over a vehicle if the crash risk is estimated to be too great and beyond the limitations of the human driver.

A number of accident risk reducing ITS applications do exist that are predominantly outside the vehicle. Variable Message Signs (VMS) is one example which is often used to regulate and optimise traffic flow with the added safety impact of achieving better vehicle separation, and therefore a reduced risk of accident occurrence. Harmonised flows have also been found to prevent vehicle pedestrian accidents owing to the lack of opportunity to cross roads at places other than pedestrian crossings (ETSC, 1999).

The ITS applications that fall into this category and which have undergone considerable research and development during more recent years include the following: speed adaptation systems, collision avoidance systems, weather information systems, vision enhancement systems, lane-keeping systems, driver and vehicle monitoring systems, policing and tutoring systems, incident management systems, systems that enable flow control, and urban traffic control systems. The ETSC (1999) report suggests that the ITS applications with the greatest potential for improving the traffic safety situation in urban areas are: collision avoidance systems, Intelligent Speed Adaptation, and urban traffic control. Together, it is estimated that the full implementation of these systems could bring about a 30 per cent reduction in the number of injuries.
ITS and the Severity/Accident Consequence Dimension

Injury reduction has been extremely successful in the past largely as a result of the introduction of international standards, recommendations, and legislation that has made the use of in-vehicle seat-belts and air-bags, and motorcycle and cycle helmets obligatory and thereafter changed peoples attitudes. Passive safety measures such as these are usually not prone to any behavioural adaptation which tends to reduce net safety gains (OECD, 1990). However, it has been pointed out there are a number of other important non-passive approaches through which injury reduction can be achieved through the use of ITS, namely: changes in speed and course to avoid an inevitable crash, changes in vehicle and roadway design and construction for both vehicle occupants and unprotected road-users, and provision of emergency notification systems (ETSC, 1999).

ITS can be used to some advantage in the provision of effective warning and interlocking systems that ensure the usage of in-vehicle protection equipment. It is also possible that protection systems can be made more effective by taking into consideration vehicle occupants’ height and weight dimensions. Emergency notification systems can also benefit from ITS technology. The time between the accident occurrence and application of medical treatment is critical for the outcome of accidents involving injury, therefore common emergency telephone numbers and GPS assisted manual or automatic emergency notification systems can greatly improve the efficiency of rescue services (ETSC, 1999).

ITS and Unprotected Road Users

There are very few ITS applications that focus specifically on the safety needs of unprotected road users in order to reduce exposure, accident risk, and accident severity. Many ITS applications do, however, indirectly benefit unprotected road users, for example, by reducing the number of vehicles on the roadway, through the use of advanced travel information, by improved public transportation services, and through traffic management which optimises the flow of traffic through particular areas. Thus, the traffic system can be made safer for unprotected road users by improving accessibility (i.e. reducing travel times and exposure), and by reducing the possibility for conflict between protected and unprotected road-users through traffic management strategies and the provision of information.

Draskóczy and Hyden (1993) suggest that cyclists can best be helped, not by automatic control and strict rules, but by the mutually flexible interaction of all road-users. Similarly, for pedestrians, the most promising approaches lie in the indirect systems which affect the interactions between pedestrians and vehicle drivers such as intelligent traffic signal systems with automatic detection, and systems that exert a controlling effect on speed thereby reducing accident severity (Carsten, 1993). The majority of problems concerning unprotected road users are related to difficulties in perceiving pedestrians and cyclists on the roadway by drivers, and failing to use (or use correctly) designated pedestrian crossings. In Sweden, statistics show that approximately 35 per cent of pedestrian-vehicle accidents involving personal injury occur in conjunction with pedestrian crossings and that considerably fewer accidents occur in countries such as England and Norway (Englund et al., 1999).

One of the few attempts to apply ITS functionality to the safety problems of unprotected road users has concerned the use of “intelligent” pedestrian crossings. These types of ITS applications involve the automatic detection of road-users waiting to cross, and crossing, the road or junction. The results of studies have shown fewer pedestrian red-light violations and improved safety in terms of the number of accidents (Carsten, 1995; ETSC, 1999). The relationship between vehicle speed and accident severity also suggests that ITS applications that successfully reduce speed, such as Intelligent Speed Adaptation and speed cameras or other policing and enforcement systems, have a significant impact on the number and severity of accidents (Várhelyi, 1996, Almqvist & Nygård, 1997).

