UNDERSTANDING PEDESTRIAN CROSSING BEHAVIOUR: A CASE STUDY IN THE WESTERN CAPE, SOUTH AFRICA

by
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Dissertation presented for the degree of *Master of Science in the Faculty of Engineering at Stellenbosch University*

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Dedication

Dedicated to my late mother, Marie Dusabe and my father, Paulin Nteziyaremye

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Declaration

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ABSTRACT

Road traffic accidents have been a global concern facing all countries. Approximately 1.2 million people are killed annually as a result of traffic accidents and 50 million are injured. More than 90 percent of road fatalities occur in the developing world which has only 48 percent of the world's registered vehicles. Beyond the problem of road fatalities, road traffic accidents result in disability and long term injury. They also cause considerable economic losses to victims and their families and damage properties and infrastructures.

In South Africa, pedestrian fatalities account for about 40 percent of all road traffic accidents. Behaviour patterns of both pedestrians and motorists at pedestrian crossings are the main influential factors of pedestrian accidents. This study investigates behaviour patterns of pedestrians negotiating different types of crossing facilities in the town of Stellenbosch, in South Africa. A total number of 17 pedestrian crossings were selected for the study on the basis of their geometric and operational characteristics. Video-based observations together with on-street interviews were used to understand crossing behaviour patterns, namely pedestrian walking speed, pedestrian delay, gaze behaviour, pedestrian-vehicle conflicts, pedestrian compliance with road traffic rules and gap-acceptance behaviour.

Results of the study showed that male pedestrians walk more than female pedestrians. The 15th percentile crossing speed for all pedestrians observed while crossing was found to be 1.13 m/s whereas the mean crossing speed was found to be 1.48 m/s. Demographic variables appeared to significantly influence pedestrian walking speed. Male and younger pedestrians exhibited higher walking speeds than female and older pedestrians. Pedestrian walking speed was also found to be affected by group size, encumbrance, type of pedestrian facility and distraction while walking. However, no effects of conflicts and the presence of a pedestrian refuge on pedestrian walking speed were found in this study. A mean total delay of 5.10 seconds was found in this study. Male and younger pedestrians experienced shorter delay compared to female and older pedestrians. The type of pedestrian facility and traffic signals during which pedestrians arrived at the kerb and crossed appeared to be other influential factors of pedestrian delay. With regard to gaze behaviour, an average number of head movements ranged from 2 to 5 at the kerb and from 3 to 5 while crossing. Conflicts with motorists peaked where crossing distances were longer and traffic volume was heavy. A red light violation ranging from 82 to 87 percent was observed in this study and on-street surveys indicated that beliefs and attitudes towards traffic control devices and traffic environment significantly explained pedestrians' unsafe crossing behaviour. The calculated critical gap and critical lag ranged from 2.19 to 3.90 seconds and the effect of crossing distance on gap-acceptance emerged in this study. Possible interventions are finally suggested.

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OPSOMMING

Padongelukke is 'n wêreldwye probleem wat al die lande in die gesig staar. Ongeveer 1,2 miljoen mense sterf jaarliks as 'n gevolg van verkeersongelukke en 50 miljoen word beseer. Meer as 90 persent van padsterftes kom voor in die ontwikkelende wêreld met slegs 48 persent van die wêreld se geregistreerde voertuie. Bo en behalwe die probleem van padsterftes, het padongelukke gestremdheid en lang termyn beserings tot gevolg. Dit veroorsaak ook aansienlike ekonomiese verliese vir die slagoffers en hul gesinne en skade aan eiendomme en infrastruktuur.

In Suid-Afrika is voetgangersterftes verantwoordelik vir sowat 40% van alle padongelukke. Gedragspatrone van beide voetgangers en motoriste by voetoorgange is die belangrikste bepalende faktore van voetganger-ongelukke. Hierdie studie ondersoek gedragspatrone van voetgangers by verskillende tipes kruisings in die dorp van Stellenbosch Suid-Afrika. ŉ Totale aantal van 17 voetoorgange is gekies vir die studie op die basis van hul geometriese en operasionele eienskappe. Video-gebaseerde waarnemings saam met op-straat onderhoude is gebruik om kruising-gedragspatrone, naamlik voetganger stapspoed, voetganger vertraging, kyk gedrag, voetganger-voertuig konflikte, voetganger nakoming van padverkeersreëls en gaping-aanvaarding gedrag te verstaan.

Resultate van die studie het getoon dat manlike voetgangers vinniger loop as vroulike voetgangers. Die 15de persentiel kruising spoed vir alle voetgangers waargeneem binne kruisings was 1,13 m/s, terwyl die gemiddelde kruising spoed 1,48 m/s is. Demografiese veranderlikes beïnvloed voetgangers loop-spoed. Manlik en jonger voetgangers loop vinniger as vroulike en ouer voetgangers. Voetgangers loop-spoed word ook geraak deur die grootte van die groep, die dra van items, die tipe voetganger-fasiliteit en afleiding terwyl geloop word. Daar is egter geen gevolge van konflikte op voetgangers loop-spoed in hierdie studie gevind nie. 'n Gemiddelde totale vertraging van 5,10 sekondes is in hierdie studie gevind. Manlik en jonger voetgangers ervaar korter vertraging in vergelyking met die vroulike en ouer voetgangers. Die tipe voetganger-fasiliteit en verkeerseine was ander invloedryke faktore van voetganger vertraging. Vir waarneming van die verkeer is gevind dat die gemiddelde aantal kopbewegings gewissel het van 2 tot 5 teen die randsteen en van 3 tot 5, tydens die kruising. Konflikte met motoriste het ŉ hoogtepunt bereik waar kruising afstande langer en verkeersvolume hoër was. Rooi lig oortredings wat wissel van 82 tot 87 persent is in hierdie studie waargeneem en op-straat opnames het aangedui dat houdings teenoor verkeer-beheer toestelle en die verkeersomgewing die voetgangers se onveilige kruising-gedrag verduidelik. Die berekende kritiese gaping het gewissel van 2,19 tot 3,90 sekondes en die effek van die kruisinglengte op gaping-aanvaarding het in hierdie studie na vore gekom. Moontlike intervensies word voorgestel.

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TABLE OF CONTENTS

Dedication i
Declaration ii
ABSTRACT iii
OPSOMMING iv
ACKNOWLEDGMENTS v
TABLE OF CONTENTS vi
LIST OF TABLES ix
LIST OF FIGURES x
Chapter 1. INTRODUCTION 1
1.1. Background 1
1.2. Problem statement 2
1.3. Aim and objectives 3
1.4. Delineations of the research 4
1.5. Research outline 4
Chapter 2. LITERATURE REVIEW 5
2.1. Introduction 5
2.1.1. Overview 5
2.2. Pedestrian safety problem 6
2.2.1. Pedestrian accidents 6
2.3. Pedestrian characteristics 19
2.3.1. Pedestrian categories 19
2.3.2. Pedestrian needs 25
2.3.3. Pedestrian walking speeds 30
2.3.4. Pedestrian crossing choices 45
2.4. Pedestrian-vehicle interaction at pedestrian crossings 49
2.4.1. Pedestrian gap-acceptance 49
2.4.2. Pedestrian road-crossing tasks 53
2.4.3. Pedestrian delay 67
2.4.4. Pedestrian compliance 72
Chapter 3. STUDY AREA 84
3.1. Overview 84
3.2. Introduction to the study area 84
3.3. Pedestrian crossing facilities in Stellenbosch 85
3.4. Pedestrian flow in Stellenbosch 86
3.5. State of pedestrian safety in Stellenbosch 88
3.6. Site selection 88
Chapter 4. METHODOLOGY 93

4.1. Overview 93
4.2. Introduction 94
4.3. Research design 94
4.3.1. Techniques used for the data acquisition 96
4.3.2. Overview of the techniques: strength and weakness 96
4.4. Methodology 97
4.4.1. Instrumentation 97
4.4.2. Data collection procedures 97
4.4.3. Sample selection 99
4.4.4. Data reduction 99
4.4.5. Limitations 110
Chapter 5. RESULTS PRESENTATION AND DISCUSSION 112
5.1 Introduction 112
5.2. Pedestrian walking speeds 112
5.2.1. Values of pedestrian walking speeds 112
5.2.2. Effect of pedestrian gender on walking speed 114
5.2.3. Effect of age on pedestrian walking speed. 120
5.2.4. Effect of Group size 126
5.2.5. Effect of encumbrance on pedestrian walking speed 131
5.2.6. Effect of distraction on pedestrian walking speed 140
5.2.7. Effect of conflicts on pedestrian walking speed 145
5.2.8. Discussion-Walking speeds 149
5.3. Pedestrian delay 152
5.3.1. Pedestrian delay values 152
5.3.2. Effect of gender on pedestrian delay 157
5.3.3. Effect of age on pedestrian delay 161
5.3.4. The effect of traffic signal on pedestrian delay 165
5.3.5. Discussion-Pedestrian delay 168
5.4. Pedestrian gaze behaviour 170
5.4.1. Number of head movements 170
5.4.2. Discussion-Gaze behaviour 173
5.5. Conflict study 173
5.5.1. Result presentation 173
5.5.2. Discussion-Conflicts 174
5.6. Compliance behaviour 175
5.6.1. Observational study 175
5.6.2. Discussion-Compliance behaviour 177

Stellenbosch University http://scholar.sun.ac.za

5.6.3. Survey 178
5.6.4. Discussion 182
5.7. Gap-acceptance 183
Chapter 6. CONCLUSION AND RECOMMENDATIONS 186
6.1. Introduction 186
6.2. Conclusions 186
6.2.1. Pedestrian walking speed 186
6.2.2. Pedestrian delay 187
6.2.3. Pedestrian gaze behaviour 187
6.2.4. Conflict study 187
6.2.5. Compliance behaviour 187
6.2.6. Gap-acceptance 188
6.2.7. Limitations 188
6.3. Recommendations 188
REFERENCES 190

Stellenbosch University http://scholar.sun.ac.za

LIST OF TABLES

Table2-1: Mean walking speeds for pedestrians with disabilities and users of various assistive devices (Source: Roess et al., 2011) 37
Table 2-2: Effect of Baggage on walking speeds (Platform only) (Source: Hermant, 2011). 37
Table2-3: Pedestrian walking speeds according to weather conditions (Source: Knoblauch et al., 1996). 43
Table 2-4: Walking speeds in Temeke (Tanzania) (Source: De Langen and Tembele, 2001). 44
Table 2-5: Models to estimate pedestrian delay 70
Table 3-1: Characteristics of selected sites 89
Table 4-1: Observation grid of reduced data variables 101
Table 5-1: Pedestrian walking speeds per pedestrian facility category 113
Table 5-2: Pedestrian walking speed by gender 115
Table 5-3: Age group distribution per pedestrian facility type 120
Table 5-4: Pedestrian walking speed by age group 121
Table 5-5: Pedestrian walking speed by group size 127
Table 5-6: Pedestrian walking speed by encumbrance 132
Table 5-7: Pedestrian walking speed by distraction 140
Table 5-8: Pedestrian walking speed by conflict 145
Table 5-9: Pedestrian delays per crossing facility type 153
Table 5-10: Pedestrian total delay by gender 157
Table 5-11: Pedestrian total delay by age group 161
Table 5-12: Average total delay per pedestrian arrival signal 166
Table 5-13: Average total delay per arrival vehicle signal 166
Table 5-14: Average total delay per crossing pedestrian signal 167
Table 5-15: Signal calling time and start-up time 168
Table 5-16: Average number of head movements at the kerb 170
Table 5-17: Average number of head movements while crossing 171
Table 5-18: Percentages of observed conflicts at pedestrian crossings 174
Table 5-19: Percentages of crossing tactics at pedestrian crossings 175
Table 5-20: Percentages of signal compliance behaviour 177
Table 5-21: Characteristics of interview respondents 178
Table 5-22: Reported reasons of spatial non-compliance 179
Table 5-23: Reported reasons of temporal non-compliance 179

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LIST OF FIGURES

Figure 2-2: Types of pedestrian accidents: adopted from National Cooperative Highway Research Program (NCHRP, 2004).......8
Figure 2-3: Pedestrian fatalities by age and gender (Source: MacKenzie et al., in press).......11
Figure 2-4: Pedestrian fatalities by age and alcohol (Source: Matzopoulos, 2005).......13
Figure 2-5: Pedestrian fatalities by time for age groups (Source: Mabunda et al., 2008).......17
Figure 2-6: Peak days per age group of pedestrians (Source: Mabunda et al., 2008).......18
Figure 2-7: Pedestrian fatalities by month for 2001-2004 (Source: Mabunda et al., 2008).......19
Figure 2-8: Wheelchairs and scooter.......24
Figure 2-9: Percentage of disabled people by type of disability (Source: Statistics South Africa, 2005).......25
Figure 2-10: Recommended pedestrian body ellipse for standing area (Source: Florida Pedestrian Facilities Planning and Design Handbook, 1999).......27
Figure 2-11: Spatial dimensions for pedestrians (Source: Washington State's Pedestrian Facilities Guidebook, 1997).......27
Figure 2-12: Pedestrian walking space requirement (Source: Florida Pedestrian Facilities Planning and Design Handbook, 1999).......28
Figure 2-13: Human dimensions when sitting (Source: Washington State's Pedestrian Facilities Guidebook, 1997).......28
Figure 2-14: Spatial bubbles needed by different categories of pedestrians (Source: Washington State's Pedestrian Facilities Guidebook, 1997).......29
Figure 2-15: Spatial dimensions for pedestrians with disabilities (Source: Axelson et al., 1999) 29
Figure 2-16: Spatial dimensions for pedestrians with disabilities (Source: Washington State's Pedestrian Facilities Guidebook, 1997).......30
Figure 2-17: Relationships between pedestrian speed and density (Source: TRB, 2000).......39
Figure 2-18: Relationships between pedestrian speed and space (Source: TRB, 2000).......39
Figure 2-19: Variation in percentile crossing speeds with number of lanes and direction of traffic movement (Source: Rastogi et al., 2011).......42
Figure 2-20: Variation in crossing speed with road width (Source: Rastogi et al., 2011).......42
Figure 2-21: Pedestrian behaviour levels, activities and interactions (Source: Papadimitriou et al., 2009).......46
Figure 2-22: Pedestrian road-crossing stages (Source: Robertson and Thoreau, 2003).......54

Stellenbosch University http://scholar.sun.ac.za

Figure 2-23: Phase 1: Identify presence, need and location of crossing place (Source: Robertson and Thoreau, 2003) 55
Figure 2-24: Phase 2: Approach crossing place (Source: Robertson and Thoreau, 2003) 55
Figure 2-25: Phase 3(a): Enter and crossing place (Source: Robertson and Thoreau, 2003) 57
Figure 2-26: Phase 3(b): Enter and crossing place (Source: Robertson and Thoreau, 2003) 58
Figure 2-27: Phase 4: Exit crossing place (Source: Robertson and Thoreau, 2003) 58
Figure 2-28: Pedestrian head movement and observation-reaction timescale: concept diagram (Source: Schoon, 2010) 60
Figure 2-29: Example of experimental results and diagrammatic comparison between (a) wheelchair users and (b) non-disabled users (Source: Schoon and Hounsell, 2006) 62
Figure 2-30: Visual scanning angle and sectors required by a southbound pedestrian wishing to cross the minor street of an unsignalised intersection (Source: Schoon, 2003) 64
Figure 2-31: Visual scanning angle and sectors required by a southbound pedestrian wishing to cross the minor street of an unsignalised intersection (Source: Schoon, 2003) 65
Figure 2-32: Elements of total crossing time (Source: Schoon, 2003) 66
Figure 2-33: The health belief model 79
Figure 2-34: The theory of planned behaviour model 81
Figure 3-1: Overview of the Chapter 84
Figure 3-2: Satellite image of Stellenbosch and its suburban settlements: Kayamandi, Cloetesville, Tenantville and Idas Valley 87
Figure 3-3: Images of selected sites 92
Figure 4-1: Overview of the Chapter 93
Figure 4-2: Research Design 95
Figure 4-3: Multi-lane effective gap measurement (Cherry et al., 2011) 108
Figure 5-1: Pedestrian walking speed per pedestrian facility type 114
Figure 5-2: Pedestrian mean walking speed by gender 116
Figure 5-3: Cumulative distribution of pedestrian walking speed by gender at signal-actuated crossings on four-lane divided roads 116
Figure5-4: Cumulative distribution of pedestrian walking speed by gender at signal-actuated crossings on four-lane undivided roads 117

Figure 5-6: Cumulative distribution of pedestrian walking speed by gender at unsignalised crossings on two-way and four-way-stop intersections 118

Stellenbosch University http://scholar.sun.ac.za

Figure 5-7: Cumulative distribution of pedestrian walking speed by gender at unsignalised mid-block crossings on two-lane roads 118
Figure 5-8: Cumulative distribution of pedestrian walking speed by gender at unsignalised mid-block crossings on four-lane undivided roads 119
Figure 5-9: Cumulative distribution of pedestrian normal walking speed by gender at sidewalks 119
Figure 5-10: Pedestrian mean walking speed by age group 122
Figure 5-11: Cumulative distribution of pedestrian walking speed by age group at signal-actuated crossings on four-lane divided roads 122
Figure 5-12: Cumulative distribution of pedestrian walking speed by age group at signal-actuated crossings on four-lane undivided roads 123
Figure 5-13: Cumulative distribution of pedestrian walking speed by age group at unsignalised crossings on T-junctions 123
Figure 5-14: Cumulative distribution of pedestrian walking speed by age group at unsignalised crossings on two-way and four-way-stop intersections 124
Figure 5-15: Cumulative distribution of pedestrian walking speed by age group at unsignalised mid-block crossings on two-lane roads 124
Figure 5-16: Cumulative distribution of pedestrian walking speed by age group at unsignalised mid-block crossings on four-lane undivided roads 125
Figure 5-17: Cumulative distribution of pedestrian walking speed by age group at sidewalks .. 125
Figure 5-18: Pedestrian mean walking speed by group size 126
Figure 5-19: Cumulative distribution of pedestrian walking speed by group size at signal-actuated crossings on four-lane divided roads 128
Figure 5-20: Cumulative distribution of pedestrian walking speed by group size at signal-actuated crossings on four-lane undivided roads 128
Figure 5-21: Cumulative distribution of pedestrian walking speed by group size at unsignalised crossings on T-junctions 129
Figure 5-22: Cumulative distribution of pedestrian walking speed by group size at unsignalised crossings on two-way and four-way-stop intersections 129
Figure 5-23: Cumulative distribution of pedestrian walking speed by group size at unsignalised mid-block crossings on two-lane roads 130
Figure5-24: Cumulative distribution of pedestrian walking speed by group size at unsignalised mid-block crossings on four-lane undivided roads 130
Figure 5-25: Cumulative distribution of pedestrian walking speed by group size at sidewalks . 131

Stellenbosch University http://scholar.sun.ac.za

Figure 5-26: Pedestrian mean walking speed by encumbrance 132
Figure 5-27: Cumulative distribution of pedestrian walking speed by encumbrance at signal-actuated crossings on four-lane divided roads 133
Figure 5-28: Cumulative distribution of pedestrian walking speed by encumbrance at signal-actuated crossings on four-lane undivided roads 133
Figure5-29: Cumulative distribution of pedestrian walking speed by encumbrance at unsignalised crossings on T-junctions 134
Figure 5-30: Cumulative distribution of pedestrian walking speed by encumbrance at unsignalised crossings on two-way and four-way-stop intersections 134
Figure 5-31: Cumulative distribution of pedestrian walking speed by encumbrance at unsignalised mid-block crossings on two-lane roads 135
Figure5-32: Cumulative distribution of pedestrian walking speed by encumbrance at unsignalised mid-block crossings on four-lane undivided roads 135
Figure 5-33: Cumulative distribution of pedestrian walking speed by encumbrance at sidewalks 136
Figure 5-34: Frequency distribution of encumbrance at signal-actuated crossings on four-lane divided roads 136
Figure 5-35: Frequency distribution of encumbrance at signal-actuated crossings on four-lane undivided roads 137
Figure 5-36: Frequency distribution of encumbrance at unsignalised crossings on T-junctions 137
Figure 5-37: Frequency distribution of encumbrance at unsignalised crossings on two-way and four-way-stop intersections 138
Figure 5-38: Frequency distribution of encumbrance at unsignalised mid-block crossings on two-lane roads 138
Figure 5-39: Frequency distribution of encumbrance at unsignalised mid-block crossings on four-lane undivided roads 139
Figure 5-40: Frequency distribution of encumbrance at sidewalks 139
Figure 5-41: Pedestrian mean walking speed by distraction 141
Figure 5-42: Cumulative distribution of pedestrian walking speed by distraction at signal-actuated crossings on four-lane divided roads 141
Figure 5-43: Cumulative distribution of pedestrian walking speed by distraction at signal-actuated crossings on four-lane undivided roads 142
Figure 5-44: Cumulative distribution of pedestrian walking speed by distraction at unsignalised crossings on T-junctions 142

Stellenbosch University http://scholar.sun.ac.za

Figure 5-45: Cumulative distribution of pedestrian walking speed by distraction at unsignalised crossings on two-way and four-way-stop intersections 143
Figure 5-46: Cumulative distribution of pedestrian walking speed by distraction at unsignalised mid-block crossings on two-lane roads 143
Figure 5-47: Cumulative distribution of pedestrian walking speed by distraction at unsignalised mid-block crossings on four-lane undivided roads 144
Figure5-48: Cumulative distribution of pedestrian walking speed by distraction at sidewalks... 144
Figure 5-49: Pedestrian mean walking speed by conflicts 146
Figure 5-50: Cumulative distribution of pedestrian walking speed by conflict at signal-actuated crossings on four-lane divided roads 146
Figure 5-51: Cumulative distribution of pedestrian walking speed by conflict at signal-actuated crossings on four-lane undivided roads 147
Figure 5-52: Cumulative distribution of pedestrian walking speed by conflict at unsignalised crossings on T-junctions 147
Figure 5-53: Cumulative distribution of pedestrian walking speed by conflict at unsignalised crossings on two-way and four-way-stop intersections 148
Figure 5-54: Cumulative distribution of pedestrian walking speed by conflict at unsignalised mid-block crossings on two-lane roads 148
Figure 5-55: Cumulative distribution of pedestrian walking speed by conflict at unsignalised mid-block crossings on four-lane undivided roads 149
Figure 5-56: Average pedestrian delays at different pedestrian crossing types 153
Figure 5-57: Cumulative distribution of kerb delay and crossing delay at signal-actuated crossings on four-lane divided roads 154
Figure5-58: Cumulative distribution of kerb delay and crossing delay at signal-actuated crossings on four-lane undivided roads 154
Figure 5-59: Cumulative distribution of kerb delay and crossing delay at unsignalised crossings on T-junctions 155
Figure 5-60: Cumulative distribution of kerb delay and crossing delay at unsignalised crossings on two-way and four-way-stop intersections 155
Figure 5-61: Cumulative distribution of kerb delay and crossing delay at unsignalised mid-block crossings on two-lane roads 156
Figure 5-62: Cumulative distribution of kerb delay and crossing delay at unsignalised mid-block crossings on four-lane undivided roads 156
Figure 5-63: Average total delay per gender 157

Figure 5-64: Cumulative distribution of the average total delay by gender at signal-actuated crossings on four-lane divided roads 158
Figure 5-65: Cumulative distribution of the average total delay by gender at signal-actuated crossings on four-lane undivided roads 158
Figure 5-66: Cumulative distribution of the average total delay by gender at unsignalised crossings on T-junctions........ 159
Figure 5-67: Cumulative distribution of the average total delay by gender at unsignalised crossings on two-way and four-way-stop intersections 159
Figure 5-68: Cumulative distribution of the average total delay by gender at unsignalised mid-block crossings on two-lane roads........ 160
Figure 5-69: Cumulative distribution of the average total delay by gender at unsignalised mid-block crossings on four-lane undivided roads 160
Figure 5-70: Average total delay by age group 162
Figure 5-71: Cumulative distribution of the average total delay by age group at signal-actuated crossings on four-lane divided roads 162
Figure 5-72: Cumulative distribution of the average total delay by age group at signal-actuated crossings on four-lane undivided roads 163
Figure 5-73: Cumulative distribution of the average total delay by age group at unsignalised crossings on T-junctions........ 163
Figure 5-74: Cumulative distribution of the average total delay by age group at unsignalised crossings on two-way and four-way-stop intersections 164
Figure 5-75: Cumulative distribution of the average total delay by age group at unsignalised mid-block crossings on two-lane roads........ 164
Figure 5-76: Cumulative distribution of the average total delay by age group at unsignalised mid-block crossings on four-lane undivided roads 165
Figure 5-77: Average total delay per pedestrian arrival signal 166
Figure 5-78: Average total delay per arrival vehicle signal........ 167
Figure 5-79: Average total delay per crossing pedestrian signal........ 168
Figure 5- 80: Average number of head movements at kerb 171
Figure 5- 81: Average number of head movements while crossing........ 172
Figure 5-82: Comparison of average head movements at kerb and while crossing 172
Figure 5-83: Distribution of observed conflicts at pedestrian crossings........ 174
Figure 5-84: Distribution of crossing tactics at pedestrian crossings........ 176
Figure 5-85: Distribution of crossing tactics at pedestrian crossings........ 176

Stellenbosch University http://scholar.sun.ac.za

Figure 5-86: Distribution of signal compliance behaviour. 177
Figure 5-86: Frequency distributions of reported reasons of spatial non-compliance 180
Figure 5-87: Frequency distributions of reported reasons of temporal non-compliance 181
Figure 5-88: Critical lag on two-lane roads 184
Figure 5-89: Critical gap on two-lane roads 184
Figure 5-90: Critical lag on four-lane roads 185
Figure 5-91: Critical on four-lane roads 185

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Chapter 1. INTRODUCTION

1.1. Background

Road accidents have been a global concern facing all countries since the introduction of motorized vehicles in the late 19th century and remain so today in many countries including South Africa. The first automobile crash-related injury was reportedly suffered by a cyclist in New York City on May 30, 1896. The first pedestrian fatality in the world occurred in London a few months later (August 17, 1896) involving a woman named Bridget Driscoll (Road Peace, [online]). Now, each year approximately 1.2 million people die as a result of road traffic accidents on the world's roads, and as many as 50 million others are injured. More than 90 percent of the deaths occur in developing and emerging countries which have only 48 percent of the world's registered vehicles (World Health Organization, 2009).

Beyond the problem of road fatalities, a large number of severe injuries are also caused by traffic accidents. According to the World Health Organization (2009), between 20 and 50 million non–fatal injuries are estimated to occur annually around the world. Those non-fatal injuries are an important source of disability and long term injury. People physically disabled as a result of a motor vehicle collision often face not only social, educational, occupational and financial deprivation, but also mental health consequences such as post-traumatic stress disorder, phobias, anxiety and depression (World Health Organization, 2009). In addition, road traffic accidents result in considerable economic losses to victims, their families, and nations as a whole, costing many countries 1 to 3 percent of their gross national product (World Health Organization, 2009).

While 80 percent of the world's vehicles are owned by 15 percent of the world's population in countries such as North America, Japan, and Western Europe, paradoxically more than 85 percent of fatalities and 90 percent of disability-adjusted life years lost from road traffic injuries occur in developing countries (Peden et al., 2004; Nantulya and Reich, 2002). A number of factors, including rapid global motorization, lack of pedestrian facilities, poor knowledge and practice of road safety measures by the general population, discourteous behaviour of motorists, high speed driving and low levels of vehicle ownership, have been the main factors contributing to the high rate of traffic accidents in the developing world (Odero et al., 1997; Peden et al., 2004; Vasconcellos, 2001). Moreover, a link between the level of motorization and pedestrian fatality rates has been identified in traffic safety research; Evans (1991) reported that the higher the degree of motorization in a country (number of motor vehicles per 100 000 population), the lower the proportion of pedestrian fatalities to total traffic fatal accidents.

According to the Road Traffic Management Corporation (RTMC), in South Africa, approximately 14,000 people die every year as a result of traffic accidents, i.e. 38 fatalities per day. This figure is equivalent to 27.91 deaths per 100,000 human population and 12.79 deaths per 10,000 registered motorized vehicles (RTMC, 2009). Based on the 2006 Millennium Development Goals, one of goals of the 2015 Traffic Safety Management Plan is to reduce by half the rate of accident fatalities arising from

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road and other transport modes by 2015. Unfortunately, the actual country's performance towards the reduction of fatalities by 50% for the assessed period is nowadays deteriorating, as it has been found to be less than the set target.

In South Africa, about 60 percent of the South African population relies on walking as primary means of transport (Department of Environmental Affairs and Tourism, 2004 cited in Albers et al., 2010). A study by Ribbens (1996) reported that the travel mode of a large proportion of the South Africa is either by public transport or by foot. About 80 percent of all trips are by public transport and only 20 percent are in private car. The road traffic accident statistics available from early 1960s show that pedestrian fatalities have always been a significant component of road traffic fatalities in South Africa. In the early 1980s pedestrians accounted for about half of all road fatalities in South Africa and the highest pedestrian fatality occurred in 1989 with a score of 5 117 pedestrian killed (Ribbens, 2002; Peden, 1997).

A variety of factors contributing to pedestrian accidents in South Africa have been identified: inconsiderate driver behaviour (e.g. speeding, intoxication, not giving way to pedestrians), undisciplined pedestrians (jaywalking, intoxication, inadequate traffic education, poor visibility to motorists), inadequate facilities for pedestrians (paved footways, pedestrian crossings, footbridges, underpasses), lack of effective law enforcement and inadequate street lighting (Peden, 1997; Ribbens, 2002). Moreover, the lack of coordination between land use and transport planning and poor transport planning have been highlighted as factors contributing to pedestrian accidents (Ribbens, 2002).

For a full understanding of the pedestrian safety problem and a suitable action plan, traffic safety researchers, engineers and planners have to address the characteristics of the victims involved, the types of pedestrian accidents, locations and time of pedestrian accident occurrence and factors contributing to pedestrian accidents.

1.2. Problem statement

The most common mode of transport is walking, at least in terms of number of trips, if not distance travelled. Almost everyone is a pedestrian at one time or another. Pedestrian safety and mobility should be elevated to a top priority in a society which values choice and freedom. In many parts of the world, walking is being promoted for its health and environmental benefits. For example, Anderson (no date [online]) estimates that a person gains one hour of expected life for every hour he/she is engaged in moderate exercise, such as walking. As long as injuries caused by collisions with motor vehicles are avoided, walking is probably the mode of transport subjected to fewest negative side effects in the form of injuries (Gärder, 2004). In addition, it is the most important means of transport and offers the greatest potential to replace shorter car trips, particularly those under 2km (Schoom, 2010) .On the other hand, it is seen as a risky undertaking because of its level of unsafety, especially in developing and emerging countries. Pedestrians blame drivers for marginalizing them and drivers blame pedestrians for behaving erratically and for failing to use designated crossing areas (Redmon, 2003).

Compared with driving, walking is subjected to fewer rules that are confined largely to road crossing or travelling on the road and that results in widespread non-compliance behaviour among pedestrians (Mullen et al., 1990). It has been shown that pedestrian accidents mostly occur when the pedestrians are crossing the road (daSilva et al., 2003; Hatfield et al., 2006; Albers et al., 2010). Such locations are therefore one of the greatest concerns for a pedestrian undertaking a walking trip and may deter the use of facilities by pedestrians, and finally affect their decisions about making the trip at all.

Crossing event includes the pedestrian's approach to a crossing and the actual crossing manoeuvre in which the pedestrian has to make a decision. The decision taken is influenced by a variety of factors such as vehicle speed, available gaps, walking speed, roadway characteristics (e.g. road width, existence of a refuge, traffic controls), delay acceptability, road user variables (e.g. gender, sex, social economic characteristics), number of pedestrians in the group and environmental factors (e.g. weather conditions). In many cases the decisions made by pedestrians are inappropriate and put them in risky conditions.

Numerous studies have addressed pedestrian behaviour and attitudes, but very few have been done in the context of developing and emerging countries like South Africa. There is thus an apparent information shortfall in patterns of pedestrian crossing behaviour, such as walking speed, gap-acceptance, pedestrian delay, pedestrian compliance with road traffic rules, decision-making process, and factors affecting all these behavioural patterns. An in-depth understanding of pedestrian crossing behaviour and attitudes would inform the design of pedestrian facilities based not only upon motorists and vehicle characteristics but also upon the behaviour and characteristics of pedestrians. Such information would also be targeted through enforcement and educational awareness campaigns. Therefore, a need for research is relevant, especially in the context of the developing and emerging world, to alert designers, planners and policy makers to pedestrian needs, characteristics and behaviour which affect their safety, comfort and attractiveness of walking in general.

1.3. Aim and objectives

The present study aims to investigate the patterns of pedestrian crossing behaviour as well as patterns of pedestrian-driver interaction at a variety of pedestrian crossing types, in order to improve our understanding of pedestrian risk in South Africa. The objectives of this study are as follows:

1. To determine pedestrian normal walking speed and crossing speed. Within this objective, the specific intentions are as follow:

    - To investigate the effects of demographic factors, such as gender and age.
    - To investigate the effects of group size, type of crossing facility, distraction, encumbrance, existence of a pedestrian refuge and conflicts with motorists.

2. To investigate pedestrian delay at different types of crossings as well as the effects of age and gender, traffic signals and the type of crossing facility.