ITS and the Road User Task

The Swedish National Road Authority (SNRA, 1996), have attempted to identify human functions that are critical for safe driving through theoretical analyses and empirical studies. These functions included: the ability to detect relevant information at the right time, the ability to identify and select relevant information, the ability to interpret the information that is gathered, the ability to make correct decisions, the ability to turn these decisions into correct action, the ability to evaluate and modify actions that are taken, the ability to correctly evaluate one’s own ability and limitations, the ability to correctly evaluate the performance and limitations of the vehicle, and the motivation to drive safely.
In their report, which was aimed at identifying ways through which the “vision zero” could be achieved, SNRA identified stress and strain, tiredness, alcohol, and medication, as factors which can have a serious negative effect on these abilities. They also identify inexperience (i.e. the lack of ability), and incorrect attitudes towards behaviour as potential problem areas with regard to safety. The SNRA sees the idea of driver support for speed adaptation (i.e. Intelligent Speed Adaptation) as having a major potential for improving road traffic safety in light of findings which suggest that as many as 50 per cent of vehicles exceed the 50 km/h speed limit in urban areas.

For a number of human factors researchers and cognitive scientists, drivers are perceived as information processors, who have limited cognitive resources that make them susceptible to excessive mental, physical, and temporal demands in terms of diminished performance (see e.g. Wickens, 1992). The potential of ITS is easily recognised when consideration is given to the fact that greater amounts of relevant information require longer times for cognitive decision making, not to mention the physical reaction time required to implement intended actions. In most cases drivers do manage to overcome “overload” situations through the use of compensatory mechanisms. A large number of different theories have been put forward to explain the nature of such mechanisms, which are of considerable importance for the design and development of ITS applications.

Endsley (1988; 1995) has suggested an integration of some of the existing research into a more comprehensive theory that can explain how situational awareness is sustained. A number of important compensatory mechanisms are proposed which suggest that slowness can be compensated by reacting to a predicted situation (for both one’s own behaviour and the behaviour of other road-users) rather than an actual occurring situation. To enable such prediction it is suggested that drivers possess and apply a repertoire of simple models to help in the fast and timely assessment and prediction of different traffic situations, where the information used in each model is selectively extracted from the complete situational scenario. Furthermore, it is suggested that many regularly performed decisions and actions are automated requiring little or no conscious attention, thereby freeing attentional resources for other more important purposes.

According to the ETSC (1999) there are a number of ITS applications that are intended to aid situational awareness for the driver, including:

- **visual enhancement systems** – Systems that facilitate driver vision or vehicle conspicuity.
- **prediction enhancement systems** – Systems that enhance prediction in the short term do not currently exist, although in the long-term Radio Traffic Information and Variable Message Signs have proved useful.
- **decision and action systems** – This includes systems that alleviate or take over certain driving tasks that can be performed more quickly and reliably than by a human controller (e.g. collision avoidance, Intelligent Speed Adaptation).
- **systems that reduce task load** – This includes any ITS application that effectively lowers the task load of the driver allowing resources to be reallocated, safety is likely to be improved in situations where the original task load was high.

In the long term there may also be positive effects on individual behaviour as a result of the fact that driving skills will become simpler and more robust in different situations. There is also the advantage of freed cognitive capacity through the use of ITS, and the fact that the learning process might be made easier and shorter with less likelihood of accidents in the first few years of driving.

Most importantly for the future of ITS there is still a lack of standardisation for ITS functions and interfaces, and implementation difficulties associated with the fact that not all vehicles have the same basic level of ITS equipment. There are also problems associated with the use of ITS applications in areas for which they have not been designed, many existing ITS function such as Adaptive Cruise Control has, for example, been developed primarily for use on motorways rather than rural roads and in urban areas. Research has also shown that many ITS applications (e.g. route-guidance systems) are neglected in demanding situations. The presentation of information must be timely to be of any use to the driver, otherwise it may simply be distracting.
Another problem exists in the over-dependence on information, which may be incorrect or unsuitable for the prevailing situation. Prediction may also be made more difficult as a result of the behavioural differences between ITS equipped and non-equipped vehicles. Existing manual skills are likely to deteriorate in the long run due to use of ITS, which can compromise performance and safety, especially in situations which call for manual override and the early identification of system failures. In a more supervisory role, the driver may also be subject to visual overload as information is often overwhelmingly presented through this modality, or alternatively may be subject to “underload” in some situations where the driving task involves little more than simple vigilance (ETSC, 1999).

Other long-term behavioural problems exist which have the ability to reduce the intended safety impact (e.g. “human-out-of-the-loop” or over-dependency problems, and “behavioural adaptation”) (OECD, 1990). Other unwanted behavioural effects associated with the use of ITS include an increase in the use of private vehicles, the unintended redistribution of traffic through residential areas, the increased use of vehicles and higher speeds in adverse weather conditions, and using the extra available time for non-driving activities (ETSC, 1999).

Estimated Safety Impact of ITS

A number of attempts have been ventured to estimate the perceived safety impact of many ITS applications or user services at different levels of implementation. Based on Swedish data, Lind (1997), estimated the safety potential for a number of different ITS applications using a methodology that involved the use of expert assessment. It was concluded that urban traffic control systems showed the greatest potential for improving traffic safety in terms of the number of accidents involving injury in the short-term future. With full implementation, incident management and heavy vehicle restrictions were also found to have considerable safety potential, as were navigation and route-guidance systems incorporating regional advice and automatic debting. British scientists Carsten and Fowkes (1998) have estimated a significant reduction in injury accidents through the use of Intelligent Speed adaptation, similar reductions have also been estimated by Várhelyi (1997) for Swedish conditions.

PIARC (1999) also report safety benefits that a number of ITS applications have actually been shown to have based on a large number of operational tests performed in North America, Europe, and Japan. The estimated safety benefits based on European data show significant improvements as a result of incident and emergency management, weather monitoring, the use of VMS, and driver monitoring. On a slightly different note, the French traffic researchers Malaterre and Fontaine (1993) attempted to assess the number of accidents that could have been avoided in urban and non-urban areas using different ITS functions. Their estimates indicated that many of the accidents occurring at junctions could be avoided in urban areas. Overall safety results showed an almost 50 per cent reduction in injury accidents for both urban and non-urban areas, although the authors are careful to mention the mitigating factors related to possible changes in behaviour and increases in mobility.

ITS and Safety Evaluation

The majority of ITS systems have a direct or indirect impact on traffic safety. To ensure the maximum safety benefit, even for ITS applications not primarily aimed at enhancing safety, a proper safety evaluation is essential (ETSC, 1999). It has been recognised that the safety aspects of ITS can be examined from three different, but overlapping approaches; system safety related specifically to the design and use of hardware and software, Human Machine Interaction (HMI) related to the interaction between systems and users, and traffic safety which concerns the general effects on the traffic system as an integrated whole. In each of the above areas a vast number of national and international procedures, guidelines, and recommendations have been developed to reduce safety problems to a minimum.

Unfortunately, these guidelines are not compulsory and there are practical issues related to enforcing compliance. The relative newness of ITS applications also means that there is little basic knowledge available on which to develop suitable safety standards. ISO has, however, developed TC204 for the standardisation of information communication and control systems in the field of urban and rural surface transport, and TC22 designated specifically for in-vehicle transport information and control systems.
The ETSC (1999), has pointed out there are a number of specific problems related to the safety evaluation of ITS applications and considers it of vital importance that resources are made available for proper safety evaluation, and that national or international authorities require system developers to demonstrate that their systems have been properly evaluated. Also, the ETSC emphasises the importance of monitoring of safety impacts even after the initial introduction phase.

Inevitably, ITS implementation will bring about changes in the traffic and driver behaviour patterns. Using a systems perspective, Draskóczy (1993) and Draskóczy, Carsten and Kulmala (1998), identified 10 possible areas in which the safety of road-users can be influenced through the introduction of ITS applications. These different areas of possible safety impact include also the secondary side-effects of systems that were not intended by the designer but which are critical for the safety evaluation of ITS applications. These areas include: direct effects of an in-vehicle system on the user (modification of the driving task), direct effects of a road-side system on the user, indirect behaviour modifying effects of the system on the user, indirect behaviour modifying effects of the system on the non-user (imitation effects), modification of interaction between users and non-users, modification of accident consequences, modification of exposure, modification of modal choice, modification of route choice, and modification of speed choice.