3. To investigate pedestrian gap-acceptance behaviour. The specific intentions within this objective are as follows:

    - To determine the values of critical gap and critical lag.

    - To investigate the relationship between gap-acceptance and crossing distance.

4. To investigate the tasks involved in road-crossing process. Within this objective, the specific intentions are as follows:

    - To investigate pedestrian gaze behaviour, such as number of head movements at the kerb and while crossing.

    - To observe pedestrian crossing tactics.

5. To examine conflicts between pedestrians and motorists.

6. To investigate pedestrian spatial and temporal non-compliance at different types of crossing facilities.

1.4. Delineations of the research

Crossing behavioural patterns focused in the present study are those of pedestrians crossing at formal pedestrian crossings. Crossing behaviour observed throughout this study are those of pedestrians crossing within the crossing markings and those who crossed within a distance situated between two stop lines at a pedestrian crossing. Jaywalking was only investigated in the surveys.

1.5. Research outline

Chapter 1 briefly outlines the background, the research problem and the research objectives, the research delineation and the research outline. Chapter 2 presents a theoretical basis of the research problem. Chapter 3 provides a description of the study area. Chapter 4 outlines the method used in collecting and analysing the data. Chapter 5 presents the results of the study and the discussion thereof. Chapter 6 presents the main conclusions of the study and suggests recommendations to the research problem.

Chapter 2. LITERATURE REVIEW

2.1. Introduction

2.1.1. Overview

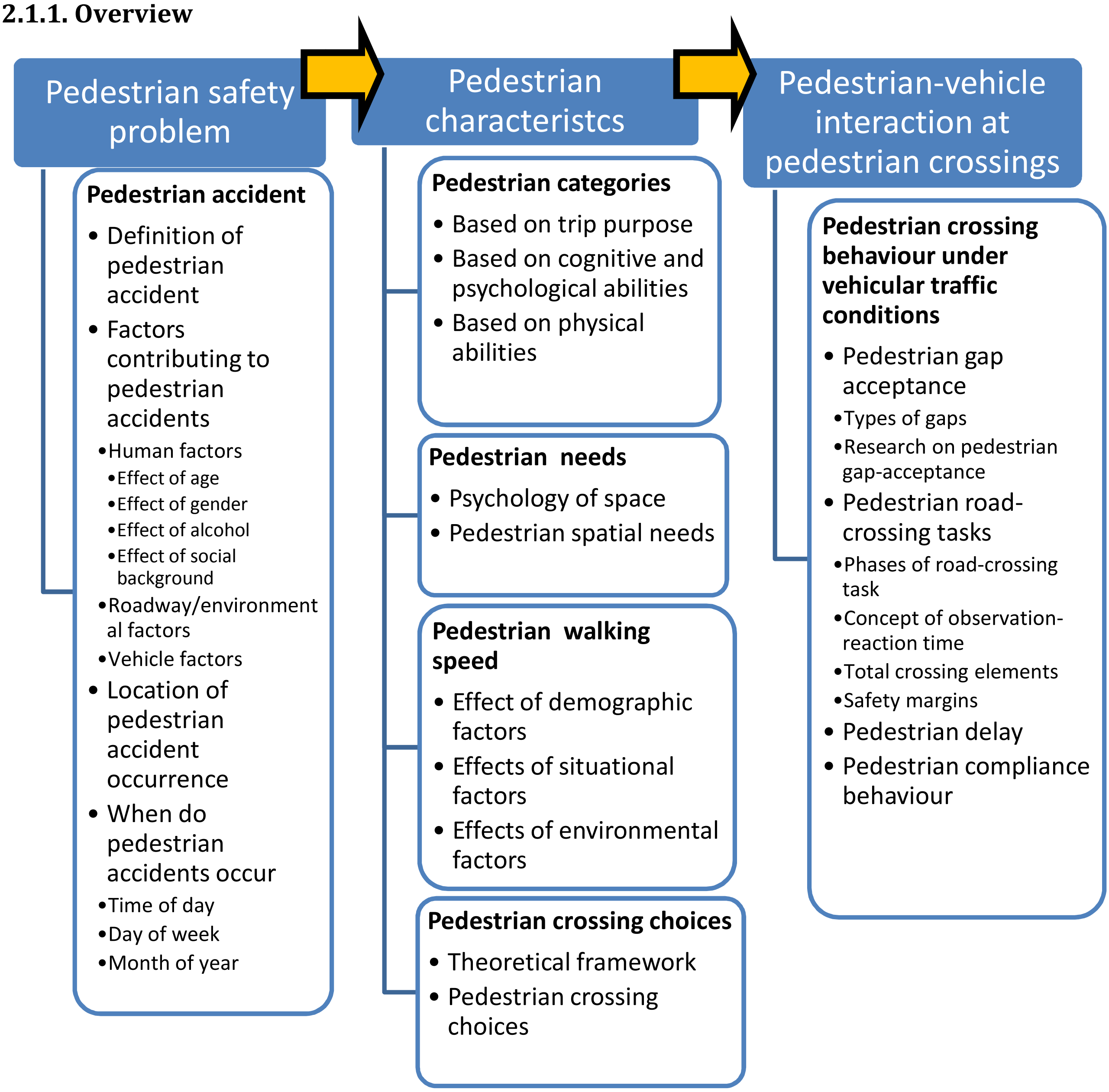

Figure 2-1: Overview of the Chapter

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2.2. Pedestrian safety problem

2.2.1. Pedestrian accidents

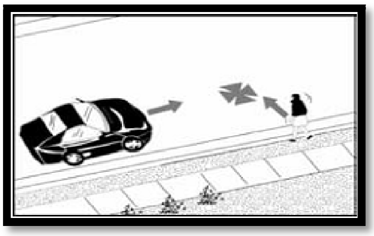
2.2.1.1. Definition of a pedestrian accident

A pedestrian is a person travelling on foot, but this definition also includes wheelchair and scooter users as well as any person travelling on small wheel such as inline skates, roller skates, skateboard, kick scooter and a person with a pram. A pedestrian accident is an accident involving one or more of the categories above cited. A pedestrian accident can be fatal or non-fatal. A fatal pedestrian accident is defined as an accident for which there is at least one pedestrian death.

Classification of pedestrian accident types has been developed and the most frequently pedestrian accidents types are defined as follows (NCHRP, 2004):

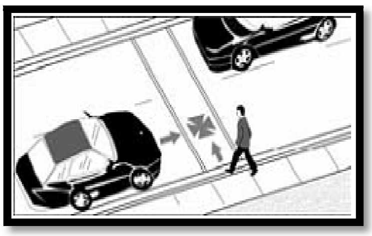
Definitions of pedestrian accident types **Examples**

1. Dart/Dash
The pedestrian is struck by a vehicle while walking or running into roadway at an intersection or mid-block crossing location. Speeding and visibility problems may be the possible cause of this type of pedestrian accident.



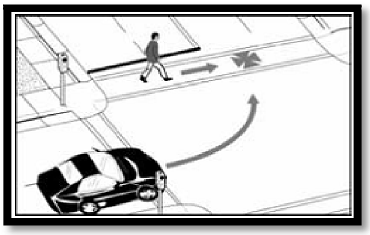
2. Multiple Threats
The pedestrian enters the roadway in front of stopped or slowed traffic and is struck by a vehicle travelling in the same directions as the stopped vehicle. The possible causes may be the pedestrian visibility blocked by stopped vehicle end/or the motorist may have been speeding.

3. Through Vehicle at Unsignalised Location
The pedestrian is struck at an unsignalised intersection or midblock location. Either the pedestrian or the motorist may have failed to yield.

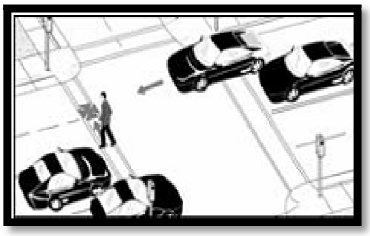


4. Bus-related
The pedestrian is struck by a vehicle either (1) by crossing in front of commercial bus stopped at a bus stop, (2) going to or from a school bus stop, or (3) going to or from waiting near a commercial bus stop. Possible causes may be insufficient gap-acceptance by pedestrian and limited sight distance.

5. Turning Vehicle at Intersection
The pedestrian is struck by a vehicle turning right or left while attempting to cross at an intersection. Pedestrian non-compliance with traffic controls and misunderstanding right-of-way especially in the case of shared green phase may be possible causes.



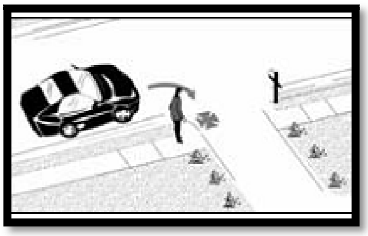
6. Through Vehicle at Signalised Location
The pedestrian is struck at a signalised intersection or midblock location by a vehicle that is travelling straight ahead. Visibility problems and non-compliance to traffic controls may be the possible causes.



7. Walking Along Roadway
The pedestrian is walking or running along the roadway and is stuck from the front or from behind by a vehicle. Lack of sidewalk, high vehicle speed and volume, and visibility problems are the possible causes.

8. Working/Playing in Road
A vehicle strikes a pedestrian who is (1) standing or walking near a disabled vehicle, (2) riding a play vehicle that is not a bicycle (e.g. wagon, sled, tricycles, and skates), (3) playing in the road, or (4) working in the road. High vehicle speed on local street is the possible cause.

9. Not in Road (Driveway, Parking Lot, Sidewalk or Other)
The pedestrian is standing or walking near the roadway edge, on the sidewalk, in a driveway or alley, or in a parking lot, and is struck by a vehicle.



10. Backing Vehicle
The pedestrian is struck by a backing vehicle on the street, in a driveway, on a sidewalk, in a parking lot, or at another location.

11. Crossing a freeway
The pedestrian is struck while crossing a freeway or an off-ramp/ on-ramp.

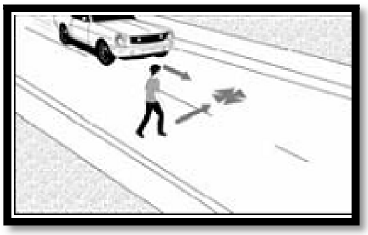


Figure 2-2: Types of pedestrian accidents: adopted from National Cooperative Highway Research Program (NCHRP, 2004)

2.2.1.2. Factors contributing to pedestrians accidents

While studying pedestrian accidents, researchers try to categorize them based on a multi-factor analysis in order to improve their understanding of these and propose suitable countermeasures. Variables mostly considered in these studies include human factors, roadway/environmental factors and vehicle factors.

a. Human factors

- **Pedestrian contributing factors**

Pedestrian factors are the main cause of pedestrian-vehicle accidents. As regards ”pedestrian contributing factors”, a study conducted in the United States identified a number of contributing factors within this group, namely with jaywalking (run into road), failure to yield and alcohol impairment as being predominant (Hunter et al., 1996). The category “run into a road” was the largest and accounted for 15 percent of all pedestrian accidents. Pedestrian behaviour associated with inattention and distraction has also been revealed by Bungum et al. (2005) as contributing factors to pedestrian accidents. These risk factors include wearing headphones, talking on a cell phone, and eating, drinking, smoking or talking while crossing (Bungum et al., 2005).

A study conducted by Afukaar et al. (2008) highlighted pedestrian actions associated with pedestrian accidents in Ghana. The pedestrian action leading to a majority of pedestrian accidents in Ghana was “crossing the roadway “(72.7 percent), followed by “walking along road” (4.4 percent) and “walking along edge” (7.7 percent).

In South Africa, a study carried out on accidents occurred in December 2002 revealed that human factors accounted for 78 percent of all fatal accidents (NDoT, 2003). With respect to “pedestrian contributing factors, jaywalking was the most influencing factor.

- **Driver contributing factors**

With respect to “driver contributing factors”, the American study by Hunter et al. (1996) highlighted that “failure to yield right-of-way” was the predominant contributing factor in this group, and often was linked with speeding. Speed has been a major contributing factor in all fatal accidents in the U.S as it contributed to 29 percent of all fatal accidents in 2000 (NHTSA, no date [online]). Similarly, speeding was the major contributing factor amongst the category of “drive contributing factors” in South Africa (National Department of Transport, [online]). In Ghana, the most common driver factor contributing to fatal pedestrian accident was excessive speed (44 percent), followed by driver inattentiveness (30 percent) (Afukaar et al., 2008).

- **Demographic factors**

  - **Age-related effects**

Research in traffic safety has shown that the largest percentage of fatal pedestrian accidents involve young adults. Accident data during 2010 revealed that pedestrian fatalities in the United States in the 25-44 year age range accounted about the third (28 percent) of all pedestrian fatalities (NHTSA, 2012).

With regard to injury severity, elderly pedestrians (more than 65 years old) and children are the most vulnerable age groups. Elderly pedestrians accounted for 19 percent of fatal accidents whereas they represented 11percent of all pedestrian injuries in 2010 (NHTSA, 2012). On the contrary, 10.4 percent of fatal accidents fall in the 5-15 year range whereas the peak (29.9 percent) of non-fatal accidents lies in this age range. This may be explained by the fact that elderly pedestrians are less likely to survive their injuries than young adult pedestrians.

Research in South Africa has shown that pedestrian fatalities peak in the 30-34 year age group (Harris et al., 2004) and that the average age of pedestrian fatalities is 32.9 years (SD=14.10), with nearly half of total pedestrian fatalities being young adults aged between 20-39 years (Mabunda et al., 2007) (see Figure 2-3). Recorded data by the National Injury Mortality Surveillance System (NIMSS) for Cape Town showed that pedestrian fatalities accounted for 59.6 percent of transport-related amongst children and adolescents age groups (0-19 year age range), of these, 80.2 percent were of school-going age (Prinsloo, 2001). In the other South African study, fatalities amongst child pedestrians under the age of 8 years have been reported to be approximately half (49 percent) of all child pedestrians killed in 1997 (du Toit and Van As, 1998).

Several studies suggested that these trends in pedestrian accidents involving children may stem from their particular vulnerability. Dunne et al. (1992) argued that parents overestimate their children’s ability to handle street crossing safely, and noted that the discrepancy between expectations and performance is greatest for the younger children

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(5 years old). The same reason may lie behind a significant number of pedestrians younger than 6 years old reported to be in accidents not accompanied by an adult in Germany (Kloeckner et al., 1989). Physical and cognitive limitations of young children have been also identified as the main cause of their higher risk exposure and risky behaviour in traffic situations. According to Venter (1998), these limitations were listed as follows:

- *Size*: A small child's view of the road is often obscured when standing on the pavement near parked cars.
- *Height of impact*: A small child's head and shoulders being at bumper or bonnet height, these parts of the body are particularly more likely to sustain severe injury upon impact.
- *Speed and distance:* Young children's perception of the speed and distance off a moving vehicle are still inadequately developed.
- *Attention:* It is difficult for children to concentrate on one particular thing for long periods of time. They also tend to be easily distracted by things of lesser importance in traffic situations.
- *Peripheral vision*: Young children have limited peripheral vision, preventing them from observing movement or objects at the periphery of their visual fields.
- *Auditory perception:* Young road users have difficulty in distinguish between the sounds made by different types of vehicles and in deciding whether a vehicle is near or far.

A relationship between accident types and age was also identified. In a study by Hunter et al. (1996) it was found that certain accident types were overrepresented in certain age groups. The youngest age group in the range of 0-9 years old were overrepresented in the intersection dash and the midblock dash, accounting for 41 and 55 percent, respectively, while only 19 percent of all pedestrian accidents affected this age group. In the 10-14 year range group, bus-related and intersection dash accidents were predominant, accounting for 24 and 23 percent, respectively, while only 11 percent of overall accidents fell in this age group. With respect to the oldest age group, backing vehicles were found to be an important threat to this category. The effects of social background are also associated with a higher likelihood of pedestrian accidents amongst younger children as it will be explained later in this study.

- **Gender-related effects**

In general, trends for fatal pedestrian accidents by gender show that there are more males than females in every age category. As example, an American study by Hunter et al. (1996) reported that the ratio of male to female fatalities varied from 3.6 to 1 in the 21 to 24 age group, down to 1.3 to 1 in the oldest age group. However, the trends for non-fatal pedestrian accidents by gender were somewhat different as the heavy predominance of males was not seen in every age category. Females were overrepresented in the 21-24 and 65-74 age groups, with the ratio of males to females of 0.6 to 1 and 0.8 to 1, respectively. Fundamental differences between the behaviour of males and females in different age categories could explain this discrepancy in ratio of male to female accidents. In the age categories where females outnumbered males in

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non-fatal accidents, the possible reason was the preponderance of females in the overall pedestrian population. The study concluded that males were overrepresented in pedestrian accidents, and the degree of overrepresentation was greater in fatal accidents than in non-fatal accidents.

In South Africa, male pedestrians have been found overrepresented in fatal accidents recorded during the 2001-2004 period, accounting for 76 percent of total fatal accidents and representing a ratio of 3.3 male fatalities for every female pedestrian fatality (MacKenzie et al., in press). This gender difference in fatal accidents involvement increased to 4.59 male fatalities for every female fatality in the age 20-39 year age group. Trends of pedestrian fatalities by gender are illustrated in Figure 2-3.

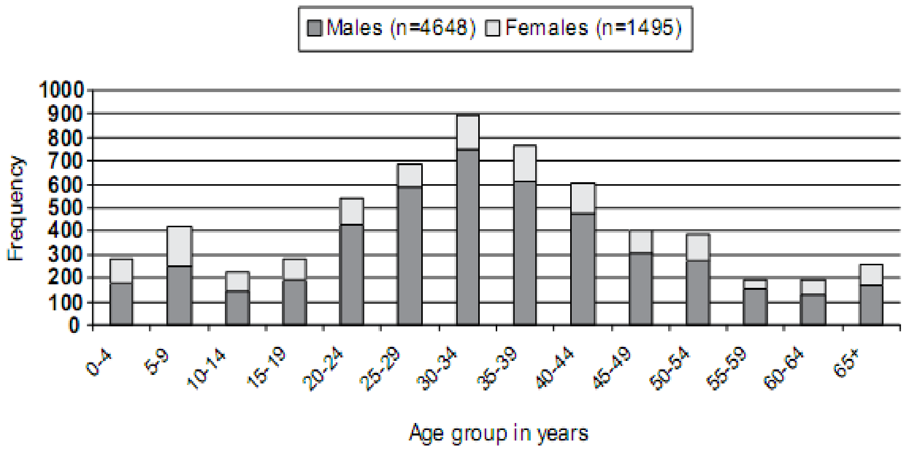

Figure 2-3: Pedestrian fatalities by age and gender (Source: MacKenzie et al., in press)

- **Alcohol-related effects**

Alcohol is a psychoactive drug, usually ingested in a drink in the form of ethanol or ethyl alcohol (Shinar, 2007). The concentration of alcohol in the blood is expressed by means of a standard measure, the Blood Alcohol Concentration (BAC). As an example, a BAC of 100% is equivalent to a concentration of 1 gram (1000 milligram) of alcohol per 1 millilitre of blood. Thus 5 milligram of alcohol per 1 millilitre of blood would yield a BAC equivalent to 0.5 %. While measuring the BAC, the road user is asked to blow into a portable breather tester to analyse their lung air. According to a study by Vanlaar (2005), the breath alcohol concentration is proportional to the BAC by a factor of 2.2727. Thus, as an example, a breath alcohol concentration of 0.44 mg alcohol per litre of exhaled air is equivalent to 1mg/ml in the blood, or 0.10% BAC.

The level of alcohol impairment is directly related to the amount of alcohol consumed. However, with regards to sensitivity to alcohol, gender differences may take place. A higher BAC will be produced in the woman than in man of equal weight after the consumption of the same amount of alcohol. This is because the alcohol impairment is a

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function of its dilution in the blood, and water constitutes 58 percent of an average man's weight, whereas it is only 49 percent of women's weight (Shinar, 2007).

In South Africa, 6 billion litres of alcohol beverages are consumed every year (Meel et al., 2006) and the estimation of adult per capita consumption of absolute alcohol is between 9 and 10 litres per year, placing South Africa amongst the higher alcohol consumption nations (Parry, 1998). It was reported that social costs of alcohol-related trauma and traffic accidents in South Africa far exceed the revenue collected. Thus, alcohol misuse and abuse is a major burden to South African society and has a great impact on the economy of the country.

Pedestrians are more likely to be involved in alcohol-related accidents as their impairment affects their ability to judge distances and vehicular speeds especially in darkness, resulting in longer perception-reaction times and poor decision-making. Disastrous situations could be expected when the driver also is alcohol-impaired, as evasive actions resulting from a realised threat could be delayed. Internationally, research has reported that 30-35 percent of fatally injured adult pedestrians have BACs exceeding 0.08 % (Stewart, 1995), and this figure may exceed 40 percent in urban areas (Blomberg and Cleven, 2000).

In South Africa, alcohol impairment has been reported to be a contributing factor in 76 percent of all deaths after interpersonal violence (Van der Spuy, 2000). It contributed also in 47.4 percent (Van Kralingen et al., 1991) and 29.1 percent (Traffic Department, City of Cape Town, 1992) of fatally injured drivers and non-fatally injured drivers, respectively. In Cape Town, alcohol appeared as a leading cause of pedestrian fatalities in 61. 2 percent, of these more than a half (59.5 percent) of the examined victims had BACs at or above 0.08% (Van der Spuy, 1991). In another South African study, the examination of blood samples in 2003 by the National Injury Mortality Surveillance System (NIMSS) revealed that 53 percent of traffic fatalities had positive BAC (Matzopoulos, 2004). Of these, pedestrians were the most impaired road users with 61 percent of alcohol-related traffic accidents. Moreover, influence of alcohol was found ubiquitous in pedestrian activity in South Africa; random sample surveys showed that 10-13 percent of non-injured pedestrians had BACs in excess of 0.08% (Directorate of Traffic Safety, 1990).

A significant gender difference in the distribution of alcohol-related accidents has been reported in a number of studies. Male pedestrians are generally overrepresented in alcohol-related accidents. As an example, male victims were more than twice as likely to have been alcohol-impaired as female victims, with 195 male victims and 84 female victims in Australia, during 1992 (Federal Office of Road Safety, 1997). In the American study by Dultz et al. (2011), of the 665 victims examined in Bellevue Hospital Centre in New York, 77.9 percent were males (74 of 95) whereas females accounted for 22.1 percent. In South Africa, the proportion of male and female pedestrians involved in alcohol-related accidents was found to be 76.7 percent and 23.3 percent, respectively (Peden et al., 1996).

Age is also one of the contributory factors of alcohol-related accidents involving pedestrians. Age distribution has been found to be different between alcohol-impaired and sober pedestrians. A study conducted in South Australia by Hutchinson et al. (2009) reported that 71 percent of those pedestrians involved in alcohol-related accidents were in the 20-to-49-year-old age range. In the United States, alcohol-related pedestrian accidents tended to be in the 21-45 year age range, whereas accidents involving sober pedestrians peaked in the age groups less than 18 and more than 55 year age range (Jehle and Cottington, 1988; Wilson and Fang, 2000). In South Africa, recorded data by Matzopoulos (2005) for Cape Town showed no significant difference in age distribution by alcohol involvement; both two groups peaked in the 30-39 year age range as illustrated in Figure 2-4.

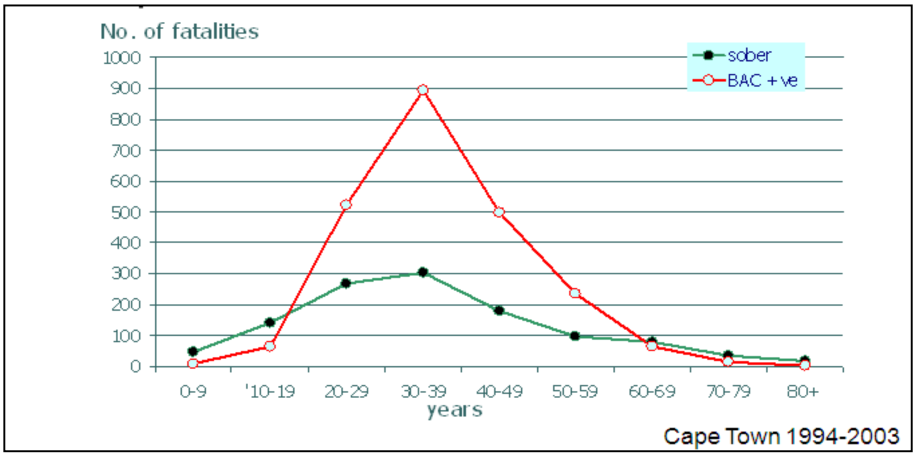

Figure 2-4: Pedestrian fatalities by age and alcohol (Source: Matzopoulos, 2005)

- **Effects of social background**

Several studies showed a link between pedestrian accident involvement and social circumstances. The correlation of social economic group (SEG) and pedestrian accident rates made that link evident. As an example, Graham et al. (2002) showed that there are more pedestrian accidents in geographical areas with high unemployment rates compared with areas with lower unemployment. While taking housing type as an indicator, another study in the United States revealed that accident rates are much higher for people living in older houses (pre-1964) and houses built by local authorities (AA Foundation for Road Safety Research, 1994; Christie, 1998). This has been explained by lack of pedestrian facilities segregated from traffic in this type of housing. A link between the social background and involvement in alcohol-related accidents has also been reported in research. As an example, alcohol-impaired victims in Australia were found dominant in retirees, tradespersons, labourers and the unemployed (Federal Office of Road Safety, 1997).

Family circumstances have been revealed also to have influence in child pedestrian accidents. A study by Christie (1998) showed that children with unemployed parents, single parents and children living in crowded accommodation are all likely to be involved in an accident. The author revealed also that household car ownership has an influence in accident rates amongst children since households with access to a car have been found less likely to be involved in an accident than those without. This may be explained by less responsibility of parents in the lower SEG for their children in traffic and less safe traffic to which their children are exposed (Christie, 1995).

Research has found also little evidence that ethnicity can influence pedestrian accident occurrence. A study carried out in The United Kingdom by Martin (2006) showed that Asian child pedestrians (aged 0-9 years) were overrepresented in road accidents by a factor of two. In the United States, a study by Dultz et al. (2011) reported a link between alcohol impairment and ethnicity: Caucasians were the most likely to be alcohol-impaired, while East Asians were the most likely to be sober. However, another study carried out Los Angeles showed that Hispanics tended to have higher BAC levels than other ethnic groups (Plurad et al., 2006). Another study carried out in New Zealand has shown several differences by ethnicity in road crossing behaviour amongst adolescents: Maori (the native people of New Zealand) were significantly more likely to engage in unsafe crossing behaviour than Caucasians and Asians (Sullman and Mann, 2009). Moreover, according to the New Zealand Ministry of Transport (2006 cited in Sullman and Mann, 2009), Maori are overrepresented in fatal road accidents, accounting for 23 percent of fatalities while making up 14 percent of New Zealand's population. Indeed, this phenomenon may be experienced where ethnicity is linked with poverty and language barriers.

b. Roadway/environment factors

Roadway and environment factors were contributing factors in 12 percent of total fatal accidents in December 2002 in South Africa (NDoT, 2003 cited in Jungu-Omara and Vanderschuren, 2006). Poor visibility was the major contributing factor, accounting for 34 percent. Other factors like sharp bends and slippery roads accounted for 17 percent each. Poor visibility may be due to inadequate street lighting, dense fog or other obstructions like in-street parked vehicles. In slippery road sections motorists may lose control of vehicles at a certain speed and fail to stop before an obstacle. An American study by Hunter et al. (1996) also showed that poor visibility was the major contributing factor to pedestrian accidents within this category. Research has also shown that poor luminous intensity is the major contributory factor of many pedestrian accidents at night-time (Plainis et al., 2006; Owens and Sivak, 1993, 1996; Elvik, 1995).

Indeed, certain roadway designs features can encourage unsafe behaviour like speeding in excessively wide and straight streets. Unsafe road-crossing behaviour may be necessitated by high-volume multilane roads with lack of pedestrian crossings at regular intervals. Traffic volume has also been identified as a risk factor for pedestrian accidents. Research has found a strong link between traffic volume and the number of children involved in pedestrian-vehicle accidents (Christie, 1995; Roberts et al., 1995). Land use may also encourage unsafe pedestrian crossing, especially where residential areas are separated from shopping areas with high-volume multilane roads.

c. Vehicle factors

Vehicles factors contributed in 10 percent of total fatal accidents in December 2002 in South Africa (NDoT, 2003 cited in Jungu-Omara and Vanderschuren, 2006). The major

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contributing vehicle factors were tyre bursts (56 percent), brakes (19 percent) and light (12 percent). In an America study, vehicle factors contributed to 12 percent of pedestrian accidents, where extended mirror, defective brakes, foggy/dirty windshield, defective tires, defective lights and oversized vehicle/load were predominant contributing factors respectively (Hunter et al., 1996).

2.2.1.3. Location of pedestrian accident occurrence

A study carried out in Ghana by Afukaar et al., (2008) identified locations where pedestrian accidents were predominant. Three settlement types were considered: (1) urban (population greater than 5000); (2) village (residents less than 5000); and (3) rural (where there are no permanent inhabitants). Results showed that living in villages was more dangerous than living in an urban centre, as 63 percent of all fatal accidents occurred in villages compared with 27 percent and 10 percent occurring in urban centres and rural segments, respectively. The reason behind this may be excessive speeds in village settlements as side friction (e.g. on-street parking) and the presence of local traffic police are not important compared to larger urban settlements. Afukaar et al., (2008) revealed that significant pedestrian fatalities (92 percent) occurred on undivided roads (without a central median) while the remaining fatal accidents (8 percent) occurred on divided roads (with traffic median islands). Further, the majority of pedestrian fatalities (82 percent) occurred on “straight sections”, whereas 10 percent and 7 percent of pedestrian fatalities took place “on incline only” and “curve only” sections, respectively. With regard to location type, the same study found that the majority (80 percent) of pedestrian fatal accidents occurred at “Not at junction” sites and T-junctions were the next important locations, with 12 percent of all pedestrian fatalities. Pedestrian fatal accidents were also found predominant in road centre (72.7 percent) whereas those happening on pedestrian crossing and within 50 m of crossing accounted for 2.6 percent and 1.8 percent, respectively.

In South Africa, more than half of all pedestrian accidents occur when pedestrians cross the road outside a pedestrian crossing (Ribbens, 1996). Another study conducted in the 1980s reported an increasing incidence of pedestrian accidents at intersections (Ribbens, 1985). Pedestrian accidents occurring at signalised intersections (in the central business district, on main arterials, and in suburban shopping areas) outnumbered those occurring at uncontrolled intersections. Non-compliance with traffic signals both by drivers and pedestrians, pedestrians walking/running into vehicles, turning vehicle-pedestrian conflicts, and visibility problems were the major causative factors identified. Pedestrian accidents on freeways, especially at interchanges also constitute a serious threat to road safety in South Africa, as about 2 000 pedestrian accidents occur annually on freeways (Ribbens, 1996). Pedestrian activities existing at interchanges include: (i) pedestrians walking through the interchange area to destinations on the other side of the freeway, (ii) pedestrians using the interchange as a modal transfer point, and (iii) pedestrians involved in activities such as selling of newspapers, flowers, and so forth (South African Roads Board, 1992 cited in Ribbens, 1996).

2.2.1.4. When do pedestrian accidents occur?

i. **Time of day**

In general, a number of studies showed a peak time for pedestrian accidents in the afternoon hours and a minor peak in the morning hours. In the United States, a peak in pedestrian accidents has been reported between 20:00 and 24:00 (30 percent), and a minor one between 16:00 and 20:00 (23 percent) (National Highway Traffic Safety Administration, August 2012). However, there was some discrepancy in distribution of pedestrian accidents in terms of their severity. As an example, an American study by Cove (1990) showed a peak of pedestrian fatalities in the evening hours between 17:00 and 23:00 and a minor peak from midnight to 2:00. It has been argued that this trend in pedestrian fatalities may be partly associated with pedestrian accidents involving fast-moving vehicles in rural road sections, pedestrians walking along a dark road and pedestrian walking under the influence of alcohol. This latter has been referred in a study conducted in South Australia by Hutchinson et al. (2009): about 50 percent of pedestrians with high BAC levels are involved in accidents during evening hours, starting from 18:00 up to 20:00 and another 35 percent occur in the early morning hours, from 23:00 up to 3:00. Moreover, it has been reported that 55 percent of pedestrians aged 16 years or older who were involved in fatal accidents at night, had a blood alcohol concentration of 0.10 percent or more in the United States. With regard to motorists involved in pedestrian accidents, the intoxication rate was only 12 percent during the same period (LaScala et al., 2001; National Highway Traffic Safety Administration, 1997).

In South Africa, Mabunda et al. (2007) reported that over 45 percent of pedestrian fatalities occurred during evening hours, between 18:00 and 24:00, with the highest incidence between 18:00 and 21:00. They also found a link between the time of fatal pedestrian accident occurrence and the pedestrian category. Pedestrian fatalities among children and adolescents peaked in the late afternoon between 16:00 and 19:00 whereas peak time of those involving young adult pedestrians (20-39 years age group) was between 18:00 and 21:00 (see Figure 2-5). Most of female and elderly pedestrian deaths occurred between 18:00 and 23:00, but another significant number of deaths of this category occurred in the morning between 06:00 and midday. Male pedestrians with high BAC levels were overrepresented (81 percent) in fatal accidents occurring between 18:00 and 06:00. This category comprised mostly pedestrians in 20-39 years range group (65 percent), followed by the 40-59 years range group (32 percent).