Draskóczy and colleagues also discuss the methods and tools that can be used for the evaluation of possible safety impacts for a number of different ITS applications and stresses the importance of identifying suitable “safety indicators” which can serve as proxy measures for safety measurement instead of the primary measure (i.e. the number of accidents involving injury and fatality). The methods and tools chosen are dependent on the nature of the ITS application as are the safety indicators. For each type of ITS application, a three stage safety evaluation plan is devised that includes system analysis and hypothesis formulation and a selection of evaluation methods and indicators for each area of safety impact, and the design of a general experimental plan for data collection (e.g. before and after studies, or studies which involve parallel control groups). There are a large number of evaluation methods that can be used, the most popular involve, for example, the use of instrumented vehicles, driving simulators, observation studies, user questionnaires, and trip diaries. The indicators that are used include, for example, steering behaviour, braking behaviour, speed behaviour, headway, manoeuvring, conflicts, human errors, and measures related to workload.

Implementation and Acceptance Issues

There are a number of important issues concerning the deployment of ITS applications in order to ensure the support of the general public. The public is unlikely to purchase systems that are not conceived as desirable, and acceptance is important for the deployment of systems, which might benefit the community as a whole. In order to be acceptable to public and private interests ITS applications must be cost-effective, reliable, and easy to use and maintain. For public authorities, ITS must be able to show increases in efficiency, reductions in environmental pollution, and most importantly reductions in the number of accidents involving injury and fatality. ITS applications that are perceived by the public to be hard to use or unsafe will not be acceptable. Ensuring adequate consumer information and, if necessary, training is also important although this must not exempt manufacturers from accepting responsibility for their products (ETSC, 1999).

The ETSC (1999) suggests that the legal framework should provide the basis for action by the public authorities and the regulatory environment in which the systems are deployed. Most importantly, the European Union has a legal responsibility to ensure a sufficient level of protection and safety to all EU citizens. The EU also has a key role in the implementation of ITS through the promotion and co-ordination of research and development activities, the technical harmonisation of standards and EU legislation, the dissemination of best practice, and by providing the necessary financial instruments.
6. THE NEED FOR MULTI-DISCIPLINARY RESEARCH

General Conclusions

There are a number of important conclusions that can be drawn on the basis of the prevailing research related to traffic safety in urban areas. The majority of the traffic safety problems in urban areas emanate from the fact that there are many different road users, and a large number of road junctions and pedestrian crossings, in a relatively small spatial area. This situation inevitably contributes to a traffic system which is inherently complex and dynamic, and where the risk for road user conflict is high. This situation places great demands on the perceptual and cognitive decision-making skills of road users. Research suggests that most accidents involving road user injury in urban areas occur at junctions, most commonly those that are unregulated or regulated only by “yield” signs.

Statistics indicate that the higher the number of adjoining roads, the greater the accident risk becomes. The provision of traffic lights or “stop” signs and suitable measures which separate turning traffic and different types of road users have been effective in reducing the accident risk for road-users, most probably due to the reduction in situational complexity. Simplification of the driving task, by reducing environmental complexity through suitable traffic engineering design is costly but usually leads to an improvement in safety. However, there are also other important essentially human considerations that are relevant with regard to the occurrence of traffic accidents.

There appears to be a number of important factors, which predispose traffic accidents. A look at the types of accidents that commonly occur in urban areas reveals common failures related to a lack of anticipation or yielding. These are often the result of perceptual and cognitive errors where road users fail to observe a situation correctly, or having observed the situation, fail to make accurate judgements. This situation is prevalent for all road user types including pedestrians and cyclists. Other factors that are known to negatively influence perceptual and cognitive abilities are: distraction, stress and strain, fatigue, alcohol and medication, inexperience, and other issues related to motivation. Research has also revealed that driving too fast for the situation, and following the car in front too closely increase the likelihood of an accident. The vast number of countermeasures that have been aimed directly at improving the driving abilities and enhancing the situational awareness of drivers (e.g. traffic safety campaigns and driver education programs) have shown little impact unless backed by large-scale policing and enforcement campaigns.

The introduction of Intelligent Transport Systems (ITS) has brought renewed hope to traffic safety researchers. ITS has the potential to influence all three of the most important safety dimensions at the traffic system level (i.e. exposure, accident risk, and the consequences or severity of an accident) for the main traffic system components (i.e. the road user, the vehicle, and the roadway). At the individual level, many solutions attempt to improve traffic safety, by compensating for the perceptual and cognitive limitations of road users in traffic situations. A great many different systems exist that have the ability to, for example, provide useful and timely information in relation to the immediate traffic environment, enhance vision, provide collision avoidance by assuming control in dangerous situations, monitor vehicle and driver status, provide emergency notification, and manage and control the flow of traffic within specific regions.