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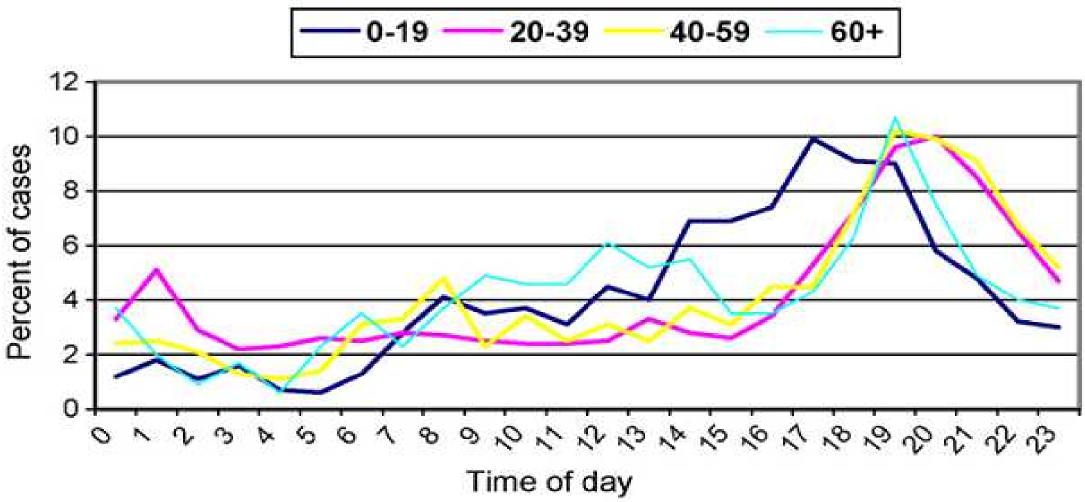

Figure 2-5: Pedestrian fatalities by time for age groups (Source: Mabunda et al., 2008)

ii. Day of week

Pedestrian accidents are generally found overrepresented during weekends. In South Africa, Mabunda et al.'s (2008) research reported that nearly a quarter of fatal pedestrian accidents recorded between 2001 and 2004 occurred on Saturday, with the 20-39 years age group being overrepresented. Sunday was the second to have a high rate of fatal pedestrian accidents (17.2 percent), followed by Friday (15.5 percent) (see Figure 2-6). Male pedestrians with high BAC levels were overrepresented (75 percent) in fatal pedestrian accidents occurring over the weekend. Over the half of fatal accidents involving children, adolescents and young adult pedestrians were found to occur during weekdays. However, some studies reported that fatal pedestrian accidents are overrepresented on Friday and Saturday, and are underrepresented on Sunday (Hutchinson et al., 2009; National Highway Traffic Safety Administration, 1997). The difference in trends of pedestrian accident involvement by day of week may stem from a number of factors like the amount of walking by day of week, less pedestrian interaction with rush-hour traffic, and/or a low rate of night drinking and walking (Campbell et al., 2004).

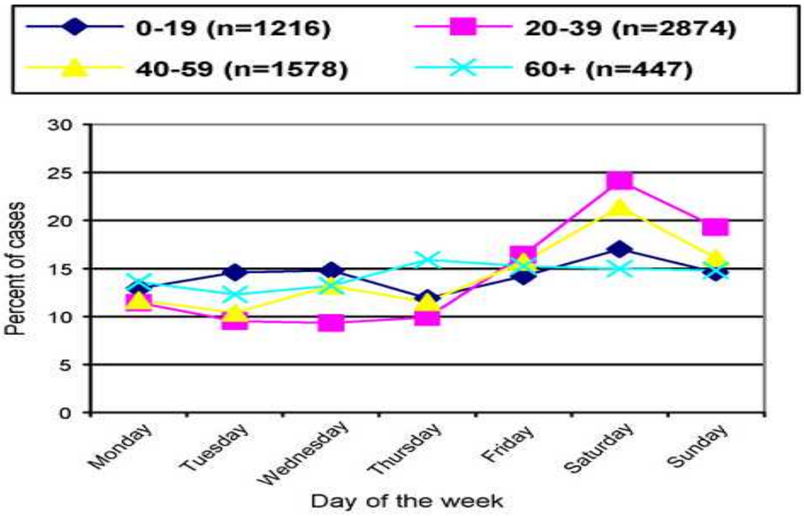

Figure 2-6: Peak days per age group of pedestrians (Source: Mabunda et al., 2008)

iii. Month of year

There are also differences in trends of pedestrian fatalities by season of year. A study carried out in the United States by Zegeer et al. (1993) showed that more pedestrian accidents involving elderly pedestrians occur during the rainy season and winter months, whereas those involving younger pedestrians are predominant during the spring and the summer. December is the month having the greatest overrepresentation of pedestrian accidents. This may be explained by festivities taking place in this particular month.

Similarly, Mabunda et al. (2008) reported that pedestrian accidents were equally distributed across the year, but overall pedestrian fatalities peaked in June (9.3 percent), followed by September (9.0 percent). The lowest pedestrian fatality rate was observed in the beginning of the year in January, and a continuous increase took place until March (see Figure 2-7).

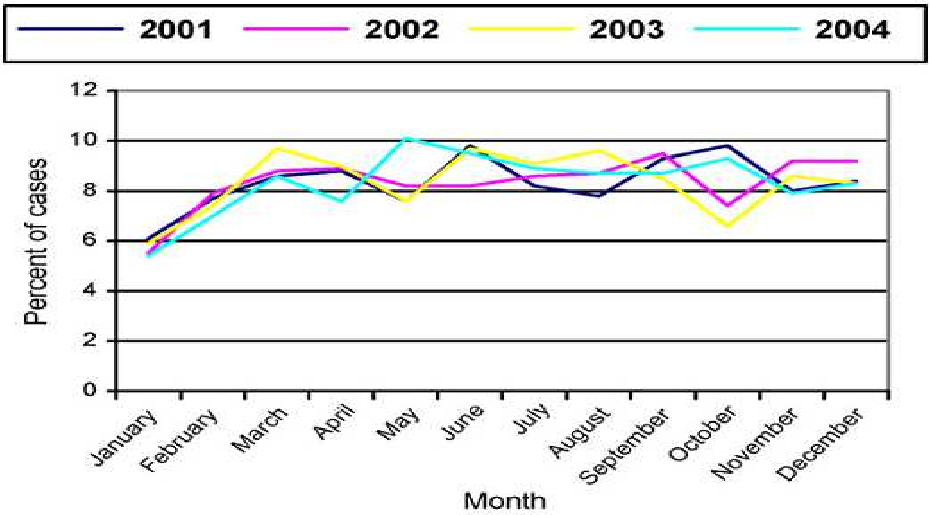

Figure 2-7: Pedestrian fatalities by month for 2001-2004 (Source: Mabunda et al., 2008)

2.3. Pedestrian characteristics

2.3.1. Pedestrian categories

Pedestrians in this study are defined as people who travel on foot or who use assistive devices to help them to walk. A much known categorisation of pedestrians has been proposed, based mainly on trip purpose, level of cognitive, sensory and physical ability (Department for Transport, 2004).

2.3.1.1. Pedestrian categories based on trip purpose

Purposes for pedestrian trips are various and should be listed as follows (OTAK, 1997):

- To and from work and school;
- Shopping;
- Social visits and events;
- Health and exercise;
- Appointments;
- Errands and deliveries;
- Recreation;
- Extra-curricular activities;
- Combined (recreational walking while shopping);
- Multimodal trips (walking to a bus stop or a train station).

Based on trip purposes, four categories of pedestrians are mainly considered in research, namely, commuters, students, shoppers, joggers and leisure walkers. Differences in these categories are generally based in their route choices, walking speeds, walking space requirement, ease of access, and the quality of land use. Commuters and students use the same facilities day after days and tend to walk faster

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than other shoppers. They prefer a fast direct route between home and work or school or when accessing public transport, regardless of quality of environment. Shoppers and leisure walkers tend to walk slower than commuters as they often carry packages or have to observe the walking environment, and look for ease of access, attractive retail environments and attractive routes. Joggers travel at higher speeds than other groups and prefer non-congested routes or routes with few physical obstructions.

2.3.1.2. Pedestrian categories based on cognitive and psychological abilities

Pedestrians vary widely in their cognitive and psychological abilities. Cognition is the ability to perceive, recognize, understand, interpret, and respond to information (Axelson et al., 1999).

a) Child pedestrians

Child pedestrians' capabilities differ significantly from those of adult pedestrians because of their physical build, developmental immaturity and lack of experience. Child pedestrians compared to adult pedestrians, present the following characteristics (FHWA and NHTSA, 1996; Pline, 1992; Fitzpatrick et al., 2006):

- Small stature of child pedestrians may make it difficult for them to evaluate correctly the traffic situation;
- Children's risk-perception is poor;
- Their ability to recognize and react to the situation is limited, especially for complex situations;
- Visual reaction time decreases with age in children, by a factor of about three between the ages of 4 and 17 (Reiss, 1977 cited in Pline, 1992);
- Auditory reaction time is also slower for younger children, and they have difficulty in correctly localizing the direction of sounds;
- Attention span is shorter in children than in adults;
- They have less peripheral vision and poorer visual acuity until about the age of 10 years;
- They have difficulty discriminating between right and left;
- They have less accuracy in judging speed and distance, thus misjudging when it is safe to cross the road;
- They lack familiarity with traffic patterns and expectations;
- They are unpredictable or impulsive;
- They are self-confident;
- Many children believe that:
  — the safest way to cross the road is to run;
  — adults will be kind to them and protect them;
  — it is safe to cross against the red light.

These characteristics are most of the time the leading causes of traffic accidents involving child pedestrians. According to the World Health Organization (WHO, 2004), road traffic fatalities involving children accounted for 21 percent of all road traffic fatalities worldwide.

b) Proficient adult pedestrians

Proficient adult pedestrians are highly competent in traffic situations and capable of perceiving and dealing with hazardous traffic situations.

c) Elderly pedestrians

The aging process is frequently associated with a general deterioration of physical, cognitive, and sensory abilities. Their physical frailty is commonly associated with the greater vulnerability. Like children, elderly people are more likely to rely on public transport and are more likely to walk than adult people because they cannot drive. They also have a lot of free time, and thus they tend to do more walking trips than other groups. The common characteristics of elderly pedestrians have been referred in several studies (FHWA and NHTSA, 1996; Pline, 1992; Knoblauch et al., 1996; Staplin et al., 1998):

- Limited vision, such as degraded acuity, poor central vision, and reduced ability to scan the environment;
- Limited attention span, memory, and cognitive abilities;
- Reduced endurance and stamina;
- Reduced tolerance for extreme temperature and environments;
- Impaired judgement, confidence, and decision-making abilities;
- Inability to do quick evasive actions;
- Decreased agility, balance and stability;
- Slower reflexes;
- Reduced walking speed;
- They are more law-abiding than the general population and thus, they are too trustworthy of traffic signals and of drivers while crossing the street;
- Reduced range of joint motion;
- Difficulty in assessing the speed of approaching vehicles, thus misjudging safe gaps between vehicles;
- Reduced ability to detect, localize, and differentiate sounds.

d) Pedestrians with sensory impairments

Sensory disabilities much commonly known are visual impairments (total blindness, partial vision loss, and colour blindness), deafness, and hearing deficit. Other types of sensory disabilities affecting touch, balance or ability to detect the position of one's own body in space could be also considered (Axelson et al., 1999).

- **Pedestrian with visual impairment**

Blind pedestrians rely on the sense of touch to explore the area and hearing to get the information about the speed, direction of travel and locations of vehicles. Two distinct types of information are processed by pedestrians with visual impairments along sidewalks and trails: detectable warnings and wayfinding information (FHWA and NHTSA, 1996). Detectable warnings are defined as surfaces that can be detected underfoot and by a person using a cane through texture, colour and resilience, and are

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intended to identify potential hazardous situations. Wayfinding information is intended to provide orientation information to the user, by means of visual cues, tactile surface and auditory information. Examples of wayfinding information include tactile guidestrip at crosswalks and audible pedestrian signals. There is little research on colour blind people, especially those who cannot distinguish red and green. The confusion is inevitable while negotiating intersections with pedestrian signals that use distinct colours.

Mobility-related characteristics of pedestrian with visual impairments have been reported by Clark-Carter et al. (1986):

- Limited perception of the path ahead;
- Navigation with limited information about surroundings, providing less protection against obstacles and other dangers;
- Reliance on memory and unchanging conditions in familiar terrain;
- The need to assimilate information obtained through non-visual sources such as texture and sound;
- Difficulty perceiving or reacting information quickly to approaching hazard.

Based on aids used for their mobility, pedestrian with visual impairments are in two categories: *cane users* and *dog-guide users*. Blind pedestrians relying on canes use two distinct techniques; touch technique and diagonal technique. The former is used in uncontrolled areas such as on sidewalk, and the latter is used primarily in controlled and familiar environments. Trained dogs are also used to guide blind pedestrians in response to a specific set of commands given by voice and hand signals (Whitstock et al., 1997). They are trained to avoid obstacles, to pause at stairs, curbs and other changes in elevations (Axelson et al., 1999).

- **Pedestrian with hearing impairment**

Hearing impairment is not believed to be a significant safety problem while negotiating sidewalks, trails or crossing streets. However, auditory cues such as the increasing noise of an approaching vehicle may be important to detect impending hazards. Therefore, people with hearing impairment depend highly on visual indicators or vibrations caused by passing traffic (Axelson et al., 1999).

e) Pedestrians with cognitive impairments

Cognitive impairments are associated with reduced ability to process information and make decisions (ITE, 1998). People with cognitive disabilities are often forced to walk as cognitive disorders can hinder the ability to think, learn, respond, and perform coordinated motor skills. Illiterate people or people unable to read or understand the language used in traffic signs often fall into this category too. That is the reason that signs which use pictures, universal symbols and colours are recommended to increase the clarity of pedestrian signals for those people who cannot read. Those people have difficulty navigating through complex environments and are more likely to be lost than normal people (Axelson et al., 1999).

2.3.1.3. Pedestrian categories based on physical abilities

Pedestrians vary widely in their degrees of mobility. Physical ability of pedestrians affects mobility in a number of ways. Two main categories of pedestrians are considered in this study, based on physical ability: *able pedestrians* and *mobility-impaired pedestrians.*

i. Able pedestrians

Able pedestrians can be subdivided into following subgroups:

- *On foot*: This category includes normal walkers and runners/joggers.
- *On small wheel*: This category includes pedestrians on in-line skates, roller skates, skateboards, kick scooters and pedestrian with a pram.

The small wheels, notably skateboards, kick scooters, roller skates and in-line skates are self-propelled and are therefore, used for utility travel. Small wheel users normally travel faster than on-foot walkers, but slower than motorised vehicles. This can result in serious injuries to the device users, especially when they travel on the roadway. Many countries don't have road rules prohibiting their use on footpaths or roadways. In many cases, they are subjected to the same design principles as those travelling on foot. However, high quality surface conditions and smooth kerb crossings should be provided to allow the ease of their travel.

ii. Mobility-impaired pedestrians

Anyone can be mobility-impaired temporarily due to age, heavy luggage, illness or injury. This category includes those who have permanent physical disability, commonly those who use wheelchairs, scooters, crutches, walking sticks or canes, walkers, orthotics, and prosthetic limb. This category also includes people with mobility impairments but who do not use assistive devices. Their common characteristics are the slower walking speed, increased space requirement to accommodate assistive devices, difficulty in changing level, and the need of good surface quality.

❖ **Wheelchair and scooter users**

Wheelchairs are of three different types: wheelchair manually self-propelled, wheelchair helper propelled, and wheelchair battery powered (see Figure 2-8). Common characteristics of wheelchair and scooter users are given as follows (Axelson et al., 1999; New Zealand Transport Agency, 2009):

- Wheelchair and scooter users often travel at higher speeds on level surfaces or downhill than walking pedestrians, but at slower speeds uphill;
- They require a wider path to travel or to pass others;
- They require more space to turn around than other pedestrians;

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— Their eye level is lower;
— Reduced stability, especially while travelling over areas with severe cross-slopes;
— Manual wheelchair users need additional work while travelling over uneven or soft surfaces.

Manually self-propelled wheelchair

Helper propelled wheelchair

Battery powered wheelchair

Electric scooter

Figure 2-8: Wheelchairs and scooter

❖ **Walking-aid users**

Walking-aid users include those who use canes, crutches, or walkers to help them to walk (Axelson et al., 1999). Their common characteristics are as follows (Bhambani and Clarkson, 1989; New Zealand Transport Agency, 2009):

— Slower walking speed;
— Reduced stability;
— Difficulty negotiating steep grades and steep cross-slopes;
— Reduced endurance;
— Inability to react quickly to dangerous situations;
— Reduced floor reach.

❖ **Prosthesis users**

People lacking one or more limbs, hands, and/or feet often use artificial device extension that replaces a missing body part. Although people using leg prostheses can achieve the levels of fitness similar to their non-disabled peers, their walking speeds are typically slower than if non-disabled people, especially those with above-knee prostheses (Ward and Meyers, 1995 cited in Axelson et al., 1999). Maintaining stability on grades or cross-slopes is also another difficulty for people with lower limb prostheses.

2.3.1.4. Disabilities in South Africa

The census carried out in 2001 revealed that 5 percent (2 255 982 persons) of the total population (44 819 778) were people with disabilities in South Africa (Statistics South Africa, 2005). Disability rate was found higher among females than males, with 1 173 939 females versus 1082 043 males. Broken down into age groups, a steady increase in disability is clearly noticeable, from 2.1 percent in the 0-9 years age group up to 27.2 percent in 80 years and over age group. At national level, sight disability was the highest prevalent (32 percent), followed by physical disability (30 percent), hearing (20 percent), emotional disability (16 percent), intellectual disability (12 percent) and lastly communication disability (7 percent). Disability profile by gender is illustrated in Figure 2-9. In Western Cape Province, a total of 186 850 (4.1 percent) persons live with different types of disabilities.

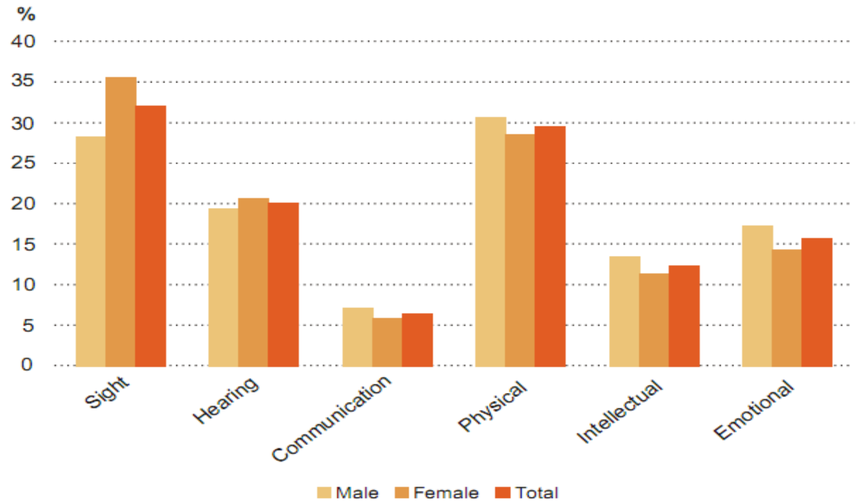

Figure 2-9: Percentage of disabled people by type of disability (Source: Statistics South Africa, 2005)

2.3.2. Pedestrian needs

2.3.2.1. Psychology of space

Five core psychological principles have been established in order to attract pedestrians to walk (Florida DOT, 1999; IHT, 2000 cited in DfT, 2004):

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- *Security and safety:* For the well-being of the user, not only must the
- infrastructure be safe, but must also guarantee its users enough security. Streets with high traffic volume and vehicles moving at high speeds, too much noise, places that are dark, too many hidden pockets, too little activity, isolated, or broken up by "dead" corners or open parking lots, blank walls or block-long voids tend to dissuade people from walking.
- *Comfort:* People tend to walk where basic amenities are provided. Those amenities include wide sidewalks, trails, good surfacing, kerb ramps, crosswalks, grade separations (underpasses and overpasses), guard railing, wide shoulders in rural areas, adequate sidewalk grades and cross slopes, furnishings that attract pedestrians (such as benches and landscaping), other technologies, design features and strategies intended to encourage walking activity (such as traffic calming devices), planting strips, shelters, public art, and lighting. People also are comfortable when they are free from fear of crime.
- *Convenience:* Attractive streets for pedestrians are those that provide a blend of services and economic life at a pedestrian scale. Routes should cater for users wishing to walk, window shop, stop to look at more pleasant environments, chat and rest. The pedestrians' ability to select their own individual walking pace and speed is also a qualitative measure of convenience.
- *Efficiency and affordability:* Streets must be affordable (not overly expensive) for all categories of people. However, the street price should not compromise its quality.
- *Attractiveness:* People should feel welcomed by the place and inspired for return visit. That feeling of welcome should be imparted by employees, by the people who share the street, and the physical presence of the street itself.

2.3.2.2. Pedestrian spatial needs

a. Pedestrian dimensions

The pedestrian body depth and shoulder breadth are recommended as the minimum implicit space standards. The plan view of the human body is seen as an ellipse defined by the body depth and shoulder breadth measurements. Fruin (1971) suggested a simplified body ellipse, as the basic space for a single standing pedestrian. That pedestrian body ellipse was of 46 cm by 61 cm (1.5 ft by 2.0 ft), with a total area of 0.28 m^2 (3 ft^2), and was that recommended in the *Highway Capacity Manual* (HCM 2000). In a recent study by Rouphail et al. (1998), a simplified body ellipse of 50cm by 60 m (1.64 ft by 1.96 ft) has been recommended for a single standing pedestrian, with a total area of 0.3 m^2 (3.2 ft^2)(see Figure 2-10). Pedestrian dimensions when walking (Figure 2-11) and when sitting (Figure 2-13) are recommended in Washington State's Pedestrian Facilities Guidebook (OTAK, 1997). As an example, the average space required for two people walking side-by-side or passing each other while travelling in opposite directions may be taken equal 1.4 metres (4.59 ft), with adequate buffer areas on either sides.

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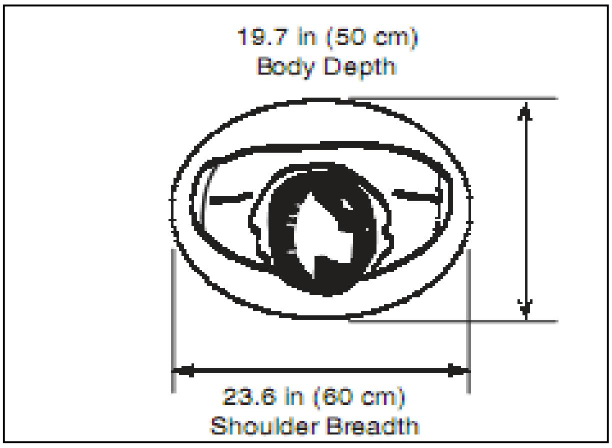

Figure 2-10: Recommended pedestrian body ellipse for standing area (Source: Florida Pedestrian Facilities Planning and Design Handbook, 1999)

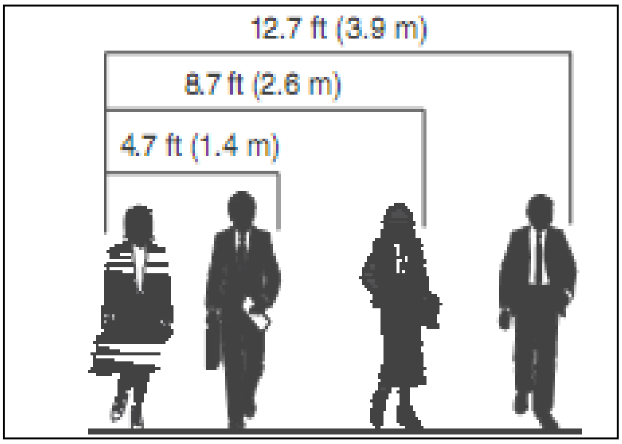

Figure 2-11: Spatial dimensions for pedestrians (Source: Washington State's Pedestrian Facilities Guidebook, 1997)

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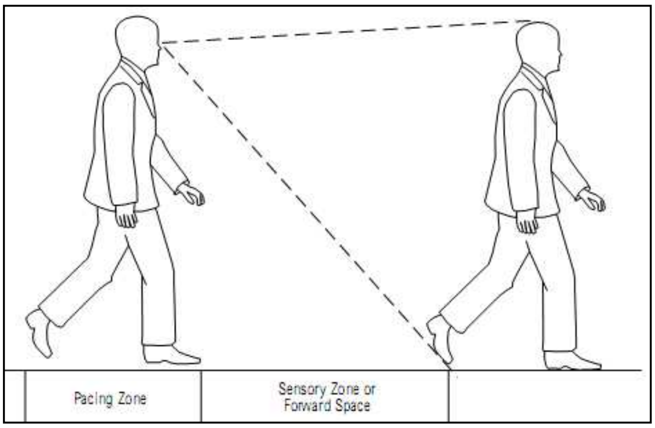

Figure 2-12: Pedestrian walking space requirement (Source: Florida Pedestrian Facilities Planning and Design Handbook, 1999)

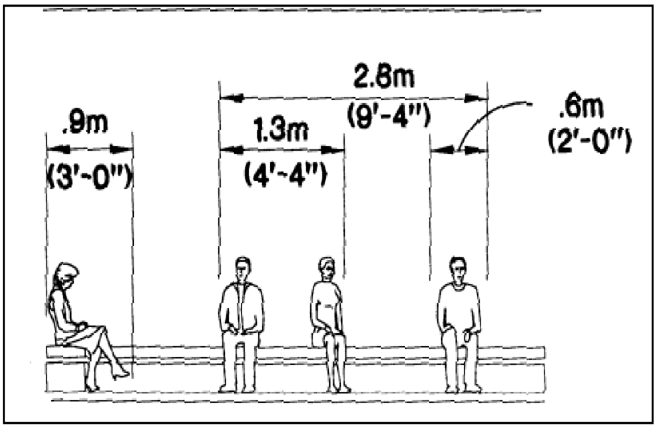

Figure 2-13: Human dimensions when sitting (Source: Washington State's Pedestrian Facilities Guidebook, 1997)

b. Spatial bubbles

Considering the breadth of human shoulders, body sway, and avoidance of contact with others, a walking pedestrian requires a certain amount of longitudinal and lateral space for comfortable movement. The longitudinal space for walking is known as *spatial bubble.* It is defined as the preferred distance of unobstructed forward vision while walking under various circumstances (OTAK, 1997). It includes a space for pacing and a space for avoiding conflicts, also called "sensory zone" or "forward" (see Figure 2-12). For a reasonable level of movement comfort, spatial bubbles for pedestrians attending public events, shoppers, leisure walkers and pedestrian walking under normal conditions are recommended in the study by the Washington State's Pedestrian Facilities Guidebook as illustrated in the Figure 2-14 (OTAK, 1997).

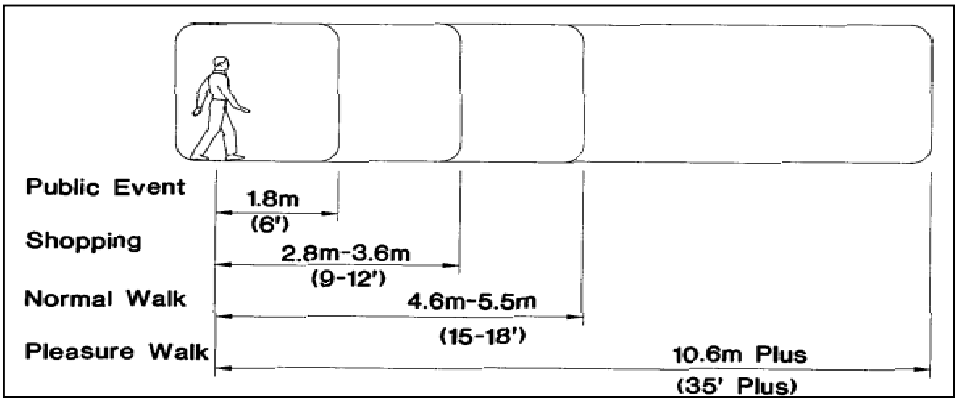

Figure 2-14: Spatial bubbles needed by different categories of pedestrians (Source: Washington State's Pedestrian Facilities Guidebook, 1997)

c. Pedestrians with disabilities

Spatial needs for disabled pedestrians vary widely depending on their physical ability and the type of assistive devices they use (Fitzpatrick et al., 2006). Wheelchair and scooter users need more space than other disabled pedestrians. Recommended spatial dimensions needed for wheelchair user, pedestrian with crutches, and a vision-impaired pedestrian using the cane technique are illustrated in Figure 2-15 and Figure 2-16.

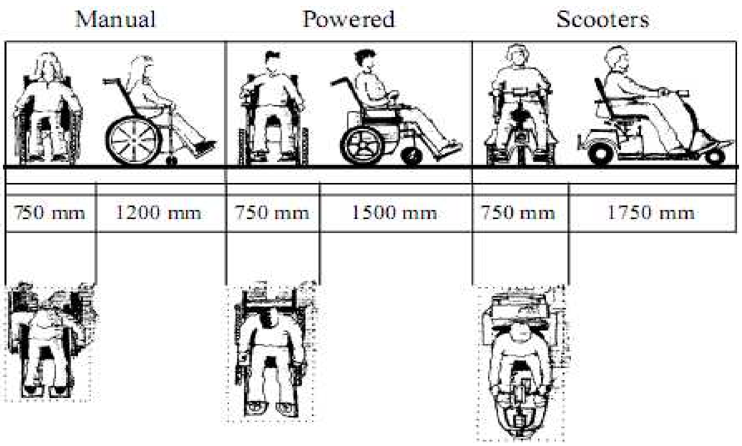

Figure 2-15: Spatial dimensions for pedestrians with disabilities (Source: Axelson et al., 1999)

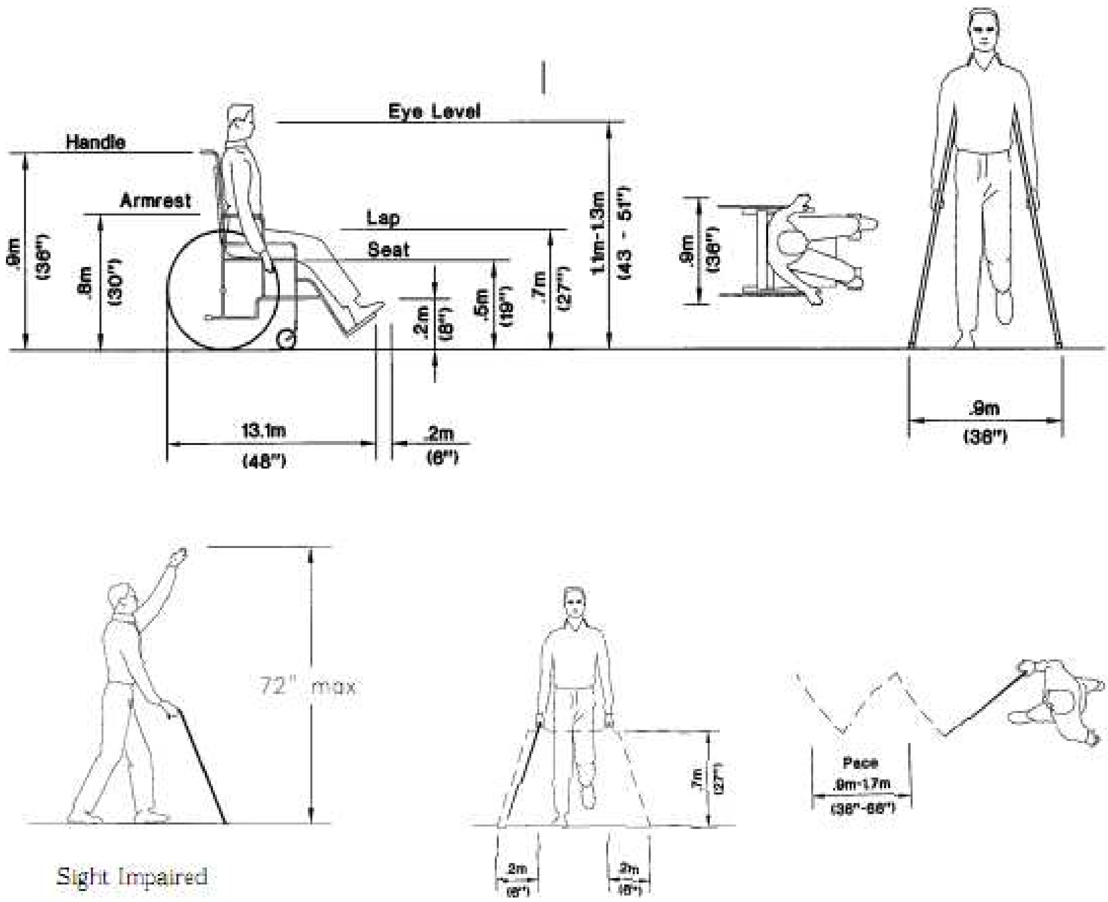

Figure 2-16: Spatial dimensions for pedestrians with disabilities (Source: Washington State's Pedestrian Facilities Guidebook, 1997)

2.3.3. Pedestrian walking speeds

As pedestrian walking speed has many applications in the design of traffic engineering facilities, an important number of studies have been published, assessing walking speeds of different categories of pedestrians at various pedestrian facilities and in different conditions. Pedestrian walking speed is considered as the key input in the implementation of safety measures and the design of appropriate facilities at pedestrian crossings. As pedestrian walking speed is affected by a number of factors, such as demographic features, personal mobility ability, trip purpose and environmental factors, differing results exist in the literature.

Design manuals, such as the *U.S Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) has suggested a walking speed of 1.22 m/s (4.0 ft/s) for calculating pedestrian clearance intervals for traffic signals (DOT, 2003). This value was similar to that one recommended by the *Manual of Uniform Traffic Control Devices* for Canada for signal timing purposes (Transportation Association of Canada, 1998). The MUTCD also states that where pedestrians routinely walk more slowly than normal, or where wheelchair users or people using other assistive devices cross the road, a walking speed of less than 1.22 m/s (4.0 ft/s) should be used in determining the pedestrian clearance times.

In *Recommended Procedures Chapter 13, 'Pedestrian', of the Highway Capacity Manual,* a pedestrian crossing speed of 1.2 m/s (3.9 ft/s) has been recommended for most conditions (Rouphail et al., 1998). A value of 1.0 m/s has been recommended by the same authors in areas with large numbers of older pedestrians or when the presence of elderly pedestrians begins to materially affect the overall speed distribution at the facility. The term "large numbers of older pedestrians" used in their study means when the percentage of elderly using the facility in question exceeds 20 percent. In similar conditions, the *Traffic Engineering Handbook* reports that a walking speed of 0.91 to 0.99 m/s (3 to 3.25 ft/s) would be more appropriate for traffic signal timing purposes (Pline, 1992).

The recent TCRP-NCHRP study by Fitzpark et al. (2006) has found a mean walking speed of 1.44 (4.72 ft/s) and a 15th percentile speed of 1.13 m/s (3.70 ft/s) for the whole sample observed. By comparing their results with those from previous works, walking speeds of 1.1 m/s (3.5 ft/s) and 0.9 m/s (3.0 ft/s) have been recommended for general population and for older or less able population, respectively.

In the United Kingdom, Willis et al. (2004) reported that a mean speed of 1.47 m/s was found in his study, with minimum and maximum walking speeds of 0.45 m/s and 5.56 m/s, respectively. A number of factors, such as gender, age, mobility, group size, time of day and location were reported in this study to have an effect on this observed walking speed as it will be addressed in the following section.

In the Netherlands, a study has been carried out by Daamen and Hoogendoorn (2006) with the purpose to assess free speed distributions for pedestrian traffic. Free speed or desired speed was defined by the authors as a speed a pedestrian walks with when it is not hindered by other pedestrians. Free speed distributions of unidirectional flows, opposite flows, and crossing flows were estimated and compared. The results from all five laboratory walking experiments showed estimated free speeds varying between a minimum of 1.44 m/s and a maximum of 1.64 m/s.

An Australian study carried out at pedestrian actuated mid-block signalised crossings in Melbourne showed an average walking speed of 1.42 m/s and a 15th percentile speed of 1.18 m/s (Akçelik & Associates, 2001). The crossing speed (1.2 m/s) recommended by AUSTROADS (1993 & 1995 cited in Akçelik & Associates, 2001) and the *Highway Capacity Manual* (HCM 2000) corresponded to the 16th percentile speed of observed pedestrians. For sites with slower pedestrians, a recommended value of 1.0 m/s corresponded to the 4th percentile speed.

In Jordan, Tarawneh (2001) conducted a study in which he evaluated pedestrian crossing speed. The results revealed that the average and 15th percent speeds in Jordan were 1.34 m/s and 1.11 m/s, respectively. For the design purpose, the 15th percentile speed of 1.11 m/s was recommended by the author, and at least 85 percent of pedestrian population are expected to be accommodated by the use of this value at signalised crossings. In areas where older pedestrians are predominant, a design speed of 0.97 m/s was recommended by Tarawneh (2001) in order to accommodate at least 85 percent of slower pedestrians.

In china, a walking speed of 1.2 m/s has been reported to be suitable for all pedestrians including older pedestrians (Shi et al., 2007). This speed has been recommended after finding that walking speeds for different categories of pedestrians at different pedestrian facilities were higher than this value in most of the cases.

A study carried out by Rastogi et al. (2011) has investigated pedestrian walking speed in three types of roads, namely, three-lane undivided, four-lane divided, and six-lane divided in seven locations in India. Effects of a number of factors, namely, traffic lanes, traffic volume, width of the road, size of the study area, land uses of the surrounding area, personal characteristics (age and gender) and group size on pedestrian crossing speed have been investigated in great extent. The mean speeds observed in this study were found in the range 1.09-1.28 m/s, with an average of 1.17 m/s. The 15^{th} percentile speeds were found to vary from 0.83 m/s to 1.02 m/s, which is less than the value recommended in many design manuals. For the design purpose, a value of 0.95 m/s (average of the 15^{th} percentile speeds) was recommended by Rastogi et al. (2011) as appropriate speed under normal crossing conditions. The observed values as well as the recommended ones in this study are much less than those in other countries, inferring that pedestrians in India may walk slower than in other countries.

In South Africa, an average speed of 1.44 m/s was reported by Jordaan and Joubert (1983 cited in Van As and Joubert, 2000). Children walked faster at approximately 1.6 m/s, whereas the slowest walking speed was observed amongst elderly pedestrians, with approximately 1.3 m/s. A design speed of 1.2 m/s which corresponds to the 15^{th} percentile speed is normally in practice, but a value of about 1.0 m/s was reported to be appropriate for slower pedestrians.

2.3.3.1. Effect of demographic factors on pedestrian walking speed

i. Effect of gender

A number of studies have shown that walking speeds vary with gender of pedestrians. As an example, a study by Coffin and Morral (1995) conducted in Canada found that walking speed was higher for men than for women, with 1.29 m/s (4.23 ft/s) and 1.24 m/s (4.07 ft/s) respectively. In another recent Canadian study, Montufar et al. (2007) have revealed that female pedestrians walk slower than male pedestrians, regardless of the age and season. Their study showed also that the walking speed of 1.2 m/s (4.00 ft/s) recommended by the Canadian and U.S MUTCD would exclude nearly 40 percent of older pedestrians in the design process on the basis of their observed crossing speed.

In the United States, gender difference in walking speed was reported by Knoblauch et al. (1996). Amongst younger pedestrians, the mean walking speed was 1.56 m/s (5.11 ft/s) for males, whereas it was 1.46 m/s (4.79 ft/s) for females. In the group of older pedestrians, the mean walking speed for males was 1.31 m/s (4.31 ft/s) whereas it was

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1.19 m/s (3.89 ft/s) for females. In the TCRP-NCHRP study by Fitzpatrick et al. (2006) male pedestrians were found to walk faster than female pedestrians, with the mean speeds being 1.45 m/s (4.75 ft/s) and 1.42 m/s (4.67 ft/s), respectively. The comparison of these results did not show a statistic difference, and underrepresentation of older women within the study set was deemed to be the reason. However, this was not the case for the Scottish study by Willis et al. (2004) who found a significant difference in walking speed between men and women, with 1.52 m/s and 1.42 m/s, respectively.

In China, a group of researchers investigated the walking speed on unsignalised mid-block crossing in Beijing. They found that pedestrian walking speed varies with the gender, group constitution (number of pedestrians in a group), and the direction or trip purpose (Shi et al. 2007). The results showed that men walk at a higher speed than women, with 1.57 m/s and 1.47 m/s at unsignalised mid-block crossing, respectively.

In Jordan, the study conducted by Tarawneh (2001) reported that generally male pedestrians walk faster than female pedestrians. The mean crossing speed was 1.35 m/s for male pedestrians whereas it was 1.33 m/s for female pedestrians. The 15th percentile speeds were 1.12 m/s and 1.11 m/s, respectively.

The same results were found in the Indian study carried out by Rastogi et al. (2011). Average crossing speed was found to be higher for male pedestrians (1.22 m/s) than female pedestrians (1.11 m/s), irrespective of road type and land use. The respective 15th percentile speeds were 0.98 m/s (in the range 0.84-1.05 m/s) and 0.91m/s (in the range 0.83-1.01 m/s). It can be noticed that these observed walking speeds fall into the lowest walking speeds cited in this study. This study suggested the value of 0.91 m/s as the design walking speed in locations where female pedestrians are predominant.

Gender-related difference in pedestrian walking speed has been investigated also in South Africa. A recent study by Hermant (2011) has explored pedestrian movement behaviour within South African railways station environments. Walking speeds at platforms and skywalks were measured at two train stations in Cape Town. Observed walking speeds were found affected by personal, situational and environmental factors. Men were found walking faster than women (1.19 m/s versus 1.01m/s). Person size was also found by Hermant (2011) to have an effect on walking speed. His results showed a decreasing trend in average walking speed with increasing body size in both genders. As an example, the average walking speeds were 1.49 m/s and 1.19 m/s for male lean build pedestrians and male large build pedestrians respectively. Female lean build pedestrians were found also to walk at higher speed than their corresponding large build pedestrians, with 1.20 m/s and 0.98 m/s, respectively. However, the absence of vehicular traffic and the type of walking environment should be considered while comparing these results with those obtained from other pedestrian facilities.

Even though gender-related difference in walking speed was highlighted in the majority of case, few studies reported similar walking speeds or a lack of significant statistic difference (see Wilson and Grayson, 1980; Tanaboriboon and Guyano, 1991 both cited in Rastagi et al., 2011; Fitzpark et al., 2006).

ii. Effect of age

Research has also noted variations in walking speeds according to the age of pedestrians. In a Canadian study published by Coffin and Morral (1995), senior pedestrians were found to walk slower than young pedestrians, with respective mean walking speeds of 1.13 m/s (3.71 m/s) and 1.34 m/s (4.40 ft/s). The same authors suggested the walking speeds of 1.0 m/s (3.28 ft/s) at crossing facilities close to seniors and nursing homes and 1.2 m/s (3.94 ft/s) at other crossing facilities.

In the United States, a number of studies and reports on pedestrian walking speed have suggested a range of walking speeds for elderly pedestrians. In a survey conducted by the *U.S Institute of Transportation Engineers* (ITE committee 4A-6 1983) in Florida, a value of 0.75 m/s (2.5 ft/s) was suggested to be an appropriate walking speed at locations with higher proportions of elderly pedestrians. This speed was found also adequate for 87 percent of observed pedestrians (ITE, 1983 cited in Knoblauch et al. 1996).

Knoblauch et al. (1996) found that the mean walking speeds for younger pedestrians (ages 14 to 64) range from 1.38 to 1.56 m/s (4.51 to 5.12 ft/s) across all conditions, with an overall mean speed of 1.46 m/s (4.79 ft/s). The mean walking speeds for older pedestrians (ages 65 and over) range from 1.14 m/s to 1.29 m/s (3.73 ft/s to 4.24 ft/s), with an overall mean speed of 1.20 m/s (3.94 ft/s). Similarly the 15^{th}-percentile walking speeds were 1.19 m/s (3.97 ft/s) and 0.94 m/s (3.08 ft/s) for younger pedestrians and older pedestrians, respectively. For design purposes, the same authors recommended walking speeds of 1.22 m/s (4.00 ft/s) for younger pedestrians and 0.91 m/s (3.00 ft/s) for older pedestrians.

The TCRP-NCHRP study by Fitzpatrick et al. (2006) has also confirmed that age-related difference in walking speed between older and younger pedestrians. They recommended a walking speeds of 1.07 m/s (3.5 ft/s) for the general population and 0.90 m/s (3.00 ft/s) for the older or less able populations. By projecting proportions of younger people and people older than 60 years old, the same authors found the proportionally weighted walking speeds of 1.09 m/s (3.56 ft/s) for the whole U.S population in the years 2025 and 2045.

A number of earlier British studies investigated pedestrian walking speed based on pedestrian characteristics. These studies reported a greater variation in walking speed between younger and older pedestrians, with an average walking speed varying from 1.11 to 1.16 m/s for older pedestrians and from 1.32 to 1.72 m/s for younger pedestrians (Sjostedt, 1967; Cresswell et al., 1978; Wilson and Grayson, 1980; Griffiths et al. 1984, all cited in Rastogi et al., 2011). The effect of age on walking speed was also reported in the study carried out by Willis et al. (2004) in the United Kingdom. Their study showed that pedestrians who appeared to fall in age group of 16-50 years old walked faster than two older groups (51-64 and 65 years old and over). The youngest group (under 16 years old) had the highest mean walking speed (1.53 m/s) with the greatest variability in speed measurement (SD being 0.447), whereas pedestrians over 64 years old exhibited the slowest mean walking speed (1.16 m/s).

Other relevant studies conducted in Europe include a Dutch study by Daamen and Hoogendorn (2006) who observed average crossing speeds of 1.24 m/s and 1.5 m/s for older and younger pedestrians, respectively. In a recent Irish study conducted at a pelican crossing in Dublin, Romero-Ortuno et al. (2009) assessed whether crossing times required by the Traffic Management Guidelines (TMT) are sufficient for elderly pedestrians when they cross at their preferred speed. The results from the linear regression analysis between four different ages (i.e. 60, 70 80 and 90) and observed walking speeds showed that age and walking speed had a strong inverse correlation. Walking speeds were found to be 1.30 m/s (95% CI 1.24-1.35) at the age of 60; 1.10 m/s (1.07-1.13) at the age of 70; 0.91 m/s (0.87-0.94) at the age of 80 and 0.73 m/s (0.66-0.80) at the age of 89. This study concluded that standard crossing times appeared insufficient for very old people, as the results showed that pedestrians aged 89 or above were likely to walk at lower speed than the minimum speed required to cross the narrowest standard road.

In the Indian study by Rastogi et al. (2011), except in one crossing in Delhi, observed 15th percentile speeds of young, adult and older pedestrians at other six locations were found to be less than the most recommended value of 1.2 m/s. Moreover, crossing speeds less than 1.2 m/s were observed in almost 85 percent of the older pedestrians and 50 percent of adult pedestrians. The average of 15th percentile speeds were found to be 1.11 m/s (1.01-1.26 m/s) for younger pedestrians, 0.93 m/s (0.92-1.00 m/s) for adult pedestrians, and 0.79 m/s (0.75-0.86 m/s) for older pedestrians. The respective average of 50th percentile speeds were 1.29 m/s (1.19-1.49 m/s), 1.12 (0.99-1.24 m/s) and 0.91 (0.81-1.00 m/s). These results highlight clearly that the crossing speeds decline with increasing age of pedestrians.

In Jordan, the Tarawneh's (2001) study indicated that the crossing speed of middle-age pedestrians (21-30 and 31-45 years old) were the fastest compared with the speed of other age groups. Middle-age group was observed to walk at an average speed of 1.48 m/s and a 15th percentile speed of 1.23 m/s. Pedestrians aged 46-65 years old were found to walk at the same speed (the mean speed being 1.29 m/s and the 15th percentile 1.07 m/s) with young pedestrians (20 years or younger). Walking speed declined for older pedestrians (65 years old and over), with the observed walking speed being the slowest compared to other age groups (mean speed being 1.17 m/s and the 15th percentile 0. 97 m/s).

2.3.3.2. Effect of situational factors on pedestrian walking speed

Situational factors are those that characterise the particular context in which a pedestrian is walking, but which are not fixed from one outing to the next (Willis et al., 2004). Situational factors such as pedestrian density, group size, and level of mobility have been reported in several studies to have an effect on pedestrian walking speed.

a. Effect of group size

Earlier study by DiPietro and King (1970 cited in Rastogi et al., 2011) observed effects of group size on pedestrian walking speed. The observed 15th percentile speeds were 0.76

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m/s for single pedestrians, 0.67 m/s for couples of pedestrians, and 0.61 m/s while walking in groups of three and four pedestrians.

In South Africa, Hermant (2011) has investigated pedestrian walking speed on platforms of train stations. Different categories of group size have been observed, and the results showed that single pedestrians walk faster (with an average of 1.22 m/s) than those walking with one or two companions (1.02 m/s and 0.92 m/s, respectively).

The Chinese study by Shi et al. (2007) revealed that a couple of pedestrians walk at a lower speed than in other group categories. The mean speed was found to be 1.25 m/s for single pedestrians, 1.07 m/s for two pedestrians and 1.13 m/s for three or four pedestrians. Most of pedestrian couples were observed talking as they walked and were less cautious, and this was the reason given by the authors for their reduced walking speed.

Contrary to the Shi et al.'s (2007) study, the Jordanian study by Tarawneh (2001) found that pedestrians crossing as a group tend to walk slower than single pedestrians or pedestrians in couples. Single pedestrians as well as pedestrians walking in couples were found to walk at the same speeds of 1.35 m/s (mean speed) and 1.12 m/s (15th percentile speed), whereas groups of three pedestrians or more walked at the mean speed of 1.33 m/s and the 15th percentile speed of 1.11 m/s.

In Knoblauch et al.(1996)'s study, a single younger pedestrian was observed to walk at average speed of 1.54 m/s (5.04 ft/s) whereas while walking with others, the average speed was 1.42 m/s (4.66 ft/s). This difference was also noticeable in the group of older pedestrians, with 1.26 m/s (4.15 ft/s) for single pedestrians and 1.22 m/s (4.00 ft/s) while walking in a group. These results were quite similar to those reported in the TCRP-NCHRP study by Fitzpatrick et al. (2006); the average crossing speed was 1.5 m/s (4.92 ft/s) for single pedestrians, whereas it was 1.42 m/s (4.65 ft/s) while a group of two pedestrians were crossing.

Group size has also been reported to have an influence on walking speed in the Scottish study by Willis et al. (2004). Single pedestrians were observed to walk significantly faster than groups of pedestrians (1.52 m/s versus 1.36 m/s). Further analysis carried out in this study on walking groups revealed also that female pedestrians were more likely to walk in groups (54 percent) than male pedestrians (46 percent).

b. Effect of mobility ability

As expected, walking speeds for pedestrian with disabilities is lower than those of non-disabled pedestrians. Results from several studies conducted on people with disabilities have shown that walking speeds vary widely with the type of assistive devices used for their mobility. Table 2-1 shows some average walking speeds for pedestrians with various disabilities and assistive devices.

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Table2-1: Mean walking speeds for pedestrians with disabilities and users of various assistive devices (Source: Roess et al., 2011)

Disability or assistive device	Mean walking speed in m/s (ft/s)
Cane	0.80 (2.62)
Crutch	0.80 (2.62)
Walkers	0.60 (2.07)
Rheumatoid arthritis (knee)	0.75 (2.46)
Wheel chair	1.08 (3.55)
Hip Arthritis	0.68 to 1.11 (2.24 to 3.66)
Immobilized knee	1.07 (3.50)
Below knee amputee	0.75 (2.46)
Above knee amputee	0.60 (1.97)

Carrying packages or luggage, pushing children in prams or pushing trolleys also have an effect on pedestrian walking speed. In the study by Hermant (2011), significance difference in walking speed has been revealed between unencumbered pedestrians and pedestrians carrying baggage. The results from this study are illustrated in Table 2-2.

Table 2-2: Effect of Baggage on walking speeds (Platform only) (Source: Hermant, 2011).

Pedestrian categories	Average walking speed (m/s)
Unencumbered pedestrian	1.34
Pedestrians with rucksack, both straps over the shoulders	1.26
Pedestrians with bag/article in one hand	1.22
Pedestrians with slingbag with one strap over shoulder	1.15
Pedestrians with bag/article in both hands	1.07

The same results were found in the Scottish study by Willis et al. (2004). Walking speeds were found to decline with increasing load weight. As an example, observed mean walking speeds for unencumbered pedestrians, pedestrians with small bag or case and pedestrians with larger shopping bags or luggage were found to be 1.50 m/s, 1.46 m/s, and 1.40 m/s, respectively. Pedestrians with small children, pram or buggy

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exhibited also slower speed (0.139 m/s) compared to other encumbered groups. Spatial requirement for those walking with large shopping bags, small children or pram was also reported by the authors to have an effect on the normal walking speed.

In another South African study conducted in Cape Town, walking speeds have been investigated at 40 signalised crossings in order to determine whether the recommended speed of 1.2 m/s would accommodate safely elderly pedestrians in crossing facilities (Amosun et al., 2007). The results failed to show the effect of carrying a small load of an average weight of a shopping bag on the normal walking speed. The mean maximal unloaded and loaded walking speeds were 1.36 ± 0.31 m/s (0.73–2.03 m/s), and 1.36 ± 0.33 m/s (0.58–2.12 m/s), respectively.

An Australian study conducted at pedestrian actuated mid-block signalised crossings in Melbourne showed that mobility-impaired pedestrians have slower walking speeds than normal pedestrians (Akçelik & Associates, 2001). The observed average speeds were 1.29 m/s and 1.45 m/s respectively, and the 15th percentile speed (1.00 m/s) for mobility-impaired pedestrians was found to be close to the value recommended by Australian and U.S design guidelines for sites with higher populations of slower pedestrians.

c. Effect of density and space

The *Highway Capacity Manual* (HCM 2000) defines pedestrian density as the average number of pedestrians per unit area within a walkway or queuing area, expressed in pedestrians per square metre (p/m^2) (TRB, 2000). A number of studies have found that walking speed is significantly affected by density, and relationships between pedestrian speed and density were proposed for different categories of pedestrians (see Pushkarev and Zupan, 1975 cited in Schoon, 2010). In all these relationships, as volume and density increase, pedestrian walking speed declines. When the density reaches about 4 p/m^2 (0.4 p/ft^2), it becomes impossible for the pedestrian to move and the walking speed becomes zero (See Figure2-17).

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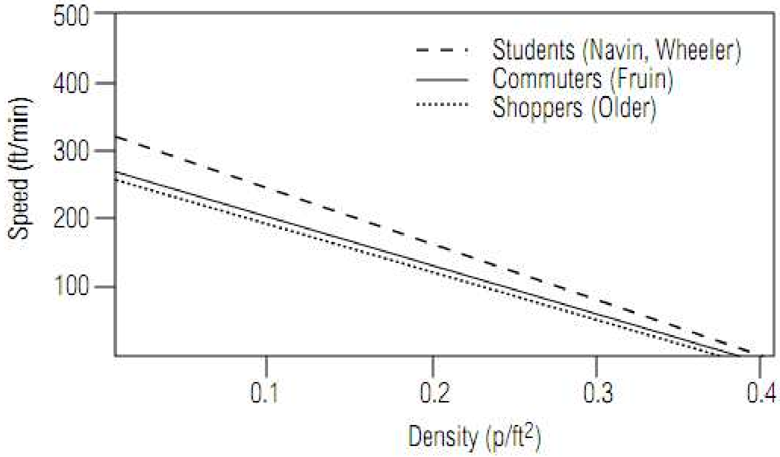

Figure 2-17: Relationships between pedestrian speed and density (Source: TRB, 2000).

As seen previously, pedestrians need unobstructed space for their comfortable walking (spatial bubble). Available walking space was another important factor reported in several studies to have an effect on pedestrian walking speed. The most relevant space-speed relationships (Figure 2-18) were proposed in the *Highway Capacity Manual* (HCM 2000) for different categories of pedestrians.

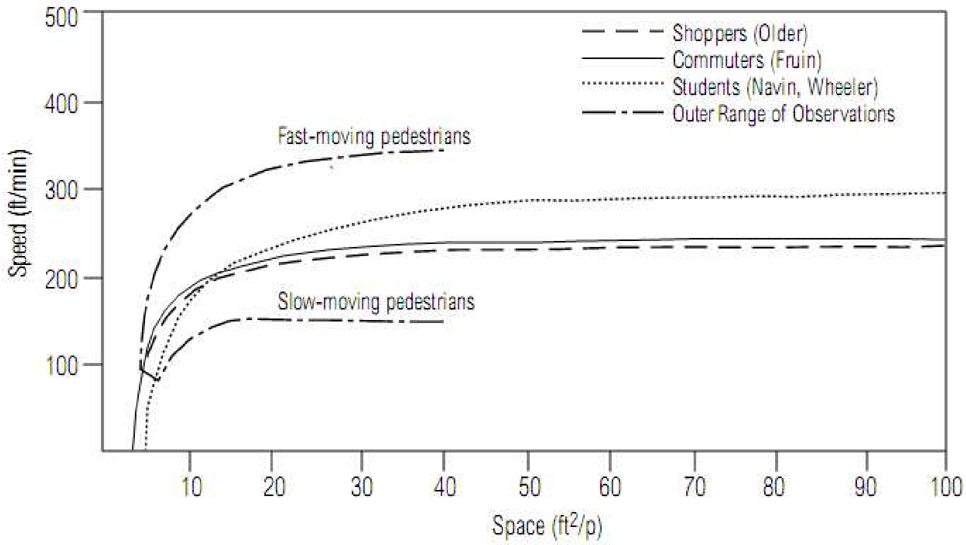

Figure 2-18: Relationships between pedestrian speed and space (Source: TRB, 2000).

From the Figure 2-18., the outer range of observations shown indicates that even for the slowest pedestrians, an average space of less than 1.5 m²/p cannot allow pedestrians to achieve their desired walking speeds. Similarly, a minimum average space of 4.0 m²/p is required for faster pedestrians walking at up to 1.8 m/s to achieve their desired speeds (TRB, 2000).

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d. Effect of distraction while walking

The use of electronic devices, such as mobile phones has been reported in an Australian study by Hatfield and Murphy (2006) to reduce crossing speeds of pedestrians. In both genders, pedestrians who crossed while talking on mobile phone were found to cross more slowly than those who crossed without using a mobile phone. However, there is a lack of published literature regarding the effects of auditory distraction such as listening to the radio on walking speed of pedestrians as well as other distraction such as eating while walking.

2.3.3.3. Effects of environmental factors on pedestrian walking speed

i. Effect of type of facility

Pedestrian walking speed has been found to vary according to the type of walking facility. The Chinese study by Shi et al. (2007) found that pedestrian walking speed was lower on footpath than at an unsignalised crosswalk; average walking speeds were 1.53 m/s and 1.13 m/s, respectively. Calming environment was deemed by the authors to be the reason of reduced speeds observed on footpath. The observed walking speed at the unsignalised crossing from this study (in the 1.46 m/s to 1.67 m/s range; average speed of 1.53 m/s) was higher than the walking speed (in the 1.25 m/s to 1.29 m/s range) found at a signalised crossing in a previous Chinese study citied in this study and carried out by Sun (2004).

In another recent Canadian study, Montufar et al. (2007) have revealed that normal walking speed is less than the crossing walking speed. The average normal walking speeds for younger and older pedestrians were 1.36 m/s (4.46ft/s) and 1.14 m/s (3.74 ft/s) respectively, whereas the average crossing speeds for younger and older pedestrians were 1.61 m/s (5.28 ft/s) and 1.36 m/s (4.46 ft/s), respectively. Normal walking speed and crossing speed have also been investigated and compared amongst older pedestrians using walkers or canes (Arango and Montufar, 2008). The observed average normal walking speed along the road segment was 0.78 m/s (2.56 ft/s), whereas while crossing a signalised intersection, the average speed was found to be 0.95 m/s (3.11 ft/s). The respective 15th percentile speeds were found to be 0.57 m/s (1.87 ft/s) and 0.73 m/s (2.39 ft/s. The pedestrians' desire to minimize their risk exposure while crossing an intersection has been deemed by the authors of these two studies to be associated with those differences between normal walking speed and crossing speed.

An uneven walking speed while crossing a divided street has been reported in several studies. The Australian study showed that pedestrian walking speed for the first half of the crossing (from roadside to median) were higher than the walking speed in the second half (from median to opposite roadside) in all three observed sites, with average crossing speeds of 1.51 m/s and 1.36 m/s, respectively (Akçelik & Associates, 2001). Although there is no big difference between crossing speeds in the first half and second half of a crosswalk, results from the Chinese study by Shi et al. (2007) confirmed that unevenness in walking speed in different stages of street crossing. The average walking speed in the first half was 1.54 m/s whereas it was 1.52 m/s in the second half. The

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same situation was also observed for pedestrians with walking difficulty; the average crossing speeds were 1.40 m/s and 1.21 m/s for the first half and the second half, respectively.

Another research was conducted in Hong Kong by Lam and Cheung (2000) in which crossing speeds at undivided roads were assessed and compared with those at divided roads. Crossing undivided roads was associated with higher walking speed compared to crossing divided roads, with average walking speeds being 1.45 m/s (86.91 m/min) and 1.35 m/s (81.28 m/min), respectively. Crossing the road in two stages allows pedestrians to re-examine the traffic conditions after finishing the first half, and this makes them less vulnerable compared to the crossing in the one stage. Thus, the reported discrepancy was deemed by the authors to be associated with the risk exposure incurred by pedestrians while crossing the road in one stage.

Pedestrian speeds while crossing have been also found to be affected by street width. As an example, in the study carried out by Tarawneh (2001) in Jordan, crossing speeds were higher in wide streets (14-16 m wide) than in narrower streets (6-8 m and 10-12 m wide), with mean speeds of 1.35 m/s and 1.34 m/s respectively. Walking speed was also found to vary with the number of travel lanes in the study by Knoblauch et al. (1996). Younger and older pedestrians were observed to cross two-lane roads at the 1.23 m/s (4.04 ft/s) and 0.95 m/s (3.12 ft/s), respectively. Their walking speeds increased while crossing roads of three to seven travel lanes, with 15th percentile speeds of 1.26 m/s (4.13 ft/s) and 0.99 m/s (3.26 ft/s), respectively.

In the Indian study by Rastogi et al. (2011), not only walking speed was found to vary with the number of travel lanes and the provision of pedestrian refuge or median, but also with the type of flow (unidirectional or bidirectional traffic). No significant difference was observed in 50th percentile speeds for all road categories. However the six-lane divided road exhibited higher 15th percentile speed but lower 50th and 85th percentile speeds than four-lane divided road (Figure 2-19). Considering the effect of road width and traffic direction, crossing speeds for three-lane undivided roads (bidirectional traffic movement) increased by 6 percent as compared with six-lane and four-lane divided roads (unidirectional traffic movement). This means that reduced width of road and unidirectional traffic movement results in psychological no-haste attitude in pedestrians (Rastogi et al., 2011). Broken down into two traffic volume (low and high traffic volume), relationships between the observed crossing speeds and widths of roads were provided as illustrated in Figure2-20.

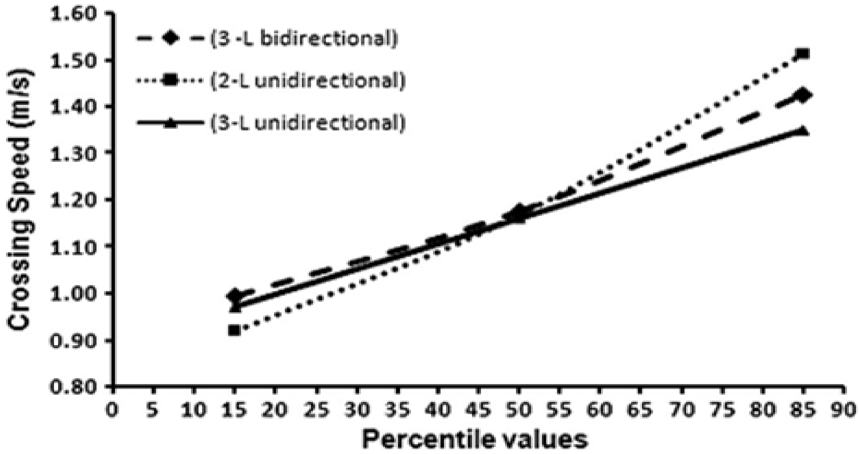

Figure 2-19: Variation in percentile crossing speeds with number of lanes and direction of traffic movement (Source: Rastogi et al., 2011)

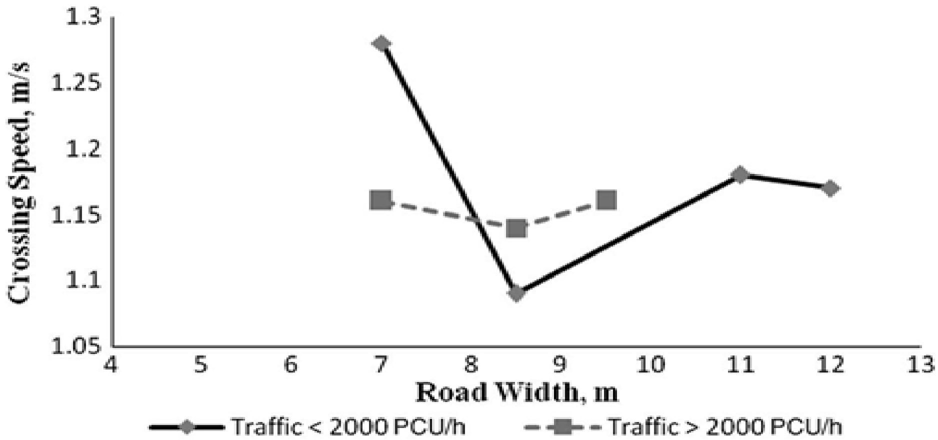

Figure 2-20: Variation in crossing speed with road width (Source: Rastogi et al., 2011)

The concave shape of these relationships stemmed from the influence of low traffic volume observed in the roads wide of 8.5 m, thus resulting in reduced crossing speeds because of psychological ease (Rastogi et al., 2011). In general case, it can be concluded that when crossing distance is quite long, pedestrians tend to rush to finish the crossing safely. It can be expected also that the closer the approaching traffic, the faster the crossing speed. This was proved by Moore (1953 cited in Knoblauch et al., 1996) who found that the crossing speed was 1.52 m/s (5 ft/s) when the approaching vehicle was 3 seconds away, whereas it was 1.22 m/s (4 ft/s) when the approaching vehicle was not too close.