There are also newer ITS applications such as, for example, intelligent junction systems and systems that aim at providing added protection to unprotected road users through the use of intelligent pedestrian crossings. The ITS applications that have been identified as having the greatest safety potential in relation to urban areas are Intelligent Speed Adaptation (ISA) and urban traffic management control systems. These systems are presumed to have a safety benefit to all types of road user, not only vehicle drivers and perhaps most importantly provide a very cost-effective means to increase safety with regard to more traditional traffic engineering measures.

Having determined the essence of urban area problems, the main actors in the traffic system and a number of countermeasures with high potential for the future, there is a distinct need for an approach that can ensure a comprehensive and accurate evaluation of safety. For such an approach to be successful it must be multi-disciplinary in nature, and must focus in detail not only on the behaviour of the individual road user, but essentially the behaviour of the entire urban area traffic system.
Future Research

In order to achieve this goal, it is not enough to look only at singular events like traffic accidents, but it is necessary to understand the interplay of road users, vehicles, and environmental conditions also during normal functioning of the system. The traffic system is designed so that not every error will necessarily lead to an accident. As accidents are partly stochastic events it is important to assess how often errors are determined to have actually contributed to accidents during normal driving, and if there are combinations of problems that are especially hazardous. If this baseline data is known, it becomes possible to model normal driving behaviour for critical locations, and to obtain conflict/error or accident/error quotas, which enable the assessment of risk for an error, or error combination.

In the French study mentioned above, it was shown that many of the road users who were involved in an accident were fatigued, but if it turned out that the same percentage of road users who do not get into an accident were fatigued then obviously fatigue could not be isolated as a contributing factor in accident risk. If, on the other hand, almost no drivers get involved in an accident when fatigued, then fatigue could be assumed to increase accident risk substantially. This illustrates the need to establish baseline frequency rates for many system variables, before it can be determined that they actually do have an influence on accident likelihood or not, or, in other words, if they are safety indicators or not. It is likely that the above mentioned quota assumes different values in different traffic situations.

There are a great many system variables that have the potential to be useful as safety indicators, however as the number of different traffic situations is infinite, it becomes necessary to prioritise certain safety critical situations and variables over others. For future research it seems most necessary to focus on those situations that most often lead to accidents, and which represent instabilities in the system. Within the urban traffic network four-legged crossings show the highest accident rate. In Sweden, crossings without any traffic lights or traffic signs, but which still have a fair amount of traffic passing through them are comparatively rare, it is therefore logical to focus on junctions that are regulated by either traffic lights or traffic signs.

For the many traffic system variables, both frequency and covariance are of interest to gain information about their potential as safety indicators. Variable selection must be based on theoretical considerations, available methods, and measurability. In order to obtain data that can be used to determine covariation between several variables, experimentation is a necessity, preferably with an instrumented car, that provides the opportunity to gather data for many different variables simultaneously, for each test participant in real traffic situations. Interesting variables include speed, headway (measured in distance as well as in time), steering wheel movements, indicator operation, and pedal operation. Questionnaires can be used to obtain demographic information and subjective judgements of a substantial amount of road users. They can serve as an additional instrument in an experimental study, enabling comparison between objective measurements and subjective experience.

In order to collect other frequency data, a traffic observation study is a suitable method. A junction that corresponds to the above mentioned situational criteria should be selected. Through observation it is possible to gain knowledge about the frequency of traffic violations, and about the distribution of accepted gaps and speeds for different road users. It is also considered necessary to stop road users and interview them about certain aspects of their behaviour, in order to gain insight into their subjective experiences, but also to compare the observed situation with how it was actually experienced.

The data that are collected by a number of the different methods like those mentioned above can be integrated into a model that describes and predicts driver behaviour in the safety critical situations that are of interest in accordance with the safety and performance indicators that are identified. This model can be fine-tuned and expanded upon on the basis of new empirical data collected at a later point in time, and it can be used as a sophisticated tool to evaluate the influence of changes that are introduced into the traffic system (e.g. the introduction of different ITS-applications). Most importantly, the model should be sensitive enough to be able to identify safety relevant changes, both at the individual level and the traffic system level. It is therefore of great practical benefit if the resulting individual model of driver behaviour can be integrated into a micro-simulation model of an urban traffic system in order to comprehend and evaluate the potential safety impact of proposed changes at a higher level prior to implementation.
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