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A positive correlation between pedestrian crossing speed and the size of the city has been found in research (Rastogi et al., 2011; Wirtz and Ries, 1992). Results from both studies revealed that the average pedestrian crossing increased with increasing area or population of the city. However, the lack of correlation between crossing speed of pedestrians and population density was reported in both studies. The revealed correlation may be attributed to the inherent intracity travel conditions and human psychological factors in these cities (Rastogi et al., 2011).

ii. Effect of time and weather

Weather conditions have been reported in a number of studies to have a significant effect on walking speed. Example of walking speeds according to weather conditions are presented in the study by Knoblauch et al. (1996) as illustrated in Table2-3. Seasonal difference in walking speed has been reported also in the study by Arango and Montufar, (2008). Normal walking speed amongst older pedestrians with no assistive devices was found to be higher in summer than in winter [1.18 m/s (3.87 ft/s) versus 1.08 m/s (3.54 ft/s)]. However, the controversial situation has been noted amongst older pedestrians with walkers or canes while crossing an intersection; the average crossing speed was noticeably found to be higher in winter than in the summer [1.01 m/s (3.31 ft/s) versus 0.87 m/s (2.85 ft/s)]. Although the reason for this difference was reported to be unclear (Arango and Montufar, 2008), it can be expected that walking speed is reduced when it is snowing, especially for older pedestrians.

Another study carried out by Lam and Cheung (2000) also reported the effect of weather conditions on walking speed at walkways. Observed walking speeds of pedestrians at the same capacity (67.4 peds/m/min) were much higher on outdoor walkways than on indoor walkways, with 0.88 m/s (53 m/min) and 0.65 m/s (38.75 m/min), respectively. According to the authors, surveyed indoor walkways were most of them air-conditioned, fully enclosed and vehicle-free, whereas pedestrians on outdoor walkways were exposed to worse environmental conditions (e.g. high temperature, wind, rain, dust, road traffic, etc.). Thus, it can be concluded that pedestrians tend to walk faster when weather conditions are not favourable.

Table2-3: Pedestrian walking speeds according to weather conditions (Source: Knoblauch et al., 1996).

Weather conditions	Mean speed [m/s (ft/s)]		15thpercentile speed [m/s (ft/s)]	
	Younger pedestrians	Older pedestrians	Younger pedestrians	Older pedestrians
Dry	1.47 (4.82)	1.23 (4.03)	1.22 (4.22)	0.97 (3.17)
Drizzle	1.52 (4.98)	1.24 (4.08)	1.28 (4.20)	0.96 (3.14)
Rain	1.60 (5.24)	1.32 (4.33)	1.30 (4.28)	1.00 (3.27)
Snow	1.60 (5.24)	1.34 (4.41)	1.32 (4.32)	1.03 (3.38)

Crossing speed during weekdays and weekends has been also investigated in several research projects. The Australian study by Bennett et al. (2001) found that pedestrian crossing speeds were similar during the weekdays and weekends. From these results, it can be concluded that the activity which generates the pedestrian flows does not have a noticeable effect on pedestrian crossing speed characteristics (Bennett et al., 2001).

Effect of time of day has been investigated in the study by Willis et al. (2004). The highest walking speed was reported during the early morning (7:00–9:00) and late afternoon (17:00–19:00), and the lowest during the midday periods (11:00–15:00). These differences were deemed to be attributed to a combination of trip purpose and group size which are disproportionately distributed across different times of day.

iii. Effect of terrain and quality of walking surface

There is a gap in research on the effect of terrain on pedestrian walking speed. However, one can expect that walking up or down a grade can affect pedestrian walking speed. That effect could be expected more noticeably for elderly pedestrians and pedestrians with disabilities.

In a study conducted by De Langen and Tembele, (2001) in Tanzania, it was shown that pedestrian walking speeds vary with walking pavement quality location, pedestrian volume, and obstructions (garbage, parked vehicles, potholes and broken pavements). Results from their studies are illustrated in Table 2-4.

Table 2-4: Walking speeds in Temeke (Tanzania) (Source: De Langen and Tembele, 2001).

Infrastructure quality	walking speeds (m/s)		
	Average	Normal	Maximum
1. Bidirectional concrete slab walkway, uncongested	1.28	1.39	1.47
2. Bidirectional bitumen paved walkway, congested	0.97	—	1.11
3. One side only bitumen paved walkway on a collector road	0.97	—	1.11
4. Bidirectional cement stabilized way, uncongested	1.28	—	1.44
5. Unpaved and well compacted walkway, one side only on a collector road	1.25	1.36	1.42
6. Unpaved, not well compacted, straight and dry walkway	1.14	1.22	1.30

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2.3.4. Pedestrian crossing choices

2.3.4.1. Theoretical framework

Understanding pedestrian crossing behaviour is a critical element of the planning and the design of urban transportation systems. Pedestrian behaviour in urban environment has been the subject of a large body of studies dealing with pedestrian movement models and behaviour models have been developed in this regard. Most pedestrian movement models deal with crowd and evacuation dynamic, and the interaction of pedestrians with vehicular traffic, whereas behaviour models generally deal with two separate aspects of pedestrian behaviour: *route choice* and *crossing behaviour* (Papadimitriou et al., 2008).

For a full understanding of pedestrian choices, pedestrian behaviour has been dealt with at three different levels, namely, *strategic level*, *tactical level* and *operational level* (Hoogendoorn and Bovy, 2004; Daamen, 2004). At the strategic level, the pedestrian elaborates an agenda of activities; he or she has to decide what activities to perform, whether to access those activities via walking and then decide the departure time. As the decisions at this level are made before the trip, the strategic level corresponds to off-road activities (Papadimitriou et al., 2008). Some details of urban design, such as the quality of pavement, traffic conditions, and environmental aesthetics may affect the pedestrian decisions of whether to walk or not. As an example, research has revealed that perception of the environment (such as land use, motorized street network, aesthetics, pedestrian infrastructure and safety) is significant in predicting walk trips (Livi Smith, 2009; Hoehner et al., 2005, Giles-Corti and Donovan, 2002). The attractiveness of the environment however is more important when walking is done for leisure purpose than for transportation-based walking (Livi Smith, 2009). In the context of developing countries like South Africa, walking is the important transport mode. As an example, walking is the second most utilised main mode (36 percent) for the entire population in Cape Town (Behrens, 2005). It can be expected thus that strategic decisions of whether to walk or not are mainly based on trip length and time.

At the tactical level, short-term decisions are made by the pedestrian in order to fulfil the objectives set at the strategic level (Ishaque and Noland, 2008). Those tactical decisions include the sequence of activities to be performed (activity scheduling), where these activities have to be performed (choice of activity area) and which route to use (route choice). The decisions set at the tactical level concern both off-road and on-road activities (Papadimitriou et al., 2009). As an example, the route choice made by the pedestrian before the trip can be based on the knowledge of the road network, constituting thus an off-road decision. However, in response to adverse conditions encountered during the trip, this off-road decision can be further influenced and modified. According to Hoogendoorn and Bovy (2004), the tactical decisions are influenced by both external factors (e.g. presence of obstacles, stimulation of the environment) and internal or personal factors (e.g. time-pressure, pedestrian attitudes).

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At the operational level, instantaneous decisions involved in walking tasks are concerned. Operational decisions affect pedestrian walking characteristics such as choice to walk fast or slow, or stop and wait, and when to cross a street (Ishaque and Noland, 2008) and walking tasks considered at this level may be grouped in three components, namely, obstacle avoidance, interaction with other pedestrians and certainly road crossing (Papadimitriou et al., 2009).

Interdependence among the three pedestrian behavioural levels has been highlighted in research as illustrated in Figure 2-21. As mentioned above, tactical decisions are made to fulfil that agenda of activities elaborated at strategic level. However, the expected tactical choice also influences the decision taken at the strategic level, making hence the decision-making process a two-way communication between these two levels (Ishaque and Noland, 2008). The decisions taken at operational level are also affected by tactical choices. For instance, pedestrians decide to walk at higher speed to save time (operational level), and adjust their route in a way that minimizes the obstacles to be encountered (by selecting the sidewalk with the least commercial activities, for example) (tactical level), in order to reach their destination by walking (strategic level). Alternatively, some components of operational level may influence the decisions at tactical level. Pedestrians may opt to postpone an activity or avoid a specific activity area if a crowd, unfavourable weather conditions or high traffic volume are expected. In this regards, the independence between tactical and operational decisions has been classified by Papadimitriou et al. (2009) into traffic-related dependences and crowd-related dependences. Traffic-related dependences concern interaction between activity area choice and obstacle avoidance, whereas the interaction between route choice and crossing behaviour is taken as a traffic-related dependence.

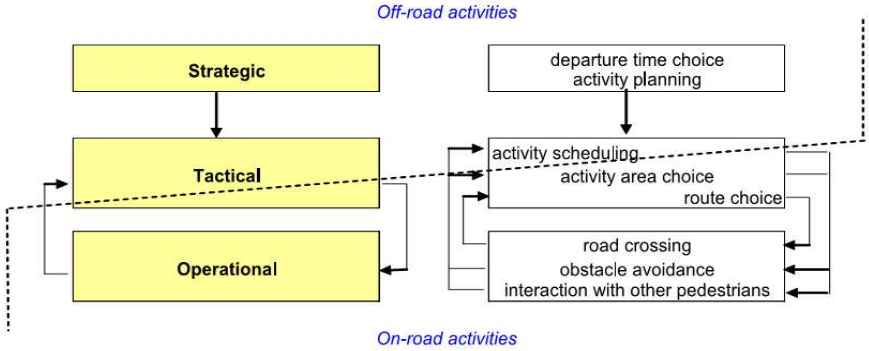

Figure 2-21: Pedestrian behaviour levels, activities and interactions (Source: Papadimitriou et al., 2009)

In particular, route choice may be set by pedestrians on the basis of the number and type of crossing facilities available as well as the conditions expected or encountered as regards road crossing. In this regards, these operational decisions may affect the route chosen by pedestrians, regardless of whether this process is set beforehand or evolves during the trip (Papadimitriou et al., 2009).

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A big number of existing research deals with pedestrian behaviour at operational level. Crossing behavioural models have been extensively developed in this regards, dealing with different aspects of pedestrian crossing behaviour at various locations and in different conditions. Some of these behavioural patterns governing the operational choice include gap-acceptance, pedestrian speed, waiting time and delay, crossing time, safety margin, level of service, pedestrian compliance, and are affected by individual characteristics, roadway characteristics, environmental characteristics and traffic conditions. At tactical level, pedestrian route choice among a number of other alternatives and the definition of origin/destinations are mainly important issues dealt with in the existing research. Models dealing with operational choice are mainly based on ordinary probabilistic or deterministic models, calibrated by means of observational data, while those dealing with tactical choice (route choice) are mainly modelled by means of simulation technique (Papadimitriou et al., 2009).

2.3.4.2. Factors influencing pedestrian crossing choices

Pedestrian crossing choices have been investigated in several studies and a number of factors governing pedestrians' decision making have been reported. The choices made by pedestrians while crossing streets could be broken down into two main components: *spatial crossing choices* and *temporal crossing choices*.

As regards spatial crossing preferences, a study was conducted by Chu et al. (2002) in the United in States, with the main objective to understand the potential determinants of pedestrian street-crossing behaviour. A model containing variables descriptive of the road environment was developed, and these variables consisted of theoretical expectation of pedestrian crossing preferences. Continuous variables included roadside walking distance, crossing distance and traffic volume, while discrete characteristics were the presence of marked crosswalks, traffic signals, and pedestrian signals (Chu et al., 2002). Results from this study identified two main locations where pedestrians would like to cross: (1) pedestrians are more likely to cross at an intersection with a traffic signal or a pedestrian signal head (Walk/Don't Walk signs), (2) pedestrian are more likely to cross at any location with a marked crosswalk than at those without. Specifically, the presence of a marked crosswalk was found to be more influential at an intersection than at a midblock location. As regards crossings at an intersection, the most influential factors in descending order were pedestrian signals, marked crosswalks, and traffic signals (Chu et al., 2002). The calculated probability of the pedestrian crossing preferences in relation to each of the variables led to the following conclusions (Chu et al., 2002):

- Increases in roadside walking distance (to an intersection) significantly affect a pedestrian's selection of the option to cross at an intersection. However, the decision to cross at an intersection is little affected by increases in the crossing distance at that intersection.
- Increases in roadside walking affect crossing at an intersection many times more than crossing midblock.
- Increases in crossing distance are twice as likely to affect jaywalking as increases in traffic volume.

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- Crossing midblock is little affected by any of the continuous variables.
- Increases in traffic volume affect jaywalking more than crossing midblock.

Some of the above findings have been found in study conducted by Behrens (2010) in South Africa. Pedestrian crossing behaviour on selected arterials and freeways in Cape Town has been investigated in a three-stage study. Different patterns of pedestrian crossing, including distance between footpath crossings and the nearest formal crossing facility (in the form of either a footway on a road bridge, or a footbridge), pedestrian movement desire lines were observed. Moreover, in order to explore pedestrian crossing attitudes and the reason of informal crossing, an exploratory roadside intercept survey was conducted. The study findings showed 62 percent of crossing on freeways and 93 percent of crossing on arterials may be unassisted or illegal. Even though the distribution of footpath crossing distances from the nearest crossing facility showed a greater use of freeway crossing facilities compared to arterial crossing facilities, patterns of crossing were found strongly associated with the location of crossing facilities in relation to dominant pedestrian movement desire lines (Behrens, 2010). The results from the intercept survey on grade-separated facilities revealed that the most common reason to choose a particular route was the desire to walk the shortest route, followed by concerns for personal security.

When they were asked their preferred crossing types, signalised crossings outnumbered (60 percent) other crossing types. Zebra crossings scored 23 percent, footbridges 3 percent and underpasses 4 percent (Turner et al., 2008). The authors argued that the poor scores attributed to footbridges and underpasses may result from additional distances to get to these crossing facilities, the presence of stairs and safety concerns. Several similarities to the findings above-mentioned emerged also in the study conducted by Schlossberg et al. (2007). Results from their survey showed that the presence of traffic control devices, shorter waiting times at signalised crossings and security concerns emerged as the most influential factors governing pedestrians' crossing choices. It has been suggested therefore that crossing facilities should be located on the pedestrian's movement desire lines. Consequently, this suggests a need of travel surveys in order to predict walking trip generation and then route choices to be opted by pedestrians. Other interventions suggested were law enforcement for revealed security concerns and educational programmes for attitudinal and behavioural change amongst pedestrians.

A big number of relevant studies has been assessed in an exhaustive study carried out by Papadimitriou et al. (2009) based on the three-level hierarchical structure of pedestrian behaviour in urban areas as discussed in the previous section. A bulk of international research carried out on pedestrian route choice and road crossing behaviour has been assessed, and a number of issues stemming from both conceptual and practical aspects of pedestrian modelling have been highlighted. As it is expected that pedestrian crossing behaviour may be a feedback of activities and conditions at tactical level, it has been suggested that interdependence between route choice and crossing behaviour should be considered. Therefore, modelling crossing behaviour should be expended to address decisions made along entire pedestrian trips in relation to individual, roadway, traffic and route characteristics.

For a full road crossing process, pedestrian choices are not always restricted to spatial choices; the pedestrian at an uncontrolled crossing must select an appropriate gap in the traffic. Similarly, at a signal controlled crossing, pedestrians are allowed to cross the street during the pedestrian green phase, but not allowed to cross during the pedestrian red phase. However, long waiting times could induce the option by the pedestrian to cross against the red phase. All these pedestrian crossing choices involving time preference could be recognised as temporal crossing choices. Pedestrian crossing patterns associated with these choices are discussed in the section below.

2.4. Pedestrian-vehicle interaction at pedestrian crossings

2.4.1. Pedestrian gap-acceptance

A basic skill that is necessary for road crossing process is the individual decision on judging safe gaps in the traffic stream through which to cross. At an uncontrolled pedestrian crossing, the pedestrian crossing process involves approaching a pedestrian crossing, and the actual crossing manoeuvre involving the pedestrian departure from one kerb to another kerb through the roadway. Before the crossing manoeuvre, the pedestrian has to wait and view available gaps, and then decide whether to accept or reject the gap for a safe crossing.

The “gap” in traffic stream is defined as the time lag between two vehicles in any lane encroaching on the pedestrian’s crossing path (Roess et al., 2011). However, some studies defined a gap using spatial terminology; they defined a gap as the distance between the pedestrian and the approaching vehicle at the time the pedestrian begins the crossing and the time-of-arrival as the time interval corresponding to that gap (Oxley et al., 1995&1997). Other researchers adopted two different terms to define a gap: *distance gap* and *time gap* (Lobjois and Cavallo, 2006). The first available gap is called a lag. It is defined in this study as the time between the pedestrian arrival at the kerb and the time it takes for the first approaching vehicle to cross the pedestrian’s path.

2.4.1.1. Types of gaps

Various kinds of gaps are encountered in existing research. As an example, several terminologies of gap were referred in the study by Brewer at al. (2006). The “*available gap”* is defined as the gap present for a pedestrian. If the pedestrian option is to accept the available gap (i.e. crosses the street within that gap), then it is an “*acceptable gap”.* If the pedestrian rejects the available gap, then it becomes the “*rejected gap”*. The “*adequate gap”* for a site is determined by dividing the crossing distance by the walking speed and adding an appropriate start-up time. The Highway Capacity Manual (HCM 2000) defined the “*critical gap”* as “the time in seconds below which a pedestrian will not attempt to begin crossing the street”. It is assumed that the pedestrian will choose to cross when the available gap is greater than the critical gap, and will reject the gap when the available gap is less than the critical gap (TRB, 2000). Another type of gap called *‘rolling gap’* has been defined in the study by Brewer at al. (2006). In the street with high volumes of traffic, a rolling gap is used by pedestrians who are not willing to cross when all lanes are completely clear, but anticipate having a gap in traffic stream as they cross the street.

2.4.1.2. Research on pedestrian gap-acceptance

There is a significant difference between pedestrian gap-acceptance behaviour and driver gap acceptance. Indeed, as motorists move at higher speed than pedestrians, they require smaller gaps in traffic stream in comparison with pedestrians. These latter have to wait longer gaps in order to cross the road safely, and this results in finding fewer appropriate gaps, especially at crosswalks on wide roads with high traffic volume. The ability of pedestrians to select appropriate gaps depends on their ability to perceive and integrate speed and distance information of approaching vehicles, and their ability to adapt their crossing speeds to specific situations and the choice of relative risk. This ability thus varies with a number of other factors, including the traffic conditions (such as speed of approaching vehicles, the frequency distribution of gaps in the traffic stream), the road characteristics (such as the width of the street, presence of refuge or median), waiting time and personal characteristics (age, gender and physical ability) (Roess et al., 2011).

Age differences in pedestrian gap-acceptance have been addressed in research (Oxley et al., 2005; Cohen et al., 1995; Lobjois and Cavallo, 2006). In the study carried out by Oxley et al. (2005) using road-crossing simulation, three age groups were tested; “younger” (30-45 years), “younger-old” (60-69) and “old-old” (more than 75 years). Amongst four variables (age group, time gap, vehicle speed, distance gap and walking time) examined for their impact on the crossing decisions made by pedestrians, distance of approaching vehicle was found as a significant predictor of crossing decisions. It was shown that all age groups make their decision based primarily on the distance of the oncoming vehicle and less so on time of arrival. However, a major difficulty processing both distance and speed of vehicles under time constraints was revealed in a large proportion of “old-old” participants, and this resulted in the revealed tendency to select insufficiently large gaps.

Lobjois and Cavallo (2006), interested by the findings from the study by Oxley et al. (2005), conducted a similar study with the main objective being to investigate the effects of age on gap selection in street crossing. A particular emphasis of this study was to study how oncoming vehicle speed and time constraint influence the time gap deemed acceptable for crossing. Three age groups (20-30; 60-70 and 70-80 years) were the subjects of this study done into two experiments. Both experiments used a simulated street-crossing situation, but time constraints were imposed on participants in one experiment only. The results showed that 70-80 age group accepted greater time gap in comparison with other two age groups. This finding was against that one from the study by Oxley et al. (2005). According to Lobjois and Cavallo (2006), age difference between the oldest pedestrians in the two studies and differences in method may be the possible reason. Another important finding from this study was the revealed influence of vehicle speed on crossing decision. This influence was found also to vary with both age of participants and time constraint imposed on decision making process. In the absence of time constraint, accepted time gaps declined as speed increased for the two older

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groups, whereas the young group selected a similar time gap at all vehicle speeds (Lobjois and Cavallo, 2006).

These results would be indicative of the influence of time pressure on decision making process amongst elderly pedestrians. Greater time gaps revealed for elderly pedestrians were also deemed to be associated with the tendency to compensate not only for their diminished ability to perceive and integrate the speed of oncoming vehicle, but also for their longer crossing times resulting from their slower crossing speeds. The same finding was also reported by the authors in their previous study (Oxley et al., 1997). This difficulty in judging and integrating speed of oncoming vehicle amongst elderly pedestrians could be explained by unsafe crossing decisions (shorter time gaps) made at higher vehicle speeds. This suggests that the decision making process is primarily based on the distance of the oncoming vehicle and lesser extent on time gap. This finding was in the line with what was found by Oxley et al. (2005). Indeed, these findings support other previous studies (e.g. Staplin and Lyles, 1991; Kline et al., 1992 both cited in Oxley, 1995) which reported a decline in motion perception skills amongst elderly people. Several factors related to this revealed reduced motion perception could be a decline of visual motion sensitivity in the elderly people (e.g. Sekuler et al., 1980 cited in Oxley, 1995), particularly while detecting slow movements (Snowden and Kavanagh, 2006), at dusk and in darkness (Wounters and Welleman, 1988 cited in Oxley, 1995) and when the oncoming vehicle is close (Lobjois and Cavallo, 2006). This latter case may be explained by the findings from the study by Lobjois and Cavallo (2006) where elderly pedestrians at short distance gaps rejected time gaps they would accept at higher speeds.

Other studies dealing with demographic patterns in gap acceptance behaviour include the early study conducted in Manchester by Cohel et al. (1955). Crossing decisions at a mid-block crossing with a refuge were examined against a variety of factors such as age, sex, speed and distance of vehicle. Results of this study showed a critical gap of 1.5 seconds (no one crossed when the vehicle was less than 1.5 seconds away). When the available gap was 7 seconds, 92 percent of pedestrians would cross, whereas everyone would cross when the available gaps were 10.5 seconds or greater. Broken down by age groups, male pedestrian in the 31-45 years category exhibited the greatest gap, while the shortest gap was observed in 16-30 years category. Alternatively, the greatest gap was found in 61 years and over categories, whereas the shortest was in 16-30 years category. The accepted gaps found in this study are very close to those found recently by Das et al. (2005); they found a critical gap of 1.5 seconds and almost all pedestrians accepted available gaps smaller than 11 seconds.

Age differences in gap-acceptance were also reported by Das et al. (2005). It was shown that children and younger pedestrians were likely to accept gaps that older pedestrians rejected. Such age differences were also found by Oxley et al. (1995 & 1997); they found that young pedestrians (30-45 years) accepted shorter gaps than older pedestrians (65 years and over).

Research has shown that female pedestrians accepted longer gaps than male pedestrians in general (Cohel at al., 1955; Wilson and Grayson, 1980, cited in Ishaque and Noland, 2008). Contrary to these findings, the absence of gender differences in gap-acceptance in the same age group of pedestrians was reported in the study by Das et al. (2005).

Brewer et al. (2006) observed gap-acceptance behaviour of pedestrians on a four-lane divided road in the United States. Characteristics of available and accepted gaps were determined and behavioural patterns associated with the observed gaps were identified. In a total of 3632 observed gaps, 3027 gaps were rejected and 605 only were accepted. Behavioural analysis showed that a big part (60 percent) of pedestrians were very familiar with “rolling gap” when they crossed the street. A statistical analysis showed that 85^{th} percentile accepted gaps were between 5.0 and 9.4 seconds and increased with crossing distance. The statistical analysis also showed that all the observed 85^{th} percentile accepted gaps were less than the calculated critical gap for a crossing speed of 1.1 m/s (3.5 ft/s), suggesting the adoption of this value as the design walking speed for general conditions.

A group of researchers have investigated pedestrian crossing behaviour on a mid-block located on six-lane road in China, with a great emphasis on factors influencing gap acceptance and rejection (Cherry et al., 2011). A total of 330 mid-block crossing scenarios were observed, including 522 accepted gaps and 158 reject gaps. The average accepted gap was found to be 8.8 seconds (S.D: 4.6 seconds, 85^{th} percentile: 13.1 seconds), while the average rejected gap was 5.3 seconds (S.D: 2.5 seconds; 85^{th} percentile: 7.3 seconds). These observed values were higher than those observed in Brewer et al. (2006). A probit model was used to estimate environmental determinants of gap-acceptance behaviour. The results showed that gap-acceptance behaviour was strongly correlated with the size of the gap, speed of traffic, waiting time and whether the gap occurred in near-side traffic (Cherry et al., 2011). Regarding the relationship between gap-acceptance and waiting time, the findings from Cherry et al. (2011) were in the line with those from DiPietro and King (1970, cited in Ishaque and Noland, 2008); they found that pedestrians with longer waiting time at the kerb were likely to accept longer gaps in traffic stream to cross. This may suggest that pedestrians who are willing to wait longer at kerb are those who are more cautious, or perhaps are less time constrained and thus accept longer gaps.

Cherry et al. (2011) also reported the absence of significant relation between group size and crossing from the roadside or the median. However, these findings are inconsistent with those reported by Das et al. (2005). These latter found that the mean minimum accepted gap increased with the increase in size of the group from one to four, and that the probability that a group of four pedestrians accepting shorter gaps was lesser than the probability of an individual pedestrian. Nevertheless, these findings differ from those reported in DiPietro and King (1970, cited in Ishaque and Noland, 2008); they found that groups of pedestrians accepted shorter gaps than individuals. Ishaque and Noland, (2008) explained their findings by arguing that peer pressure, lack of attention and perception of safety in numbers which are characteristic of pedestrian crossing in groups may be the possible reason. Regarding crossing from kerbside or median (or pedestrian refuge), Das at al. (2005) found that pedestrians waiting on pedestrian refuge or medians are more willing to accept shorter gaps than those waiting on kerbside.

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Another Chinese study was carried out by Shi et al. (2007) on an unsignalised mid-block crossing in Beijing. Gap-acceptance was one of the pedestrian crossing behaviour investigated in this study. Accepted gaps were in the 3.81-34.89 seconds range whereas those rejected were in the 0.28-6.33 seconds range. This indicates that the ambiguity in decision making of whether to cross or not lies within the 3.81-6.33 seconds range, regardless of other contributing factors (Shi et al., 2007). The calculated critical gap was found to be 4.8 seconds and is greater than those reported in Cohel et al. (1955) and in Das et al. (2005).

A relationship between pedestrian gap-acceptance and crossing speed has been reported in a several studies (Moore; 1953; Virkler, 1998; DiPietro and King, 1970, cited in Ishaque and Noland, 2008); those who accepted shorter gaps increased their speed to compensate their risk taken. Moore (1953) found that a crossing speed of 1.57 m/s corresponded to an accepted gap of less than 3 seconds, while a crossing speed of 1.2 m/s corresponded to an accepted gap of 7 seconds. Virkler, (1998, cited in Ishaque and Noland, 2008) also reported that pedestrians arriving during the clearance interval that follows the pedestrian phase exhibited higher walking speed while crossing , rather than choosing to wait for the next pedestrian phase. Gates et al. (2006) also revealed that pedestrians who crossed during the red phases walked roughly between 0.15 and 0.18 m/s (0.5-0.6 ft/s) faster than those who crossed during the green phase. Similarly, Lam et al. (1995, cited in Ishaque and Noland, 2008) reported higher pedestrian crossing speeds in red phase than in green phase in Hong Kong.

At signalised pedestrian crossings, gap-acceptance behaviour was found to depend on pedestrian arrival phase (Schroeder et al., 2008) and the cycle length. As an example, signal non-compliance was found higher when pedestrian arrival was during non-green phases (Li et al., 2004; Schroeder et al., 2008).

2.4.2. Pedestrian road-crossing tasks

The complexity of road-crossing process has been investigated in a number of studies. A series of tasks involved in a safe road-crossing includes tasks such as information gathering, decision making, and good mobility skills (Geruschat et al., 2003). The first task has been used by other researchers as detection and identification (Schoon, 2003). An analysis of a road-crossing task carried out by Robertson and Thoreau (2003) highlighted four main different phases of crossing task, namely, (1) identify presence, need and location of crossing place, (2) approach crossing place, (3) enter and cross at crossing place, and (4) exit crossing place (Figure 2-22). However, other researchers have broken down crossing event into three main phases: (1) walking to the kerb, (2) waiting at the kerb, (3) crossing the road (Geruschat et al, 2003; Schoon, 2003).

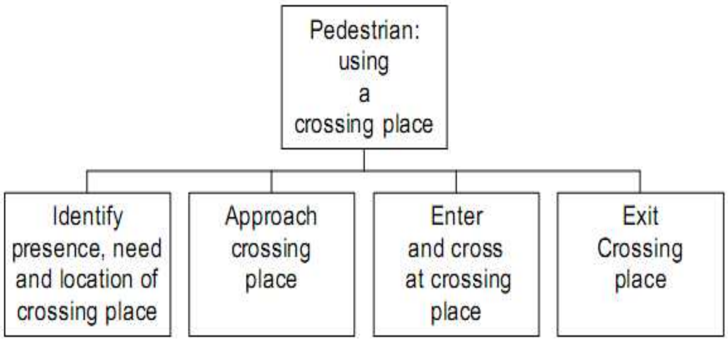

Figure 2-22: Pedestrian road-crossing stages (Source: Robertson and Thoreau, 2003)

2.4.2.1. Phases of road-crossing task

The road-crossing phases addressed in this section are a result of the study conducted by Robertson and Thoreau (2003). The relevant tasks involved in each phase are applicable for unsignalised pedestrian crossings but differences in rules governing right-of-way among different types of this type of pedestrian crossing (zebra crossing, informal crossing places, etc.) should be considered. This task analysis takes into account the recommendations in the Highway Code, but includes also other tasks involved realistically in crossing practice, such as informal crossing rules which would be omitted in an ideal approach (Robertson and Thoreau, 2003).

Phase 1: Identify presence, need and location of crossing

At this phase, the pedestrian has to decide whether he or she needs to cross the road and if so, he or she has to find where an appropriate place to cross is located and finally to judge whether a particular crossing place type is needed. The details of this stage are illustrated in Figure 2-23.

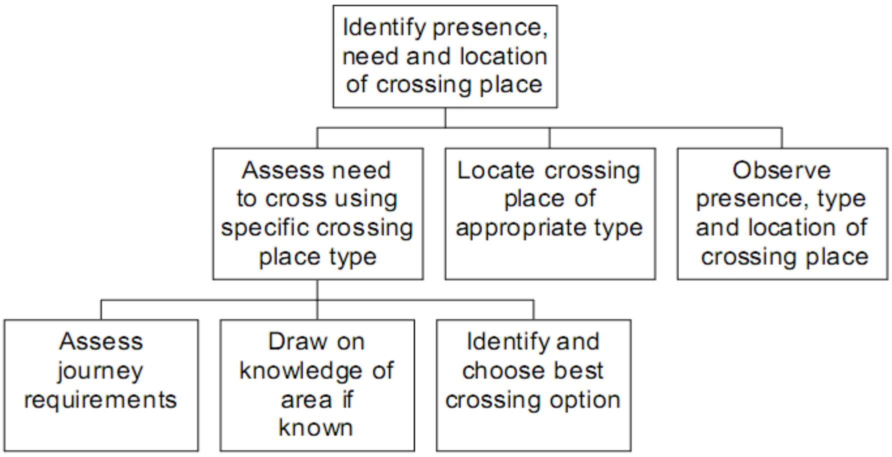

Figure 2-23: Phase 1: Identify presence, need and location of crossing place (Source: Robertson and Thoreau, 2003)

Phase 2: Approach crossing place

At this phase, the pedestrian approaches the crossing place and stops at the kerb to assess the traffic conditions. First, he or she assesses the use of the crossing place, then recalls rules governing the interaction with other road users and finally, on the basis of previous tasks, the safety and usability of the crossing place are assessed. Figure 2-24 illustrates different components involved in this phase.

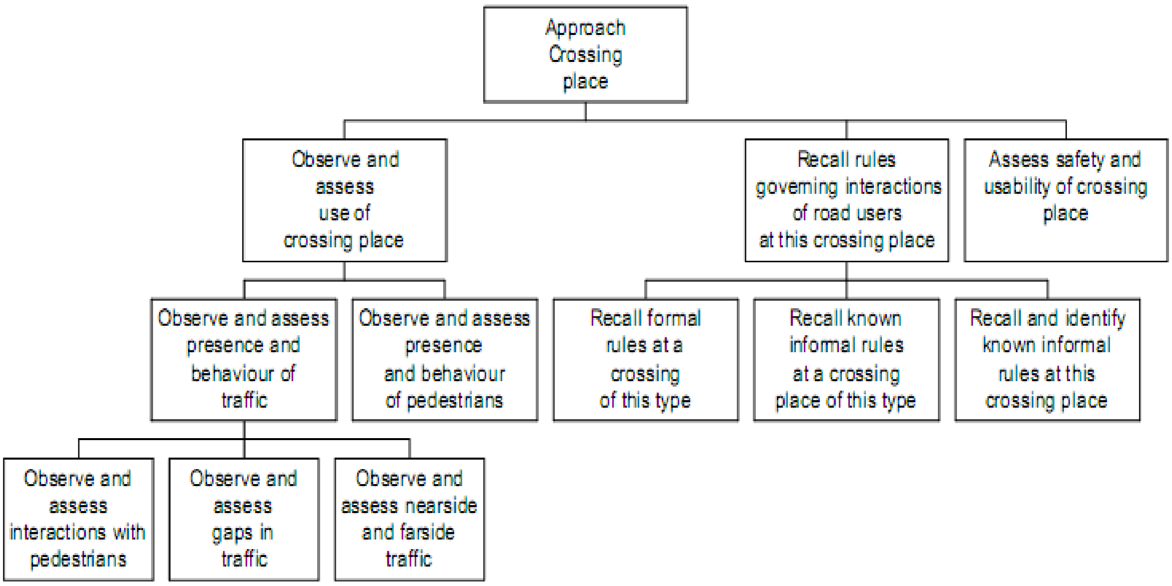

Figure 2-24: Phase 2: Approach crossing place (Source: Robertson and Thoreau, 2003)

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Phase 3: Enter and cross at crossing place

It is the phase of preparation of the road crossing, during which all important decisions relating to when and how to cross the road are taken. Tasks involved at this phase are split into two main parts: Phase 3 (a) and Phase 3 (b). Stage 3 (a) involves the decision-making process which precedes the physical road crossing. During this phase, the pedestrian observes hazards, assesses options and chooses the most appropriate crossing option and then finds a safe passage. Detailed tasks involved in this phase are illustrated in Figure 2-25. The Phase 3 (b) involves the time of stay in the carriageway in crossing event from the first step forward to cross the road. During this phase, the pedestrian may reassess the hazards and may alter his or her behaviour if a threat is realised. The tasks involved at this phase are illustrated in Figure 2-26.

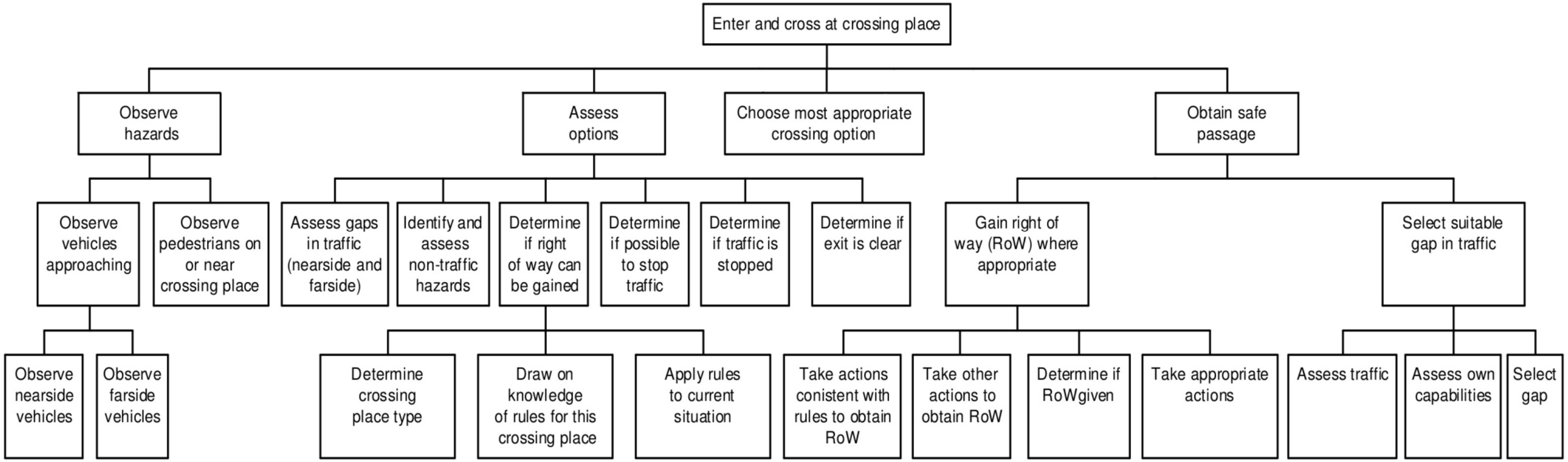

Figure 2-25: Phase 3(a): Enter and crossing place (Source: Robertson and Thoreau, 2003)

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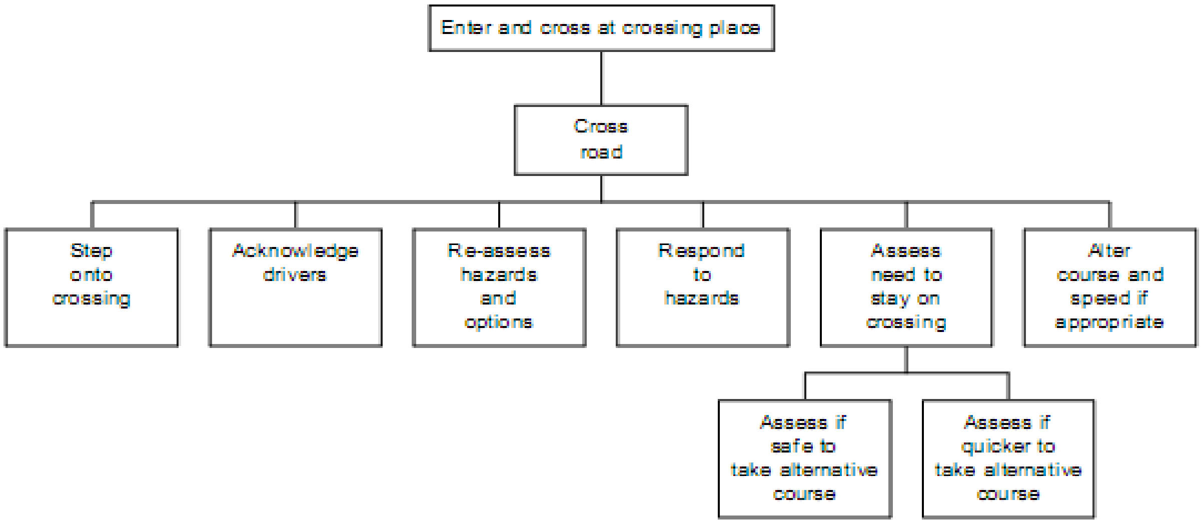

Figure 2-26: Phase 3(b): Enter and crossing place (Source: Robertson and Thoreau, 2003)

Phase 4: Exit crossing place

At this phase, the pedestrian exits the crossing and reaches the opposite kerb. The task made at this phase depends upon the hazards experienced by the pedestrian while negotiating the kerb and upon the decisions relating to the route choice after crossing the carriageway. The tasks involved at this phase are summarized in Figure2-27.

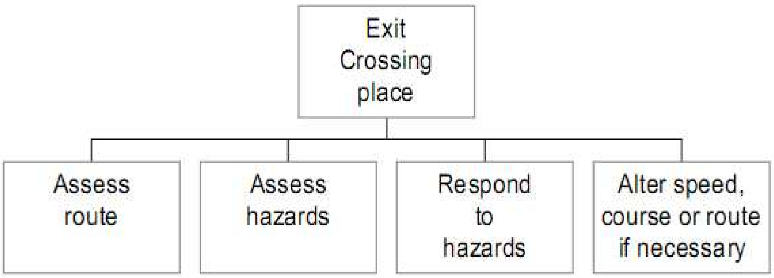

Figure 2-27: Phase 4: Exit crossing place (Source: Robertson and Thoreau, 2003)

In this task analysis carried out by Robertson and Thoreau (2003), perception of traffic in terms of distance, speed and time, as well as the decision making process were considered as lower level tasks and were not mentioned in their detailed task analysis. However, Schoon (2003) put a great emphasis on observing and reacting to approaching traffic in crossing analysis. He split the mental and physical task of crossing a road into three elements: (1) observing and reacting to approaching traffic (the observation-reaction time); (2) crossing the carriageway; and (3) gaining the opposite kerb to become fully positioned on the opposite footway. The two last elements may coincide with the two last phases proposed by Robertson and Thoreau (2003).

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2.4.2.2. Concept of observation-reaction

The term “observation-reaction” instead of “perception-reaction” used for drivers was adopted for pedestrians because these latter expect to see a vehicle before crossing the road, whereas a driver in the normal driving task may expect a random appearance (and therefore a need and time to perceive the nature) of a reason for crossing. Pedestrians also require time to observe and react to the traffic conditions and take appropriate action (Schoon, 2003 cited in Schoon, 2006). During the observation-reaction time, four main tasks are involved: detection, identification, decision and response. However, this observational procedure must be repeated as a result of insufficient gaps in the approaching traffic stream until the final decision is to cross the road and the corresponding response undertaken is to react by starting to cross the carriageway. For pedestrians pushing a trolley, a pram, wheelchair and scooter users, the first action is to initiate a forward movement to cross part of footpath, if the starting point is at the top of a ramp (Schoon, 2010). Therefore, the four tasks involved in observation-reaction time may be included in the Stage 3 (a) proposed by Robertson and Thoreau (2003).

a) Three forms of pedestrian observation-reaction time

Three forms of observation-reaction time were proposed by Schoon (2003), based upon the UK’s drive-on-the left rule:

- Total observation-reaction time (TOR): It is the total time taken by the pedestrian standing at the kerb from the beginning of his or her first look to the right, then the look to the left and the second look to the right again, then the look to the ahead position, until he or she starts to step from the kerb onto the carriageway.
- Penultimate observation-reaction time (POR): It is the time from the end of the left look, including the last look to the right, to the point where the pedestrian starts to cross the carriageway. This POR corresponds to the time in which no further focus on traffic approaching from the left. The extent of this loss of focus depends on the speed of head turning movement (left saccade) and on the extent of the pedestrian’s peripheral vision and mental processing abilities (Schoon, 2003).
- Last observation-reaction time (LOR): It is the time starting at the end of the last look at the right (second saccade) and then through the look ahead across the road in the direction of walking until the point the pedestrian steps into the carriageway to cross.

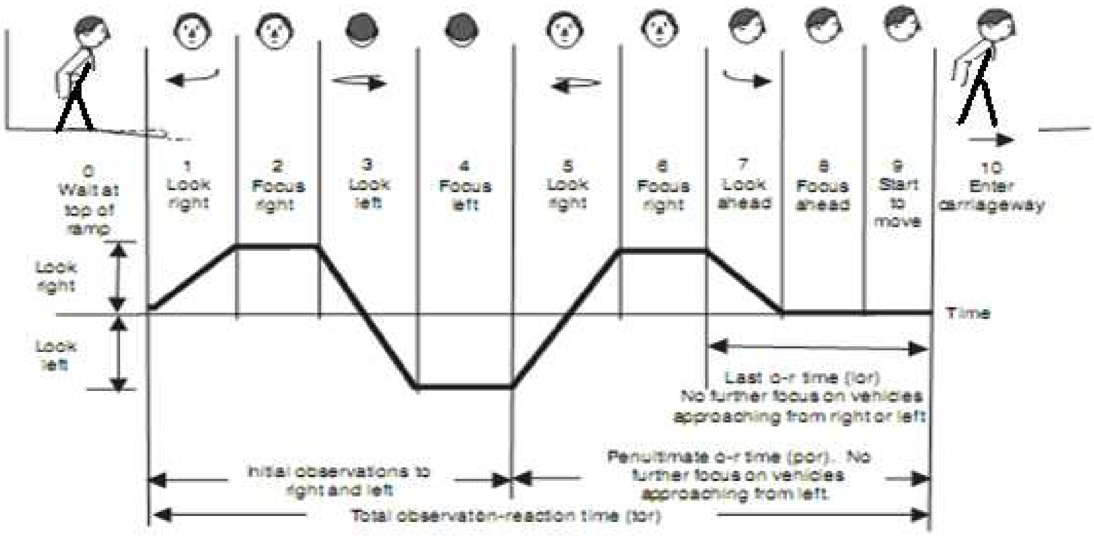

Figure 2-28: Pedestrian head movement and observation-reaction timescale: concept diagram (Source: Schoon, 2010)

Figure 2-28 illustrates the TOR, POR and LOR times for a pedestrian crossing a straight two-way carriageway and looking first to the right (right saccade). It is assumed that for a two-way road with no refuge island (or median), the pedestrian first looks at the direction of the most immediate traffic threat (right saccade) under drive-on-the left rules. If the pedestrian looks to the left first, only the terminologies related to looking left and the right change but the procedure is essentially the same. In this diagram the focusing time at the end of each head movement is represented by a horizontal line, indicating that there is no head movement during these times. Pedestrian observation stages are associated with extensive head and some shoulder movement, except for encumbered people or wheelchair users for whom angular movement may be difficult or impossible. Schoon (2010) used also dashed lines in the diagram to indicate the possible action of most pedestrians to start focusing on an approaching vehicle during the head movement and complete the focussing, observation, etc. while the head is stationary. Shorter focus times may indicate the absence of an approaching vehicle from the direction of looking; the head is immediately turned (in the minimum time case) in the opposite direction.

From the pedestrian's point view, the application of reaction-reaction times implies the following assumptions (Schoon, 2010):

- For a two-way road, the POR and LOR times are applicable in each relevant direction.
- For a one-way road, or in the presence of pedestrians' refuge island (or median), the LOR is theoretically applicable since the traffic should only approach from one direction, and this would be the LOR time. However, physical and operational features of the crossing location may be checked carefully to ensure that a pedestrian does not become vulnerable because of some unpredictable traffic movement.

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b) Values of pedestrian observation-reaction times

Values of pedestrian observation-reaction times have been presented from the findings of a pilot study conducted by Schoon (2005). Observation-reaction times of male and female adult pedestrians at a kerb adjacent to a length of straight road were measured for each of the nine elements of the total observation-reaction time. The 85^{th} percentile times are shown diagrammatically in Figure 2-29. The range of average times for the major head movements and focusing for these four subjects were as follows (Schoon, 2005):

- Range of an average head saccade of 90 degrees was between 0.29 s and 0.45 s.
- Range of an average head saccade of 180 degrees was between 0.34 s and 0.67s.
- Range of average focus times to either left or right was between 0.19 s and 0.35 s.
- Range of final focus ahead time before walking was between 0.16 s and 0.32 s.
- Range of average TOR times was between 2.42 s and 3.15 s.
- Range of average POR times was between 1.02 s and 1.60 s.
- Range of average LOR times was between 0.44 s and 0.73 s.

Gender-related differences in pedestrian observation-reaction times as illustrated in Figure 2-29 may not be informative as the sample size (four subjects) is not only too small to represent a wider population of pedestrians but also represents the same pedestrian category (mature adults).

The same procedure was applied to determine observation-reaction times of wheelchair users and a comparison with those of non-disabled pedestrians was done in the study by Schoon and Hounsell (2006). Results for observed selected wheelchair users, together with those for non-disabled users are illustrated in Figure 2-29. As it is expected, significant differences in findings result from the additional time required by wheelchair users to negotiate the kerb before entering the carriageway. It is important to note that in both cases (non-disabled and disabled people) longer observation-reaction times could be expected at locations where pedestrians are required to look partially backwards, such as at street intersections.

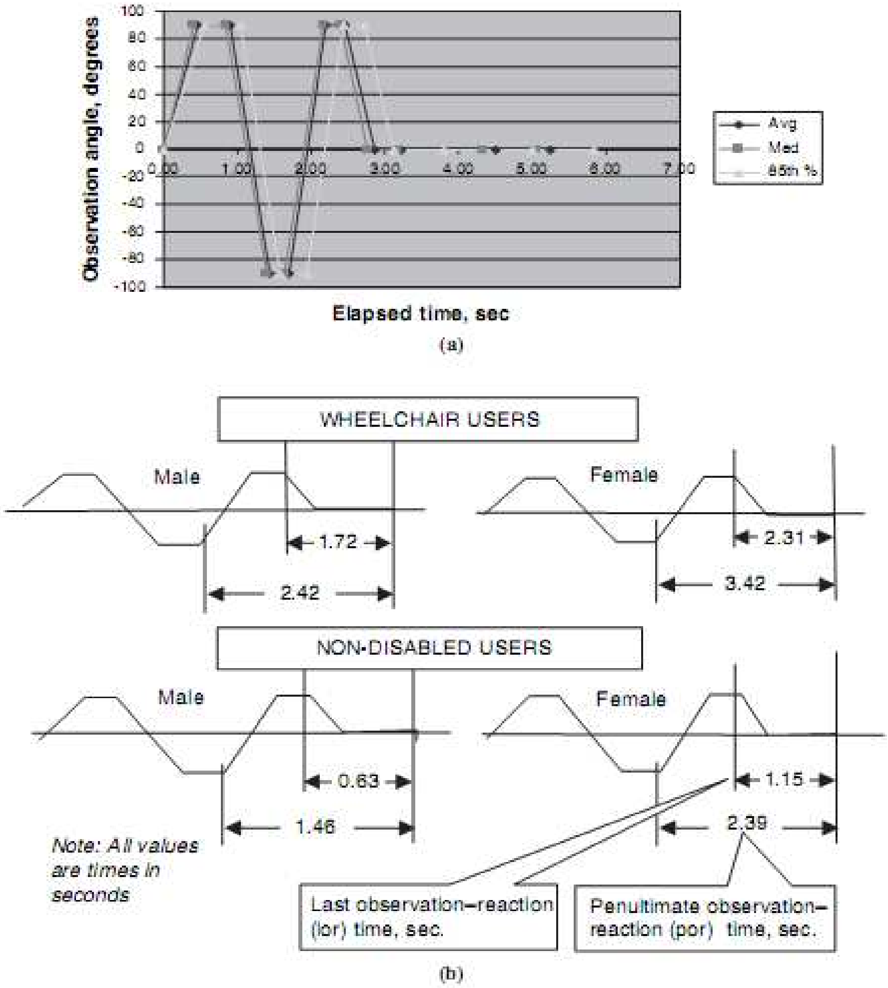

Figure 2-29: Example of experimental results and diagrammatic comparison between (a) wheelchair users and (b) non-disabled users (Source: Schoon and Hounsell, 2006)

c) Factors influencing pedestrian observational tasks

It is important to note that the characteristics of observation-reaction depend upon a number of factors, such as pedestrian characteristics, pedestrian crossing type, and environmental conditions. It can be expected that limited ability of disabled people and encumbered people as discussed earlier may in some way deter the observational procedure, making them more vulnerable to a possible accident or imposing them longer delays.

Gender difference in gaze behaviour has been reported by Tom and Granié (2011). Before crossing, men were likely to look at moving vehicles more than women, and women were likely to look at traffic lights and other pedestrians more than men. While crossing, women focused on other pedestrian more than men did, particularly on signalised crossings. This discrepancy may be attributed to a more prevalence of social influence on decision-making and peer compliance among women than men.

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Alternatively, the natural tendency among men is to focus on dynamic features of traffic environment, such as moving vehicles, but they are less sensitive to static features, such as traffic lights in their decision-making process (Tom and Granié, 2011). Observational behaviour however was found in many studies to be quite similar among different age categories (Geruschat et al., 2003; DfT, 2004).

The type of crossing facility can also influence the pedestrian observational tasks. Observational tasks required at unsignalised crossing may be more complicated than those required at signalised crossings. Moreover, crossing at junctions requires a greater visual scanning angle than that required at non-junctions. As an example, pedestrians require a scanning angle close to 265 degrees to satisfy their need to detect, identify, decide and take an appropriate action. For a non-junction location such as a zebra crossing, a scanning angle close to 180 degrees is required. That is, the greater the scanning angle requires a greater time to conduct an extensive head and some shoulder movement (Schoon, 2003).

The role of crossing type was also reported by Geruschat et al. (2003) to influence the pedestrian observational task. An analysis of directional observations done within 4 seconds before crossing highlighted differences in gaze targets between crossing at a signalised crosswalk and at a roundabout. At a signalised crossing, pedestrians compliant with traffic lights directed mainly their fixations on traffic lights, whereas those who crossed against traffic lights directed mainly their fixations onto vehicles. At a roundabout, pedestrians directed the majority of their fixations on vehicles. Focusing on vehicles being a task relevant to gap detection, crossing at a roundabout and crossing against traffic lights at signalised crossing may rely on features of available gaps in the traffic stream.

Environmental conditions, such as weather conditions, amount of illumination, unexpected appearance of obstacles, and general density of traffic, noise, and unpredictability of other road users may also influence the pedestrian observational tasks (Shoon, 2003). As an example, a loud noise from a vehicle may force pedestrians to turn their head and direct their attention to the source of noise, even if it was not intended for decision-making. However, there is a need of research to assess how all those factors influence the pedestrian observational tasks.

d) Visual scanning angles at unsignalised intersections

The basic requirements of a pedestrian standing at the kerb with the intention to cross at an unsignalised intersection include a number of eye and body movements and the mental coordination for a safe crossing. The size of scanning angle required by the pedestrian is determined by the type of crossing facility, its environment and the characteristics of interacting vehicles. The scanning angle has been defined by Schoon (2003) as the angle needed to be scanned by the pedestrian negotiating a pedestrian crossing in order to detect, identify and then find adequate gaps through oncoming vehicles. The scanning angle required by the pedestrian wishing to cross at unsignalised four-way and T-intersections is about 265 degrees. Schoon (2003) divided this scanning angle into four sectors designated by A to D, as presented in Figure 2-30.

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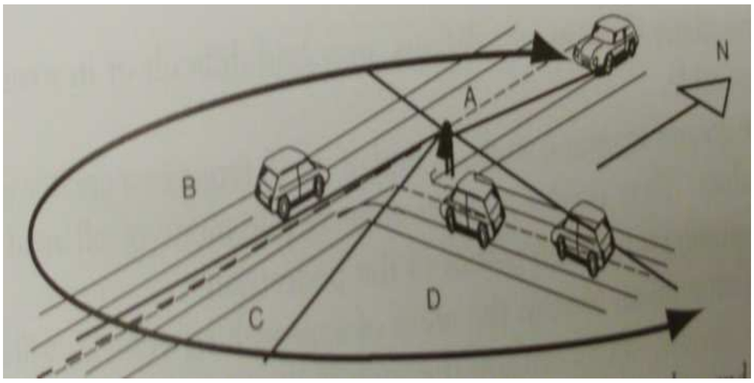

Figure 2-30: Visual scanning angle and sectors required by a southbound pedestrian wishing to cross the minor street of an unsignalised intersection (Source: Schoon, 2003)

The sectors of total scanning angle are described as follows:

- Sector A: This sector includes left-turning vehicles approaching from behind the pedestrian's position.
- Sector B: It includes right-turning vehicles approaching from the front of the pedestrian's position, between approximately +10 and +90 degrees. For a four-way intersection, this sector includes also vehicles approaching from a leg opposite to that the pedestrian wants to cross.
- Sector C: This sector includes pedestrians approaching and crossing from the opposite side of crossing on ahead of the pedestrian.
- Sector D: It includes approaching vehicles in the leg the pedestrian wants to cross, turning left or right in the intersecting street for a T-intersection or crossing this latter in the case of four-way intersections.

In the case the pedestrian's intention is to cross the minor street in the northbound direction, the similar scanning and sectors diagram can be constructed as illustrated in Figure 2-31. The greater scanning angle, the greater the time required to conduct it and the amount of information to be processed. During the scanning process, the pedestrian may lose focus on certain areas and may initiate the crossing with unobserved approaching traffic which could result in a possible accident. The presence of heavy traffic obscuring sight lines or poor visibility due to other factors such as rain or fog could worsen this situation.

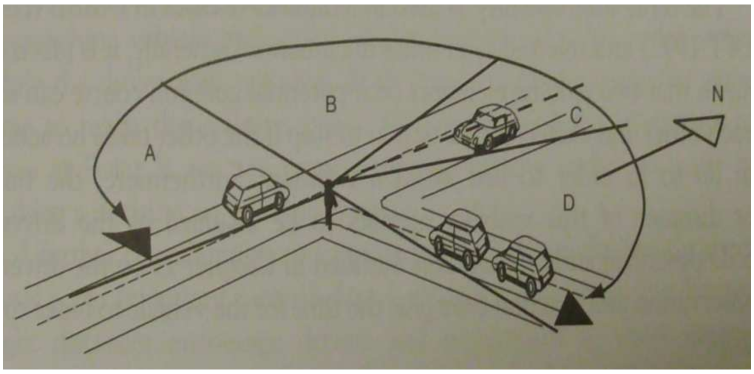

Figure 2-31: Visual scanning angle and sectors required by a southbound pedestrian wishing to cross the minor street of an unsignalised intersection (Source: Schoon, 2003)

e) Pedestrian observations during walking

Some observational tasks are performed by pedestrians while crossing the carriageway to ensure that the decisions and actions taken at the kerb are still safe, and that the appearance of undetected approaching traffic could not be a threat for their safety. The analysis of directional looking behaviour done in the study by Oxley et al. (1995) reported an average number of head movements ranging from 2.6 to 3 while pedestrians were crossing a road. The time spent looking at near-side traffic as a proportion of total looking in both directions while crossing an undivided road accounted for 34.5 percent for younger pedestrians and 26.9 percent for old pedestrians. Looking at far-side traffic accounted for 65.4 percent and 73.1 percent, respectively.

These findings are indicative of great emphasis on looking to far-side traffic while crossing, and are supportive of the concept of observation-reaction proposed by Shoon (2003). Indeed, the final focus done at the kerb on near-side traffic is done during the "last observation-reaction time" (LOR) while the final focus on far-side traffic is done at the starting point of the 'penultimate observation-reaction time' (POR). Thus, the POR corresponds to the loss of focus on the far-side traffic and this loss is compensated by the great emphasis put on looking at the far-side traffic once the road-crossing is initiated.

Looking at the ground and at other pedestrians while crossing the carriageway have been reported by Tom and Granié (2011) to be a significant component of directional observations at unsignalised pedestrian crossings: they accounted for 55.0 percent and 45.0 percent, respectively. At signalised intersections, looking at the ground accounted for 5.0 percent.

2.4.2.3. Total crossing time elements

The total crossing time includes the pedestrian observation-reaction time, walking time, and a safety margin (Schoon, 2003). The walking time is that amount of time during which the pedestrian is vulnerable to an accident with motor vehicles and is determined by the walking speed discussed previously and the width of the carriageway. Elements of total pedestrian crossing time are illustrated in Figure 2-32.

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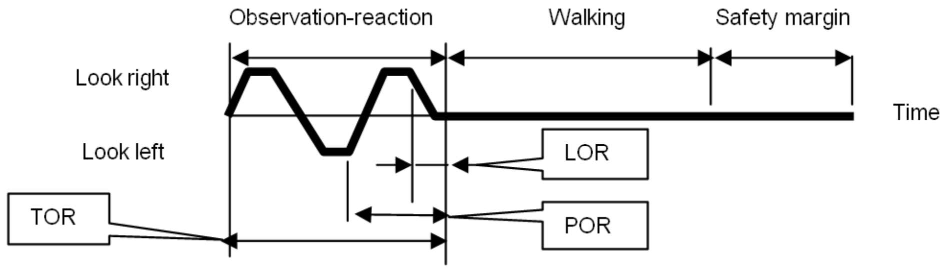

Figure 2-32: Elements of total crossing time (Source: Schoon, 2003)

2.4.2.4. Safety margin

A safety margin is defined as the amount of time from the moment the pedestrian crosses the virtual conflict zone until the next vehicle reaches the same zone. A fundamental definition has been adopted by several researchers while conducting experiments in a simulated road environment (Cavallo et al., 2009; Lobjois and Cavallo, 2007, 2009; Oxley et al., 2005, 2006; Tung et al., 2008). They defined a safety margin as the sum of the mean walking time (i.e. the average of normal and fast walking times) plus decision time, being subtracted from the time gap of the approaching vehicle. This definition is shown in the following equation:

$$Safety\ margin = Time\ gap - (Walking\ time + Decision\ time)$$

A safety margin is considered in research as an objective measurement of a safe gap or a safe crossing decision. Negative safety margins suggest that pedestrians accept gaps shorter than their crossing time, and therefore, drivers would have to take evasive action to avoid a collision. However, negative safety margins may correspond to an accident and are not expected in a real crossing event. Thus, a safety margin is used as an indicator of relative safety, with a greater safety margin representing a safe gap or a safe crossing decision (Zhuang and Wu, 2010).

Age-related differences in the safety margin have been investigated. In a simulated traffic environment done into two experiments, a large proportion (64.2-76 %) of elderly pedestrians (75 years old and more) was found to make unsafe decisions (negative safety margins) compared to younger pedestrians. Younger adult pedestrians (30-45 years old) and younger-old (60-69 years old) who made unsafe decisions were in proportions of 14.5-19% and 10.6-18% respectively (Oxley et al., 2005). The comparison of the findings from the two experiments revealed that time constraint did not affect the observed unsafe behaviour of a large proportion of elderly pedestrians.

Contrary to the findings above, a similar study conducted by Lobois and Cavallo (2006) failed to show age-related differences in safety margins and unsafe decision rates. The mean safety margins ranged from 2.5 s to 2.8 s for the 20-30 years group, from 2.0 s to 2.7 s for the 60-70 years group and from 2.1 s to 2.9 s for the 70-80 years group. This discrepancy may due to the age difference between the oldest pedestrians in the two studies (Lobois and Cavallo, 2006). However, impact of speed of oncoming vehicle on

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measured safety margins was noticeable; safety margins declined with increasing vehicle speed for elderly pedestrians. This finding is indicative of great impact of vehicle speed on crossing decisions of elderly pedestrians.

Safety margins have also been found to be affected by alcohol impairment (Oxley et al., 2006). Greater safety margins were found to be predominant amongst participants with low levels of BAC (<0.06%) and a lack of difference between safety margins adopted by participants with high levels of BAC (>0.07%) and those adopted by sober participants was reported (Oxley et al., 2006). This suggests that high levels of BAC are associated with increased confidence and risky behaviour.

In a Chinese study conducted by Zhuang and Wu (2010), factors influencing pedestrian safety and their perceived safety have been investigated at a six-lane road. Results from correlation analysis, followed by regression analysis and finally checked by path analysis showed a number of important variables closely related to safety. Among these variables, vehicle type was the most important predictor; lower safety margins were found when an oncoming vehicle is a car rather than a large bus. Pedestrian age also was strongly correlated with the safety margin; middle-aged pedestrians exhibited greater safety margins than other age groups. Correlation between high running frequency and lower safety margins also was revealed. However, bigger group size exhibited greater safety margins. Normally, larger group size can reduce the crossing speed, but gains easier the right-of-way against motorists than individual pedestrians (Himanem and Kulmala, 1988). Finally, higher looking frequency at left and right before the crossing was correlated with greater safety margins. The frequency rather than duration of looking before crossing was a very important behaviour enhancing the safe crossing. This implies that pedestrians have to turn their heads frequently with short duration of fixation to update any change in traffic situation and restore (Zhuang and Wu, 2010).

Another important finding from this study includes the relationship among some of these variables. Longer waiting times increased group size and frequency of looking at moving vehicles before crossing. Looking behaviour before crossing reduced the running frequency, but increased the frequency of going backwards. Finally, larger group size reduced the crossing speed while high running frequency increased the crossing speed.

2.4.3. Pedestrian delay

Delay is one of the qualitative measures of the level-of-service (LOS) of any transportation system. The competition for road space between motorists and pedestrians results in delays for all road users. The main problem at signalised crossings is the balance of delays between motorists and pedestrians. The failure to balance delays between motorists and pedestrians remains a deficiency of signalised pedestrian crossings. Pedestrians are the ones who are often marginalised in road management and experience longer delays than motorists. As an example, aggregate pedestrian delay at signalised crossings was found to be 10 times longer than that for motorists (Hunt, 1993 cited in Carsten et al., 1998). Excessive delay may result in feeling of frustration, which may lead in turn to signal non-compliance. Pedestrian delay

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was defined in research mostly as the amount of time between the pedestrian arrival at the kerb and the point at which he or she steps off the kerb. However, other studies (e.g. Li et al., 2005) stipulated that the definition of pedestrian delay should include also the delay experienced while crossing, caused mainly by conflicting turning vehicles. Therefore, pedestrian delay is defined as the additional travel time experienced by a pedestrian while crossing a road. Pedestrian delay, together with space requirements are the key performance measures of the LOS criteria for pedestrians at an intersection (TRB, 2000).

2.4.3.1. Pedestrian delay models

Models to estimate pedestrian delays have been proposed in the literature. The much known pedestrian delay model is the one proposed in the Highway Capacity Manual (HCM) and developed by Braun and Roddin (1978 cited in Li et al., 2005). According to this model, the average delay per pedestrian is given by the following equation:

$$d = \frac{(C - G)^2}{2C}$$

Where d is the average pedestrian delay, C is the signal cycle length, and G is the effective green time for pedestrians. It was assumed in this model that (1) the pedestrian arrival rate is uniformly distributed, (2) the pedestrian is compliant with traffic signal, (3) the signal cycle length is fixed and (4) there is no pedestrian signal actuation (Braun and Roddin, 1978 cited in Li et al., 2005).

In traffic conditions where those assumptions were not fulfilled, models were developed, mostly derived from the HCM's formula, to take into consideration situations different from those assumed in the initial model. The technical report written by Rouphail et al., (1998) summarised existing models of pedestrian delay in different traffic conditions. They cited a study by Pretty (1979) who presented separately two models for undivided streets and divided streets, under the assumptions that pedestrian arrival rates are uniformly distributed and pedestrian phases are equal. They presented also a study by Dunn and Pretty (1984) who proposed two models to estimate pedestrian delay at pelican crossings, one for a narrow roadway (two-lane road) and another for a wider roadway (four-lane road). Another cited study (Roddin, 1981) took into consideration pedestrian non-compliance with traffic signal by assuming that there is no delay for those who violate the traffic signals.

An Australian study conducted by Virkler (1998) considered in his model the pedestrians' benefits of crossing during clearance phases. Several seconds gained by the pedestrians entering the crossing during the clearance phase are subtracted from the duration of effective red signal. Considering higher proportions of red light violation, delays experienced by pedestrians while crossing (delay caused by turning vehicles) and pedestrian arrival rates not uniformly distributed throughout cycle length, Li et al., (2005) developed a model representing traffic conditions in the context of developing world. Their new methodology consisted of dividing the signal cycle length into 13 sub-

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phases to consider the non- uniformity of pedestrian arrival rates. The above-mentioned models are presented in Table 2-5.

Recents delay models have been developed mostly to extend and improve the ealier models. Bestian and Rouphail (2010) developed a model to estimate pedestrian delay at single-lane roundabouts. The Pretty's (1979) model for estimating pedestrian delay at a two-stage crossing has been improved by Wang and Tian (2010). Cheng et al. (2010) have extended the existing model to estimate pedestrian delay at signal-actuated crossings. Another model to estimate pedestrian delay at intersections with conflicting vehicular platoon has been also proposed by Chen et al., 2010).

Table 2-5: Models to estimate pedestrian delay

Author	Pedestrian delay model
Pretty (1979)	$d_1 = \frac{P}{2C}(C-G)^2$ (for pedestrias crossing one street) Where: d_1 = total delay to pedestrians crossing one street (ped-h/h) P = pedestrian volume crossing one street (peds/h) G = pedestrian green time C= Signal cycle length $d_2 = P_d(0.75\ C - G)^2$ (for pedestrias crossing two streets) Where: P_d =pedestrian volume crossing two streets (ped/h) It is assumed here that one-half the signal length separates the two pedestrian green phases
Dann and Pretty (1984)	$d = \frac{(g+10)^2}{2(g+15)}$ (for two − lane roads) $d = \frac{(g+15)^2}{2(g+20)}$ (for four − lane roads) Where: d = average delay per pedestrian (s) g = duration of vehicle green signal (s) G = pedestrian green time The parenthetical expressions in the denominator represent the cycle length for the above expressions, which assume pedestrian signal compliance
Roddin (1981)	$d = \frac{F(R-A)^2}{2(G-R-A)}$ Where: F = fraction of pedestrians arriving during non-green phases and comply with traffic signals R = duration of pedestrian red signal (or Don't Walk signal) G = duration of pedestrian green signal (or Walk signal) A = duration of clearance phase (or flashing Don't Walk signal)

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Virkler (1998)	$$d = \frac{[C-(G+0.69\,A)]^2}{2C}$$ Where: d = average delay per pedestrian (s) C = signal cycle length G = duration of pedestrian green signal (or Walk signal) A = duration of clearance phase (or flashing Don't Walk signal)
Li et al. (2005)	$$d = d_G + \frac{k_{NU}kR_E{}^2}{2C}$$ Where: d = average delay of pedestrians arriving during each sub-phase C = signal cycle length d_G =average delay of pedestrians arriving during green phases (set to be 2.1 s) k_{NU} = adjustment factor for non-uniform arrival rate for pedestrians $$k_{NU} = \frac{C(n_T-n_G)}{n_T(C-G)}$$ Where: n_G =number of pedestrian arriving during green phases n_T =overall number of pedestrians k =absolute value of decreasing line of the slope from the relationship between average pedestrian delay and arrival sub-phase $$k = 1-[1-(-0.08+0.90\,q)]P_W$$ Where: q = vehicle flow rate P_W =percentage of pedestrians willing to violate traffic signal if there are acceptable gaps R_E =effective red time $$R_E = C-(G+0.67A)$$ Where: A =duration of clearance phase (or flashing Don't Walk signal)

2.4.3.2. Factors influencing pedestrian delay

As all those delay models include the variable “signal cycle length”, it is obvious that signal timing has a great influence on pedestrian delay. Vehicle minimum green times have been reported also to influence the delay experienced by pedestrians at signalised intersections: longer minimum green times were associated with longer waiting times (Van Houten et al., 2007).

Pedestrian delay has also been associated with a number of factors. The impact of demographic variables on pedestrian delay have been reported in the research: Old pedestrians experience longer delays than younger pedestrians (Goldschmidt, 1977 cited in Ishaque and Noland, 2008; DfT, 2004). Familiarity with a pedestrian crossing emerged from the Hamed’s (2001) study as an influential foctor of pedestrian delay. A link between pedestrian delay and the vehicular traffic volume has been noted in the report of the National Cooperative Highway Research Program (NCHRP). It is stated that pedestrian delay increases as vehicular traffic volumes increases at unsignalised intersection (Fitzpatrick et al., 2006). The traffic flow in the near-side lane of the road was reported also to have the greater impact on the pedestrian delay than the traffic flow in the far-side lane (Hine and Russell, 1996). Pedestrian arrival phase is another influential factor of pedestrian delay (Li et al., 2005; Schroeder et al., 2008, Van Houten et al., 2007). Indeed, pedestrians who arrive late in the signal cycle experience shorter delays than those who arrive early in the signal cycle. Geometric characteristics of a pedestrian crossing, such as crossing distance and presence of refuges could also influence pedestrian delay. As an example, the report by Fitzpatrick et al. (2006) indicated that pedestrian delay at refuges was shorter than that experienced at kerbs. Although the effect of the number of heavy vehicles, speed and crossing distance on pedestrian delay was noted in research (Goldschmidt, 1977 cited in Ishaque and Noland, 2008), further research is needed to investigate their effect.

The type of pedestrian crossing significantly affects pedestrian delay. Shorter delays are expected at zebra crossing because pedestrians have priority over motorists and longer delays are expected at signalised crossings. As an example, mean pedestrian delays were found to be 4.9 seconds at zebra crossing, 14.4 seconds at signal controlled intersections and the highest delay was found at pelican crossings (Crompton, 1979, cited in Ishaque and Noland, 2008). The installation of an automatic pedestrian detection device and a smart lighting system decreased the delay from 7.5 seconds to 3.8 seconds per pedestrian in the study conducted by Nambisan et al. (2009).

2.4.4. Pedestrian compliance

Pedestrians are usually subjected to fewer traffic rules compared to drivers on the road (speed limits, manoeuvre restrictions, etc.). They are small compared to the size of a vehicle and this makes them more responsive and flexible (they can easily make changes in course and speed) than drivers. All those factors, together with some social psychological variables, demographic variables, situational factors (e.g. traffic volume, presence of other pedestrians and waiting time), physical characteristics (e.g. crossing

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distance, presence of pedestrian refuge) of the crossing and physical conditions (e.g. bad weather, darkness) may hinder their efforts to comply with traffic rules. Crossing compliance may be defined as the percentage of pedestrians who crossed the road in compliance with designated crossing and/or with the green man signal indication. Therefore, two types of pedestrian compliance exist in research: temporal crossing compliance, i.e. compliance with traffic signal rules and spatial crossing compliance, i.e. compliance with formal marked crossings. A variety of studies have been conducted to examine the rate of pedestrian non-compliance and some factors contributing to that propensity have been addressed.

2.4.4.1. Level of pedestrian compliance

There is a significant variation in pedestrians' level of compliance in research as all those factors above-mentioned and their level of control differ from one population to another. The effect of culture, law and its level of enforcement is also another influential factor of pedestrian compliance with traffic rules.

a. Temporal compliance

A study conducted by Virkler (1998) in Australia at 18 signalised pedestrian crossings observed the rate of pedestrian compliance with traffic signals. Those who crossed within the green signal were referred to as "complying", those who entered the crossing during the clearance interval were referred as "runners" and "jumpers" were those who entered the crossing during the red signal. The rate of non-compliance with the traffic signals ranged from 2.6 percent to 66.7 percent. Daff et al. (1991) reported in their study conducted in Sydney that the rate of compliance with pedestrian signals varied from 54 percent to 84 percent. Another Australian study reported a mean proportion of 19 percent of pedestrian crossing during the Steady Don't Walk signal (Barker et al., 1991 cited in TRL, 2009).

In the UK, Reading et al. (1995) reported a red light violation ranging from 17 percent to 49 percent. Other two British studies reported a red light violation ranging from 42 percent to 92 percent (Wall, 2000) and a red light violation accounting for 49 percent in London (Sterling et al., 2009). Nearly half of pedestrians failed to push the button at one site (in a small town) and the same behaviour accounted for 73 percent in London (Davies, 1992 cited in Carsten et al., 1998). Zeedyk and Kelly (2003) observed behaviour of adult-child pairs when they were crossing at four signalised crossings (Pelican) located in the city of Dundee in Scotland. Results showed that adult pedestrians generally set good models of pedestrian behaviour to children when they cross at pelican crossings. Ninety- eight percent crossed in the crossing, 98 percent stopped at the kerb, 91 percent checked whether the traffic had stopped, 81 percent waited for the green man signal and 76 percent held children's hand while crossing. However, a failure to use the crossing event as an opportunity to teach children about safe crossing behaviour was reasonably noticeable; only 6 percent of adults were observed instructing children prior crossing and only 21 percent of adults encouraged children to activate the signal themselves (Zeedyk and Kelly, 2003).

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An American study conducted by Stephanie and Machemehl (1999) observed 712 crossing scenarios at signalised intersections. Results showed that red light running accounted for 41 percent of all crossing scenarios, of them 12 percent occurred during the clearance phase (Flashing Don't Walk signal) and 29 percent occurred during the Steady Don't Walk signal. High percentages of pedestrians pressing pushbuttons have been reported in the United States: the pedestrian signal was actuated by 70 percent at a crossing located on a four-lane undivided road, whereas it was actuated by 71 percent at a crossing located on a three-lane one way road (Van Houten et al., 2007). In France, a poor rate of signal actuation was reported at a location in Toulouse: 82 percent of pedestrians failed to push the button (Levelt, 1992 cited in Carsten et al., 1998). A recent study by Tom and Granié (2011) reported red light running accounting for 11.2 percent at signalised crossings.

In the developing world, Yang et al. (2006) investigated pedestrian signal compliance under different circumstances in China. When pedestrians were asked their frequency level of signal non-compliance, results indicated a rate of signal non-compliance fluctuating between 45 percent and 83 percent. Videotaped data at three signalised intersections showed a mean value of 85 percent of signal non-compliance (red light runners). In Poland, a red light violation accounting for 17 percent was reported (Tracz and Tarko, 1993). Running a red light was also reported by 16.4 percent of respondents in an Israeli study conducted by Rosenbloom et al. (2004) and few years later, red light violation was observed in 5.5 percent of all crossing scenarios (Rosenbloom, 2009). A Greek study conducted by Galanis and Eliou (2012) at 12 signalised crossing indicated that 15 percent of observed pedestrians crossed during the red light and the remaining (85 percent) crossed during the green light. In New Zealand, while answering surveys, almost half of pedestrians admitted to crossing "occasionally" during the steady red man signal and 21 percent to "regularly" crossing during the steady red man (Turner et al., 2008).

Research has shown varied levels of temporal compliance according to the type of signalised crossing. While evaluating the impact of countdown timers on pedestrian behaviour, Keegan and O' Mahony (2003) revealed that the replacement of signalised crossing by countdown timers resulted in reduction of red light running from 35 percent to 24 percent. A number of other studies dealing with the effect of countdown timers in pedestrian behaviour have been reviewed in the report of the Transport Research Laboratory (Kennedy and Sexton, 2009). Those studies were conducted in the United States and used either before-and-after studies or comparison sites. Results from comparison studies showed that the level of compliance with pedestrian signals was lower at sites with the presence of countdown timers compared to the sites without countdown timers (Leonard and Juckes, 1999; Huang and zegeer, 2000; Pulugurtha and Nambisan, 2004; Schattler et al, 2007). With regard to before-and-after studies, countdown timers have been reported to enhance the compliance with Walk signal and to reduce the proportion of pedestrians crossing during the Flashing Don't Walk signal (e.g. Eccles et al., 2004; PHA transportation Consultants, 2005; Schattler et al., 2007). However, The installation of countdown timers has been pointed out in some studies to increase the proportion of pedestrians crossing during the Steady Don't Walk signal (e.g.

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DSK Associates, 2001; Reddy et al., 2008) and to decrease the proportion of pedestrians crossing during the Walk signal (Botha et al., 2002).

The city of London conducted a study to evaluate potential road safety Puffin (Pedestrian User-Friendly Intelligent) compared to those of Pelican crossings. It was reported that 20 percent of users of Pelican and 28 percent users of Puffin did not use the pedestrian pushbutton. Observational study showed that 80 percent of users of both facilities crossed on the green man signal. Observations and pedestrian interviews showed no significant difference in crossing behaviour between two crossing facilities. Observational data showed that 1 percent of users of Pelican crossings crossed during the flashing green man (equivalent to flashing red man in South Africa) whereas only 0.1 percent of users of Puffin crossings were observed crossing during all-red period. Levels of self-reported non-compliance accounted for 39 percent at Pelican crossings and 41 percent at Puffin crossings (Transport for London, 2006).

The reduction in cycle length was found also to significantly improve the compliance rate in the study by Keegan and O' Mahony (2003). After the installation of countdown timers, the reduction in cycle length resulted in the reduction of red light violation from 15 percent to 8 percent. However, some researchers failed to show a relationship between non-compliance and cycle time (e.g. Barker et al., 1991, Garder, 1989 cited in TRL, 2006). Effect of varying vehicle minimum green times on pedestrian signal compliance has been investigated in an American study conducted by Van Houten et al., (2007).Their study noted that the rate of signal compliance dropped off with an increasing vehicle minimum green time.

b. Spatial compliance

Crossing at a designated crossing facility has been examined in a study conducted by Sisiopiku and Akin (2003). Compliance behaviour was observed at different types of crossings located in a divided urban boulevard next to the campus of Michigan State University. Results from a survey conducted on pedestrian compliance preferences revealed a spatial non-compliance rate of 41 percent. With respect to an observational study, the calculated spatial compliance rates were found to be 82.8 percent for signalised intersections, 71.2 percent for mid-block crossings and 67.5 percent for unsignalised intersections.

Spatial compliance was one of the focuses in the study conducted in two Israeli cities, Bnei-Brak and Ramat-Gan (Rosenbloom et al., 2004). Crossing the road at non-designated crossing was found in 6.3 percent of all observed crossing scenarios.

In South Africa, pedestrian crossing points on two arterials (Klipfontein Road and Buitengracht Street), a major collector (Cavendish Street) and two freeways (the N2 and the R300) all located in Cape Town were observed in a three-stage study (Behrens, 2010). Results showed that only 15 percent of crossings occurred at the crossing facility on Klipfontein Road. The remaining (85 percent) were distributed away from the crossing. On the Buitengracht Street, a rate ranging from 1 percent to 5 percent of crossings was observed to occur at the crossings and the remaining (95-99 percent) were observed away from the crossing, with the highest concentration at 61-70 metres from the crossing facility. A high rate of spatial compliance (80 percent) was observed on Cavendish Street. A crossing facility located close to the pedestrian movement desire lines was the reason of this high level of spatial compliance for that road. On freeways, the first study indicated the concentration of crossing points between 100 and 300 metres from the nearest crossing facility, whereas only 5-15 percent was located at crossing facilities. In the second study, 38 percent occurred at crossing facilities and the remaining (62 percent) were distributed elsewhere.

2.4.4.2. Factors influencing pedestrian non-compliance with traffic rules

i. Waiting time

Travel time is one of the fundamental costs of transport activities and savings in travel time are a major benefit justifying the viability of a transport infrastructure and service improvement. Unsafe road-crossing behaviour reported in a number of studies has been a result of various factors, including disutility of waiting time. Pedestrians' unpleasantness of waiting conditions and the uncertainty of the waiting time are two forms of disutility of waiting time (MVA et al., 1987).

In relation to the reported disutility of waiting time, an Irish study conducted by Keegan and O'Mahony (2003) evaluated the impact of countdown timers on pedestrian behaviour. Countdown timers are used to eliminate that uncertainty by informing the remaining time for the green signal to be displayed. A before-and-after study was conducted in the City of Dublin and pedestrians' road-crossing behaviour was examined using three techniques: video observations, questionnaire and interviews. Pedestrians who waited for the green signal were referred to as "waiters" and those who crossed against the red man signal were referred to as "walkers". Pedestrians were asked to estimate the time they had waited for before crossing the road and their responses were compared to the calculated average waiting time for the whole sample. Amongst waiters, the installation of countdown timers reduced the overestimation of the waiting time by 60 percent (from 29 to 4 seconds). The reduction amongst walkers was from 87 to 26 seconds. While asked whether the waiting time was reasonable or not, the perception of being too long was reported by 17 percent of waiters in the before study and reduced to 7 percent in the after study. Those who reported that it was reasonable were 82 percent and 93 percent after the installation of countdown timers.

In line with the previous findings, the perception of long duration of red signal has been found by Yang et al. (2006) to be more influential in enhancing pedestrian signal non-compliance. Research has reported that the longer the waiting time at the kerb, the higher is the red light violation (Wang et al, 2009; Baass, 1989; Asaba and Saito, 1998; Daff et al., 1991; Tiwari et al., 2007; Turner et al., 2008). This conclusion emerged in the study by Baass (1989) after finding that pedestrians who waited between 40 and 60 seconds violated the red light more than those who waited less than 30 seconds, supporting thus the statement that pedestrians are normally prepared to wait up to 30 seconds for the green signal (TRB, 2000; Hunt, 1995, Wall, 2000). A link between jaywalking and the pedestrians' feeling of impatience emerged also in the Japanese study conducted by Asaba and Saito (1998). Therefore, it is clear that the length of waiting time, the pedestrians' perception and uncertainty of waiting time are motivational factors of temporal non-compliance.

A link between pedestrian compliance and pedestrian arrival phase has emerged from research. Stephanie and Mechemehl (1999) found that 91 percent of pedestrians who arrived during the Flashing Don't Walk signal violated the red light signal. Of them, 74 percent crossed immediately (during the Flashing Don't Walk signal) and 17 percent crossed during the Steady Don't Walk signal. However, red right running accounted only for 39 percent amongst those who arrived during the Steady Don't Walk signal. Of them, the majority (35 percent) crossed in the same signal period. Compliance rate by pedestrian arrival phase was also presented in the Rosenbloom's (2009) study: 40.5 percent of all arrivals occurred during the red light, and only 5.5 percent of all observed pedestrians crossed against the pedestrian red signal.

ii. Crossing distance

Longer crossing distances may hinder the opportunity to violate a pedestrian red signal unless a pedestrian refuge is provided. Virkler (1998) reported a link between crossing distance and pedestrian temporal compliance: higher proportions of red light runners were found where crossing distances were shorter (one-way street). The same finding emerged from the study by Stephanie and Machemehl (1999): compliance behaviour increased with the width of the street.

iii. Familiarity with crossing

As pedestrians regularly use a pedestrian crossing, they become familiar with the sequence of traffic signals and the signal timing. They acquire the skills to cross the road unsafely which increase their vulnerability to injury in case of misjudgement. Familiarity has been investigated in the study conducted by Hamed (2001): shorter waiting times and fewer crossing attempts were likely observed amongst pedestrians who frequently use a certain pedestrian crossing and who live nearby the crossing. However, familiarity with the pedestrian crossing failed to explain the unsafe road-crossing behaviour in several studies (e.g. Garder, 1989).

iv. Impairment

Pedestrians with physical disability or sensory impairment may be more cautious in a road environment than able pedestrians as they are aware of their limited ability (Kennedy and Sexton, 2009). Nevertheless, in the case where impairment affects the perceptual and cognitive skills necessary to cross the road safely, it can appear as an influential factor of road-crossing behaviour. Alcohol impairment is the well known influential factor in risky road behaviour and traffic injuries in general as referred to previously. Electronic devices such as MP3 players and mobile phones have been regarded as another form of impairment as they can deter pedestrians from hearing the oncoming traffic (Kennedy and Sexton, 2009). For example, a link between the use of a mobile phone and the pedestrians' failure to look at oncoming traffic while crossing at signalised intersection was reported in the study by Hatfield and Murphy (2006).

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v. Physical conditions

Inclement weather conditions such as a storm may encourage pedestrians to cross the road in risky conditions. The use of an umbrella during wet weather may cause difficulty in seeing oncoming traffic (Kennedy and Sexton, 2009).

vi. Situational factors: traffic volume and speed, peer pressure and location of crossing facility vis-a-vis pedestrian movement desire lines

Traffic volume has been reported in several studies to influence the pedestrian compliance. Impatient pedestrians generally base their crossing decisions on oncoming traffic rather than pedestrian signals (Asaba and Saito, 1998). When the traffic is heavy, pedestrians are more likely to wait for the green signal (Yagil, 2000; Daff et al., 1991; Garder, 1989; Keegan and O' Mahony's, 2003) probably because available gaps during the red signal become shorter than those they would choose in low traffic volume conditions. Brewer et al. (2006) revealed that on streets with high volumes of traffic, pedestrians use rolling gaps when they cross. This is seen as a very risky crossing behaviour as pedestrians are forced to stand in the crossing waiting the lanes to be clear. In the other hand, red light running has been reported to be significant on roads with low traffic volume (Virkler, 1998; Stephanie and Machemehl, 1999; Yang et al., 2006). Nevertheless, influence of traffic volume on pedestrian compliance was found insignificant in some studies (e.g. Rosenbloom, 2009). Crossing during the pedestrian red signal may also be hindered by the perceived risk caused by traffic moving at high speeds.

The location of a crossing facility relative to the pedestrians' desire lines was found to be the most influential factor of spatial non-compliance. In a survey conducted by Sisiopiku and Akin (2003), the results showed that distance between the pedestrians' desire lines and the location of the designated crossing significantly influenced the pedestrians' choice of jaywalking. Supporting this finding, Behrens (2010) also reported a higher level of spatial compliance at crossing facilities located on dominant pedestrian desire lines.

Research has shown that the presence of other pedestrians at crossing facility is another influential factor of pedestrian compliance (Yang et al., 2006). The presence of other pedestrians was found to decrease the frequency of red light violation in the Rosenbloom's (2009) study. It was reported that the presence of few pedestrians at an intersection increases the pedestrians' tendency to check for the traffic before crossing (Andrew, 1991 cited in Martin, 2006). Indeed, normal individuals tend to stick to social norms when they are surrounded by other people in order to avoid social criticism.

vii. Social psychological variables

Social psychological variables have been found to play a key role in influencing pedestrian crossing behaviour. Researchers have applied behaviour models to explain the extent to which components of models could predict the actual behaviour amongst pedestrians. Two behavioural models significantly applied in road safety research include the 'health belief model' (HBM) and the 'theory of planned behaviour' (TPB).

❖ **The health belief model**

The health belief model was initially developed with the specific purpose of understanding precautionary health behaviour (Rosenstock, 1966; Becker, 1974). According to this model, the person's behaviour is influenced by the following cognitive factors representing the perceived threat and net benefits:

- Perceived susceptibility (their opinion of the chances of being involved in the behaviour);
- Perceived severity (their opinion of how serious the behaviour and its consequences are);
- Perceived benefits (their opinion about the positive consequences of adopting the behaviour);
- Perceived barriers (their opinion of the tangible and psychological costs associated with the adoption of the behaviour).

A recent construct, '*self-efficacy'* was added to the traditional health belief model. It reflects the person's confidence in the ability to successfully perform behaviour. A person's behaviour would be also influenced by an additional construct *'cues to action'* which reflects factors activating their readiness to change.

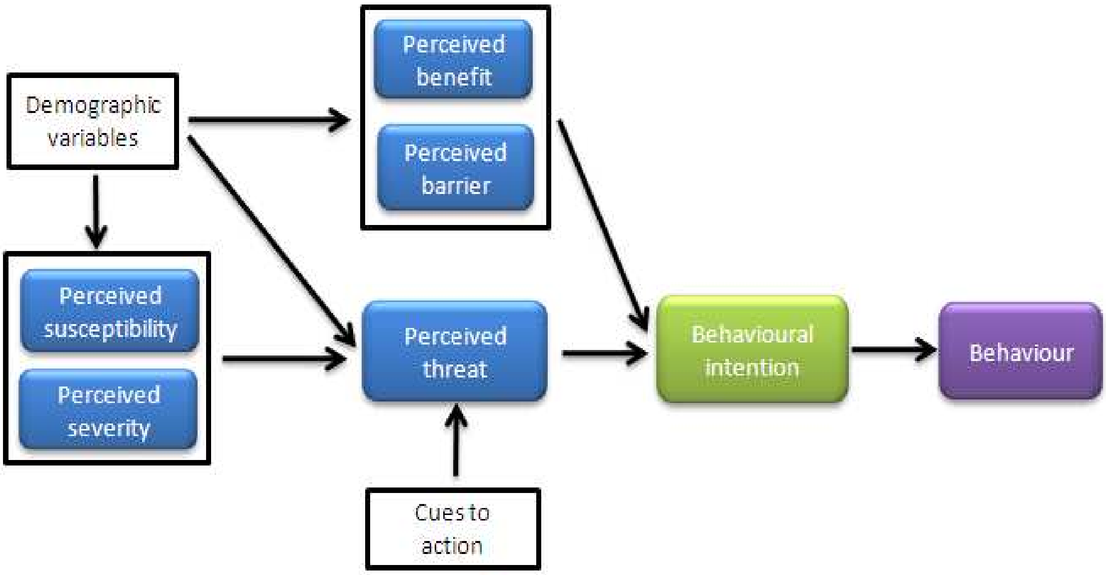

Figure 2-33: The health belief model

Yagil (2000) applied the health belief model to explore pedestrians' self-reported crossing behaviour in relation with the components of the model, instrumental motives, normative motives and situational variables. Two perspectives of obedience to laws, argued by Tyler (1990) were used in Yagil's (2000) study: instrumental motives and normative motives. Instrumental motives are defined as reaction initiated by gains and losses relating to obeying or disobeying the law, whereas normative motives explains

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the sense of obligation to obey the law as a function of the individual's values and beliefs (Yagil, 1998). A questionnaire was administered to 203 students at two higher education institutions in Israel. Questions depicting (1) beliefs and motives relating to unsafe road crossing (e.g. crossing in Don't Walk signal); (2) normative motives (e.g. sense of obligation to obey laws relating to pedestrian behaviour and belief in the law); (3) instrumental motives (perceived danger of crossing against a Don't Walk signal and perceived likelihood of an encounter with the police); and (4) situational factors such as traffic volume, physical conditions (darkness, bad weather, long duration of a Don't Walk' signal), mood and presence of other pedestrians. Results confirmed a significance prediction of road-crossing behaviour with the health belief model. The components of the model such as perceived benefits and perceived barriers regarding unsafe road-crossing behaviour contributed significantly to the prediction of behaviour and influenced the decision making at similar frequency. Normative motives (especially expressed in terms of sense of obligation to obey the law) predicted more significantly the road-crossing behaviour than did instrumental motives and the components of the health belief model.

The health belief model was also applied in traffic safety research to predict helmet use among cyclists (Arnold and Quine, 1994) and safe-riding behaviour among motorcyclists (Rutter et al., 1995).

- **The theory of planned behaviour (TPB)**

The theory of planned behaviour (Ajzen, 1988, 1991) is another social psychological model commonly used in traffic safety research to predict motivational determinants of unsafe behaviour. According to the theory of planned behaviour, intention is given a key role in predicting the actual behaviour and the intention in turn is determined by three constructs:

- Attitude, which consists of beliefs about the likely outcomes of the behaviour and the person's overall positive or negative evaluation of the behaviour;
- Subjective norm, which consists of person's normative beliefs about what other groups would expect them to do and the motivation to comply with their opinions;
- Perceived behavioural control, which consists of the person's perception of the ease or difficulty of performing the behaviour.

Several studies have examined the relationship between the components of the theory of planned behaviour (attitude, subjective norm and perceived behavioural control) and the intention to cross the road. The suitability of the theory of planned behaviour in predicting the intention to engage in risky crossing has been confirmed in research (Muyano Diaz, 2002; Holland and Hill, 2007; Evans and Norman, 1998; Elliot, 2004).

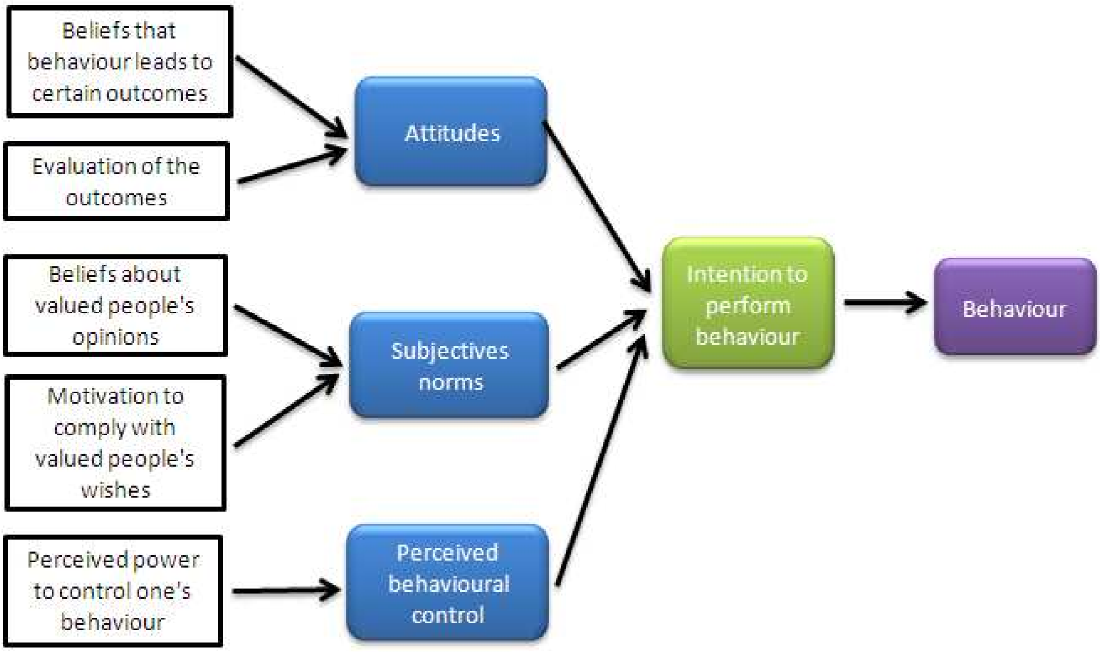

Figure 2-34: The theory of planned behaviour model

The traditional theory of planned behaviour has been extended in some studies to include other social cognitive variables, such as anticipated affect, moral norm and self-identity (Evans and Norman, 2003). Following Evans and Norman (2003), anticipated affect reflects anticipated feelings after performing behaviour (e.g. 'My taking chance and running across the road would make me big'), moral norm reflects feelings of personal responsibility for performing or not a behaviour (e.g. 'It would be quite wrong for me to take a chance and run across the road') and self-identity deals with individual's perception of himself or herself as a safe pedestrian. Evans and Norman (2003) applied this extended model to examine road-crossing behaviour amongst adolescents. A questionnaire included a scenario depicting an unsafe road-crossing behaviour, followed with a series of questionnaire measuring the components of the traditional TPB and the additional variables above-mentioned. The unsafe road-crossing behaviour consisted of crossing a road at a non-designated crossing in dark conditions, by taking a chance onto oncoming traffic and by running. Results revealed that the TPB variables were able to explain 25 percent of the intention to cross the road as depicted in the scenario, with perceived behaviour control as the strongest predictor of intention. With regard to additional variables, only anticipated affect and self-identity showed additional predictive utility of intention to cross, justifying thus their inclusion in intention predictors. The TPB variables together with additional variables (self-identity, anticipated affect, age and gender) succeeded to explain 37 percent of road-crossing intentions.

Conformity tendency and perceived risk are other additional variables examined by Zhou et al. (2009) for their potential influence on road-crossing behaviour. Conformity tendency was defined by "person's intention or willingness to be influenced or controlled by others" (Zhou et al., 2009). Two road-crossing scenarios were presented in a questionnaire to examine the role of people's conformity tendency in road-crossing

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intentions. These two road-crossing scenarios depicted a conformity situation (road-crossing behaviour that is consistent with other pedestrian s' behaviour) and a non-conformity situation (road-crossing behaviour that is inconsistent with other pedestrians' behaviour). A series of questions were administered to 426 respondents to measure the components of the TPB and additional variables (anticipated affect, moral norm, self-identity and perceived risk). Results showed that attitude, subjective norm, perceived behavioural control, perceived risk and conformity tendency emerged as significant predictors of behavioural intention in both of the two scenarios.

In contrast to the findings from the study by Zhou et al. (2009), self-identity emerged as a significant predictor of road-crossing intention in two of three scenarios presented in a study by Evans and Norman (1998). Adult pedestrians were subjects of this study, and three crossing scenarios presented in the questionnaire included crossing a dual carriageway, crossing at a pelican crossing against the red man signal, and crossing a busy residential road between parked cars. A series of questions were asked to measure the prediction of the variables of the TPB and self-identity as an additional variable. The variables of the TPB predicted the intention of the unsafe crossing behaviour between 37 and 49 percent, with perceived behavioural control being the strongest predictor of crossing intention in each scenario. Perceived behavioural control was measured by asking how easy or difficult it would be to cross the road in those three situations. The relevant finding suggests that pedestrians are more likely intended to engage in unsafe road-crossing when road-crossing behaviour is seen to be easy to perform. Self-identity explained also 3 percent of variance in intention to violate the red light in the study conducted by Elliot (2004).

viii. Demographic variables

The effect of age and gender has been pointed out by many authors to influence crossing behaviour of pedestrians. Old pedestrians have been found more compliant than other age groups when they cross the road (Daff et al, 1991; Rosenbloom et al., 2004; Rosenbloom, 2009; Muyano Diaz, 2002; Holland and Hill, 2007; Zhou et al., 2009).

Research has reported that non-compliant behaviour amongst children is linked to the lack of experience and limited cognitive ability (Pline, 1992; NCHRP, 2006). Following this finding, Zeedyk et al. (2002) conducted a study in the UK to investigate children's behaviour while crossing a road. Fifty-six children of 5-6 years old were observed inconspicuously in two realistic road-crossing scenarios, one at a T-junction and the other between parked vehicles. Children were told to collect eight letters posted individually on trees, lamp posts and street furniture located at opposite side of the street. An adult person was situated near each site to help children who needed any assistance. Information gathered included behavioural patterns such as stopping at the kerb, looking for traffic, direction of gaze and crossing styles. Results showed that children's performance while crossing the road was extremely poor. Only 18 percent of them requested assistance from an adult (which was regarded as optimum performance). Of those who crossed on their own, about 40 percent failed to look at the moving traffic and 60 percent failed to stop at the kerb before stepping into the road.

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Interestingly, single observation (partial looking) and often directed in inappropriate direction (i.e. to the left instead of to the right) was predominantly observed amongst those who looked.

Adolescents have been found to be less cautious when they cross the road, not because they lack sufficient perceptual and skills to cross the road safely (Whitebread and Neilson, 1996), but rather because they fail to deploy the skills they acquired (Evans and Norman, 2003). A study conducted by Elliott and Baughan (2003) indicated that running, temporal non-compliance and failure to check whether the traffic had completely stopped before crossing were the predominant unsafe behaviour performed by adolescents.

Gender is another demographic variable mostly reported in research to influence pedestrian behaviour. Female pedestrians have been found to be more compliant than male pedestrians. Red light running has been found to be more frequent amongst male pedestrians than female pedestrians (Rosenbloom et al., 2004; Rosenbloom, 2009; Muyano Diaz, 2002; Yagil, 2000, Latrémouille et al., 2004; Tom and Granié, 2011; Keegan and O'Mhonny, 2003). Few studies exploring gender differences in spatial compliance also reported a higher level of compliant behaviour amongst female pedestrians (Latrémouille et al., 2004; Rosenbloom et al., 2004). However, no difference in spatial compliance has been found in a recent study conducted by Tom end Granié (2011). Nevertheless, their study indicated that men seem to comply differently with temporal and spatial rules; they were observed running more frequently on signalised crossings than on unsignalised crossings (11.1 percent versus 2 percent) and ending their crossing more frequently outside the marked area on unsignalised crossing than on signalised crossings (32 percent versus 20 percent).

Gender-related differences in motivational determinants of crossing behaviour emerged in several studies applying the two social psychological models. Muyano Diaz (2002) revealed that male pedestrians are more likely to commit violations, more likely to intend to cross and perceived the risk less than female pedestrians. By applying the health believe model, Yagil (2000) reported that the presence and behaviour of other pedestrians were the most influential factor amongst female participants, whereas male participants were influenced more significantly by situational factors (traffic volume and physical conditions). Moreover, it was revealed that crossing behaviour amongst men was more predicted by normative motives than did instrumental motives, whereas instrumental motive such as "perceived danger of unsafe crossing behaviour" was the most influential factor amongst women. Another interesting finding emerged from the study by Zeedyk and Kelly (2003): while observing adult-child pairs crossing the road, adult pedestrians were observed more likely to hold girl's hands than boys' hands. The authors argued that this behavioural pattern may be due to the perceived greater need of protection or control with regard to girls, whereas in contrary evidences that boys are more impulsive in traffic environment than girls exist in the literature.

Chapter 3. STUDY AREA

3.1. Overview

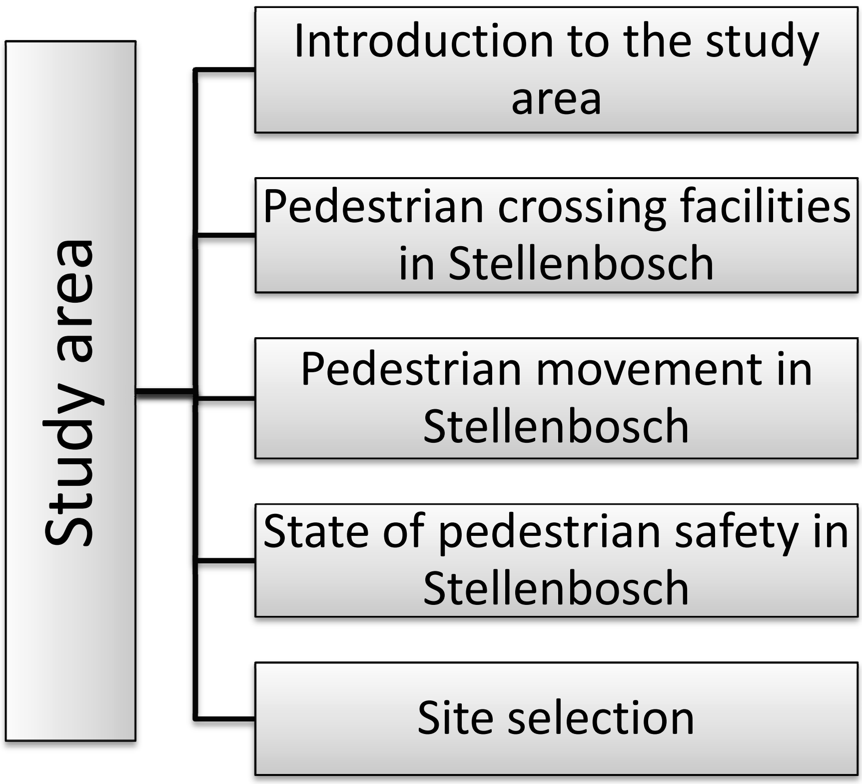

Figure 3-1: Overview of the Chapter

3.2. Introduction to the study area

Stellenbosch is a town situated in the Western Cape Province, in the heart of the Cape Winelands region. It is located about 50 kilometres east of Cape Town and 28 kilometres from the Cape Town International Airport. After Cape Town, Stellenbosch is the second oldest European settlement in the province. The town has its own municipality and is home to the University of Stellenbosch.

According to the 2007 Community Survey, the population in Stellenbosch Municipality had an average annual growth rate of 9.3 percent, increasing from 117713 inhabitants in 2001 to 200521 in 2007, students not included (Stellenbosch Municipality, 2012). In particular, a higher annual growth rate of 13.8 percent was found amongst the Black population. The population of Stellenbosch was expected to reach an average of

270323 habitants by 2010. The majority (56.4 percent) of the population of Stellenbosch is Coloured (mixed-race and Khoisan descent), followed by Whites (21.6 percent), Black (20.1 percent) and then Asians (0.2 percent). The most common language is Afrikaans (69.4 percent), followed by IsiXhosa (19.8 percent) and English (8.4 percent).

The analysis of age distribution in 2001 revealed that about a quarter (25.4 percent) of the population in the Stellenbosch Municipality were less than 15 years and a high proportion (40.4 percent) fell in the 15-34 age range. Children together with youth represented 66.1 percent of the total population in Stellenbosch in 2007. The economically active population (15-64 years) accounted for 70 percent whereas the elderly composition was 4.2 percent of the population in 2007. The female population outnumbered the male population, at 51.3 percent and 48.7 percent, respectively (Stellenbosch Municipality, 2012).

The rate of unemployment in Stellenbosch was 17.1 percent in 2007 in the whole population. This reported unemployment was more frequent amongst the Coloured population (50.2 percent), followed by Black population (47.3 percent). The youth (15-34) is most likely to be unemployed, accounting for 70.1 percent of the total unemployment. The economic sectors in Stellenbosch employed 75 021 people in 2007. Of them, 20.2 percent were in manufacturing, 17.4 percent were in community, social and personal services, 16.3 percent were in trade (wholesale and retail trade) and 12.7 percent were in agriculture, hunting, forestry and fishing. Other remaining sectors employed 33.6 percent of workers (Stellenbosch Municipality, 2010).

3.3. Pedestrian crossing facilities in Stellenbosch

Pilot observations carried out in Stellenbosch Town identified several types of pedestrian crossings which have been categorized as follows:

1) *Pedestrian crossings at signalised intersections*: These pedestrian crossings are controlled by a signal activated by a pedestrian push-button (signal-actuated crossings). Three signal types are available for pedestrians: the green man, the flashing red man and the steady red man. The green phase for pedestrians is not protected and turning vehicles are often in conflict with pedestrians. Traffic signals are generally located at junctions with high traffic volumes and on high speed roads. Pedestrians are allowed to start crossing during the green phase (green man). Crossing in steady red man is prohibited and no pedestrian should be still in the crossing during the steady red man. The flashing red man indicates that pedestrians who already have started crossing must finish crossing, but none may enter the crosswalk to start crossing. Some pedestrian crossings at signalised intersections are equipped with accessible pedestrian signals (APS) providing audible information that coincides with visual pedestrian signal. The APS is provided for pedestrians who are blind or visually impaired. The type of crossing marking used is standard marking with yielding line close to the crossing.
2) *Pedestrian crossings at unsignalised intersections*: These pedestrian crossings are located at T-junctions or four-leg intersections, controlled by STOP signs. They are of three types: (a) marked pedestrian crossings; (b) unmarked pedestrian crossings

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(with textured pavement); and (c) informal pedestrian crossing (without any marking or textured pavement).

3) *Mid-block crossings*: They take the form of zebra crossing, raised pedestrian crossings (crossings at flat-top speed humps or speed table), and signal-actuated mid-block crossings. Continental marking is mainly used for zebra crossings and signal-actuated mid-block crossings, but most raised pedestrian crossings are unmarked and their visibility is enhanced by the use of coloured paving (cobblestones or bricks).
4) *Pedestrian crossing at roundabout:* Unmarked crossings and zebra crossings are provided at few roundabouts and mini-roundabouts, with splitter islands occasionally used as refuges for pedestrians.
5) *Overpass:* One overpass is situated on Merriman Avenue and is used mainly by students of Stellenbosch University.

3.4. Pedestrian flow in Stellenbosch

The main pedestrian trip generators in Stellenbosch may be categorized as follows:

- *Residential suburbs*: Four main suburban settlements, namely Kayamandi, Cloetesville, Tenantville and Idas Valley produce walking trips towards or from the CBD of the town and the Stellenbosch University (see Figure 3-1). These suburban settlements are populated predominantly by low-income households for which the lack of private mobility in these areas is compensated by greater non-motorized transport (NMT) dependence. The majority of residents, especially in Kayamandi, use walking as their main transport mode for work, retail or other relevant activities. Bird Street serves as the main route for the majority of residents from Kayamandi, Tenantville and Cloetesville towards the CBD and the Stellenbosch University.
- *Public transport*: Stellenbosch and Du Toit are two train stations situated in the outskirts of the town and they attract walking trips. The Stellenbosch train station attracts walking trips towards or from Stellenbosch Central, while Du Toit train station attracts walking trips mainly towards or from the neighbouring residential settlements (Kayamandi, Cloetesville and Idas Valley). Bergzicht taxi rank is one formal terminal in Stellenbosch, but another informal taxi rank is located on the northern end of Bird Street, near the R304 Bridge. Walking trips are thus attracted by these taxi ranks or other intermediate taxi stations.
- *The town CBD*: Business activities which are characteristic of the central town attract a number of intra-zonal or inter-zonal walking trips. Those walking trips originate from residential settlements, public parking places, shopping malls and other retailing places.
- *Stellenbosch University and other educational institutions*: Pedestrian movement is highly noticeable around and in the main campus of Stellenbosch University and other educational institutions located in the town. A great change in walking activity is experienced during holidays.

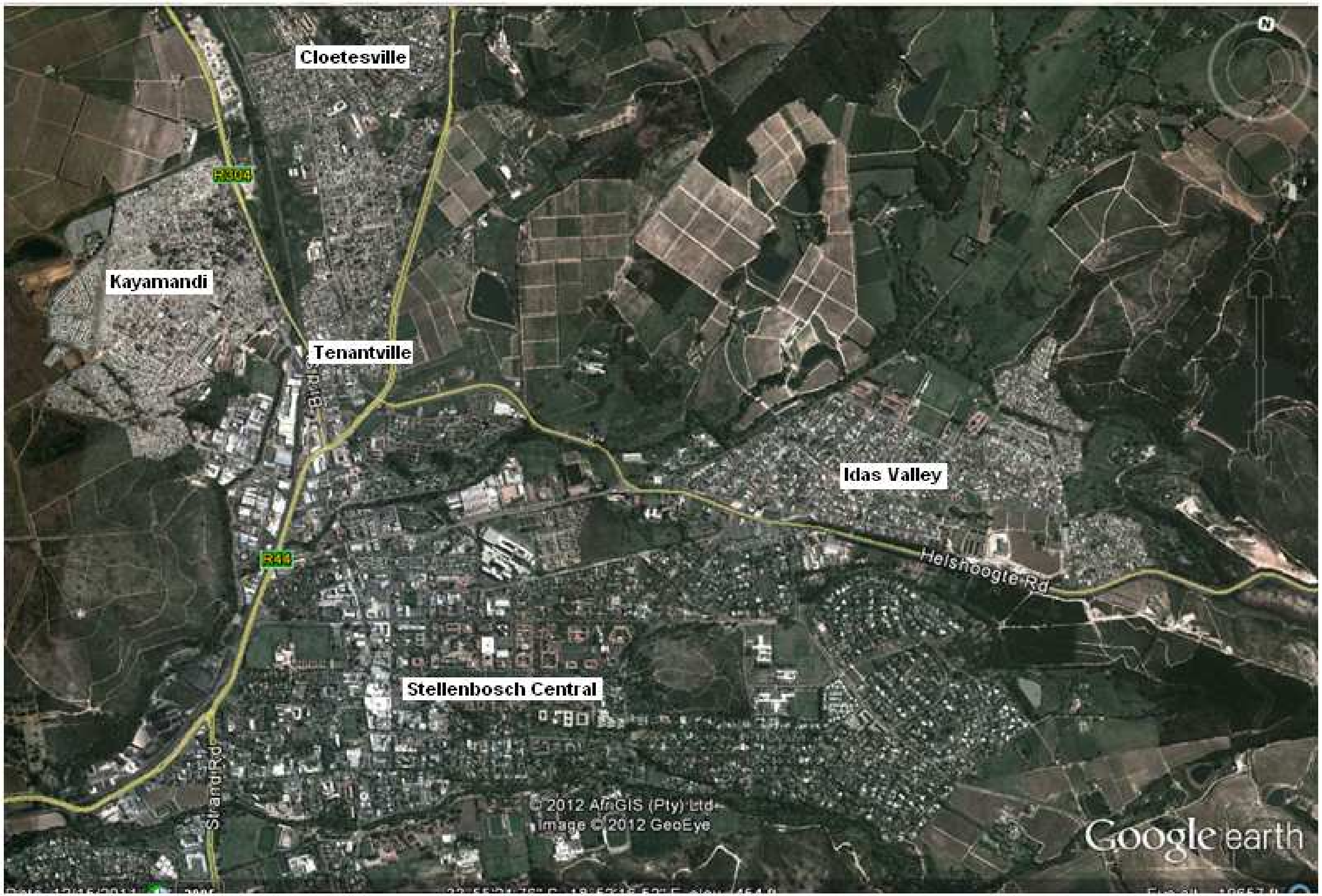


Figure 3-2: Satellite image of Stellenbosch and its suburban settlements: Kayamandi, Cloetesville, Tenantville and Idas Valley

3.5. State of pedestrian safety in Stellenbosch

Crossing outside a pedestrian crossing is the main unsafe behaviour leading to a majority of pedestrian accidents occurring in Stellenbosch. An analysis of pedestrian flow along Bird Street carried out by Roux (2010) revealed that 69 percent of total pedestrian accidents occurring from the beginning of 2007 to August 2009 on Bird Street took place at informal pedestrian crossings. Pedestrian accidents peaked in two age groups, 20-30years and 40-50 years, accounting for 25 percent of total pedestrian accidents each. A small peak (15 percent) involved children less than 10 years. Male pedestrians outnumbered female pedestrians in pedestrian accident involvement, with 67 and 33 percent, respectively. The majority (84 percent) of those accidents occurred during weekdays, with the peak (21 percent) occurring on Tuesday. With respect to the time of occurrence, pedestrian accidents peaked from 3:00 pm to 7:00 pm and a small peak appeared between 6:00 am and 10:00 am. Illegal pedestrian crossing (jaywalking) contributed to 69 percent of total pedestrian accidents, followed by crossing at T-intersections (14 percent), crossing at midblock locations (11percent) and finally crossing at signalised intersections (6 percent). Similar trends of pedestrian accidents could be expected for other streets in Stellenbosch.

3.6. Site selection

The main objective of this study is to investigate pedestrian crossing behaviour at various types of pedestrian crossings. The site selection was thus based on the type of data needed (crossing speed, gap-acceptance, pedestrian delay, pedestrian compliant behaviour and pedestrian gaze behaviour), ease of data collection, pedestrian volume at crossing facility, type of road to cross and the type of crossing facility. Patterns of pedestrian crossing behaviour were recorded at 17 pedestrian crossings located in Stellenbosch. Of these, six pedestrian crossings are located at signalised intersections, four are located at signalised mid-block crossings, five are located at unsignalised mid-block crossings (zebra and raised crossings), four are located at unsignalised intersections (four-way and T-intersections), three are signalised mid-block crossings and finally five pedestrian crossings are unsignalised mid-block crossings (four zebra crossings and one raised pedestrian crossing). The sites were selected in an effort to represent the different operational and geometric characteristics of roads (four-lane divided roads, four-lane undivided roads, and two-lane undivided roads), different types of traffic control (signalised intersections, unsignalised intersections, signalised mid-block, unsignalised mid-block) and junctions (four-way intersections and T-intersections). The characteristics of selected sites are summarized in Table 3-1.

Table 3-1: Characteristics of selected sites

No	Location	Type of crossing facility	Type of road
1	Adam Tas/Bird Street Intersection	Signal-actuated crossing (at intersection)	Four-lane divided road (Adam Tas) and two-lane undivided road (Bird Street)
2	Bird Street/Jan Celliers Road Intersection	Signal-actuated crossing (at intersection)	Two-lane undivided roads (both)
3	Bird Street/Merriman Avenue Intersection	Signal-actuated crossing (at intersection)	Two-lane undivided roads (Bird Street) and four-lane undivided road (Merriman Avenue)
4	Merriman Avenue/Ryneveld Street intersection	Signal-actuated crossing (at intersection)	Four-lane undivided road (Merriman Avenue) and two-lane undivided road (Ryneveld Street)
5	Merriman Avenue/Andriga Street intersection	Signal-actuated crossing (at intersection)	Four-lane undivided road (Merriman Avenue) and two-lane undivided road (Andriga Street)
6	Merriman Avenue/De Beer Road Intersection	Unsignalised intersection (two-way-stop)	Two-lane undivided road (De Beer Road)
7	Bosman Road/Banghoek Road Intersection	Unsignalised intersection (four-way-stop)	Two-lane undivided roads (both)
8	Merriman Avenue/De Beer Road Intersection	Unsignalised intersection (zebra crossing)	Four-lane undivided road (Merriman Avenue) and two-lane undivided road (De Beer Street)
9	Kromrivier Street	Unsignalised T-intersection	Two-lane undivided road (Bird Street) and two-lane undivided road (Kromrivier Street)
10	Crozier Street	Unsignalised T-intersection	Two-lane undivided road (Bird Street) and two-lane undivided road (Crozier Street)
11	Bird Street	Signal-actuated mid-block crossing	Two-lane undivided road (Bird Street)
12	Merriman Avenue	Signal-actuated mid-block crossing	Four-lane undivided road (Merriman Avenue)
13	R 44 (Strand Road)	Signal-actuated mid-block crossing	Four-lane divided road (R44)
14	Helshoogte Road	Unsignalised mid-block crossing (zebra crossing)	Four-lane undivided road (Helshoogte Road)
15	Bird Street	Unsignalised mid-block crossing (zebra crossing)	Two-lane undivided road (Bird Street)
16	Bosman Road	Unsignalised mid-block crossing (zebra crossing)	Two-lane undivided road (Bosman Road)
17	Ryneveld Street	Unsignalised mid-block crossing (raised crossing)	Two-lane undivided road (Ryneveld Street)

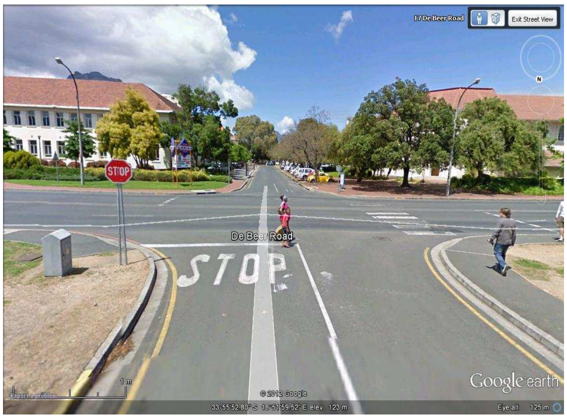
Crossing No.1

Crossing No.2

Crossing No.3

Crossing No.4

Crossing No.5



Crossing No.6

Crossing No.7

Crossing No.8

Crossing No.9

Crossing No.10

Crossing No.11

Crossing No.12

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Crossing No.13

Crossing No.14

Crossing No.15

Crossing No.16

Crossing No.17

Figure 3-3: Images of selected sites

Chapter 4. METHODOLOGY

4.1. Overview

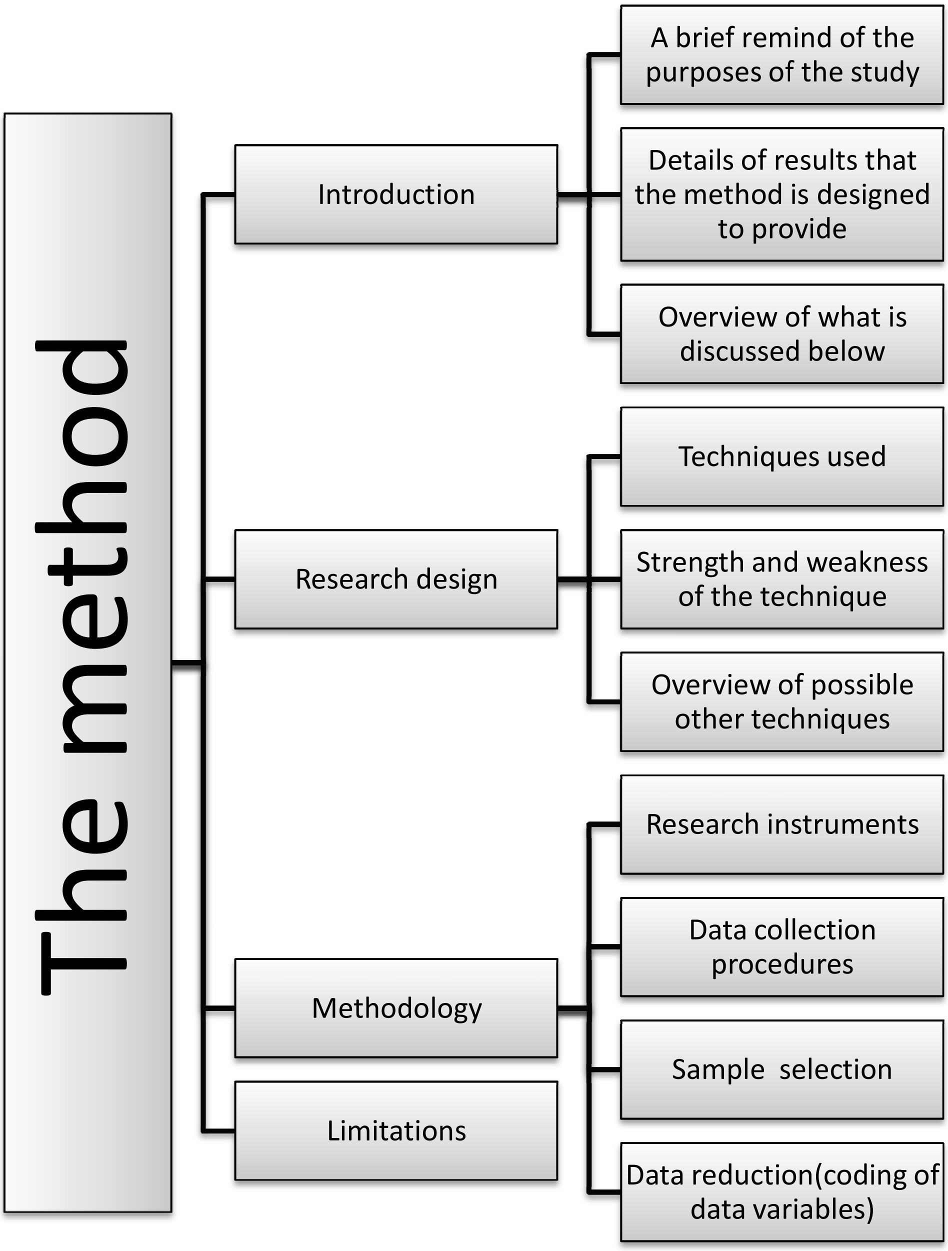

Figure 4-1: Overview of the Chapter

4.2. Introduction

This chapter outlines the method used to investigate the patterns of road-crossing behaviour exhibited by pedestrians in the study. The specific patterns of road-crossing behaviour for which the method is designed are as follows:

- Pedestrian crossing speed and pedestrian normal walking speed;
- Pedestrian delay;
- Gap-acceptance;
- Observational behaviour;
- Pedestrian-vehicle conflicts; and
- Pedestrian compliance with traffic rules.

Another purpose of the study was to explore any possible interdependencies between these patterns. Finally, the effect of demographic variables (i.e. age and gender), situational factors (e.g. group size, traffic flow patterns) and physical characteristics of the road (e.g. type of crossing facility, crossing distance, and presence of a pedestrian refuge) on targeted rod-crossing behaviour is also investigated throughout this study.

The purpose of the method presented in this section is to obtain appropriate quantitative and qualitative data which is required for an assessment of pedestrian road-crossing behaviour and a comparison with existing knowledge.

4.3. Research design

This section presents the overall approach used in the present study to reach the research objectives. The research design includes the main components and procedures followed throughout the present study. A review of previous work relevant to the present study served to identify and define scientifically the research problem. The literature review also provided the existing theory base for the research problem and the methodological approaches which are in use in the research.

The data collected during the study was subsequently evaluated with statistical analysis. In Figure 4-2, it can be seen how the literature review feeds into identification for the research problem, the understanding of pedestrian behaviour, and the development of an appropriate methodology for this study.

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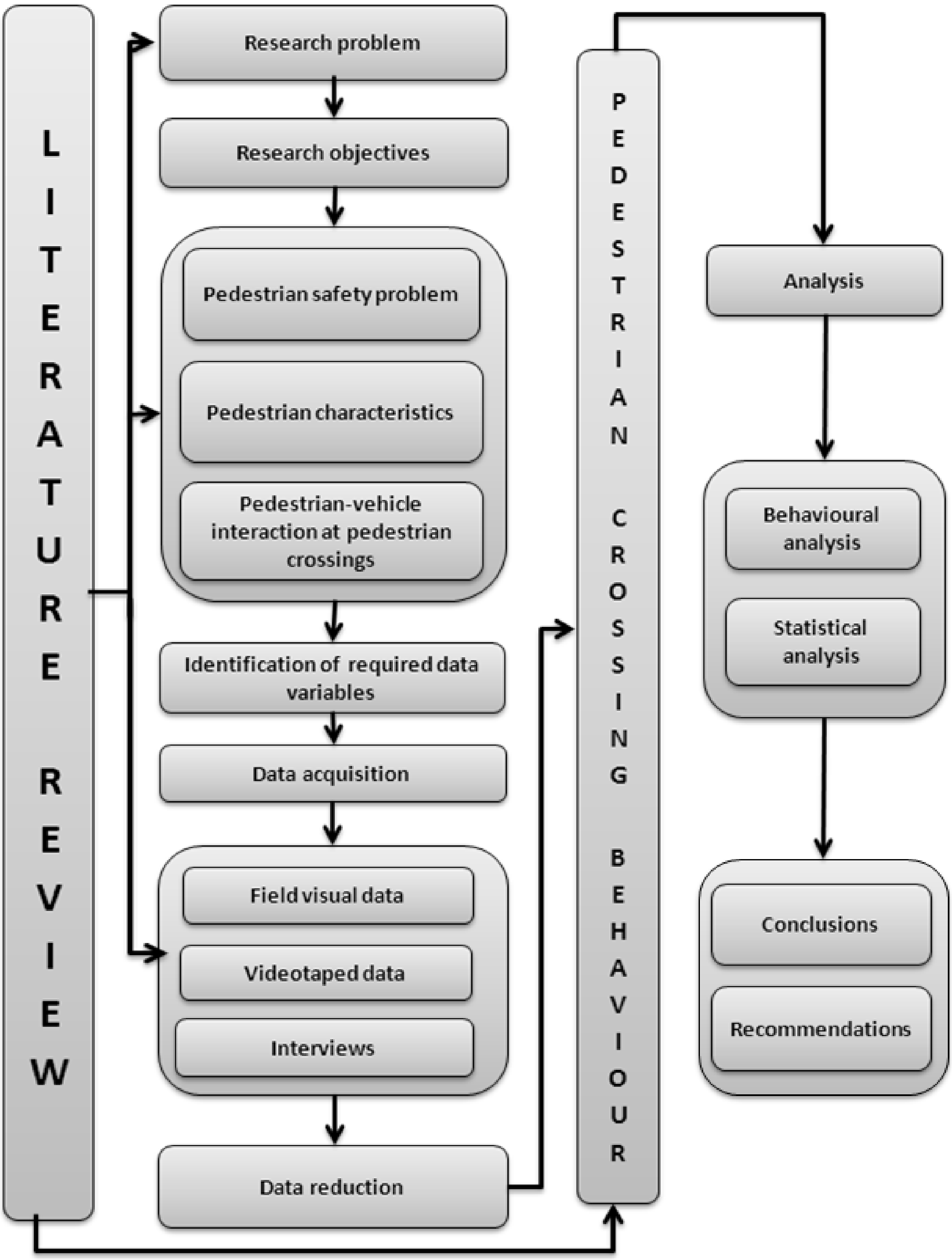

Figure 4-2: Research Design

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4.3.1. Techniques used for the data acquisition

The data was acquired with the use of three techniques:

- Manual data collection;
- Image videotaping;
- Surveys.

4.3.2. Overview of the techniques: strength and weakness

4.3.2.1. Manual data collection

Manual data collection involves the on-site data recording on blank sheets or printed data sheets. This technique has an advantage of providing necessary details by visual observations. However, the use of this technique presents extreme difficulties in recording the necessary information, particularly in complicated traffic conditions (e.g. high vehicular or pedestrian volumes and high speeds) and bad weather conditions (e.g. windy and wet weathers).

4.3.2.2. Image videotaping

Image videotaping is done by the use of video cameras. This technique enables the observer to record multiple events taking place simultaneously during the recording period. A major advantage of this technique is the possibility to review recorded events numerous times, by rewinding and fast-forwarding recorded images frame by frame. Zoom properties of video cameras also enhance the record of necessary information. However, one of the major problems with this technique is a substantial amount of time required to translate images into numerical data. In addition, the poor quality and insufficient resolution of video images can sometimes hinder the gathering of some details (e.g. age and gender of pedestrians or motorists). For this reason, the suitable option is to combine image videotaping and personal visual observations to take into considerations this drawback. In the case where a wide field of view is needed, multiple video cameras could be used but care must be taken to obtain precise synchronization. Longer recording periods require also long-life batteries or replacement of batteries, which could lead to an interruption of events to be recorded.

4.3.2.3. Surveys

In the survey technique, systematic and well-structured questions are administered to a selected sample of participants. Survey data exists in the form of verbal or written answers to particular asked questions. The intention of surveys is understand an observed pattern of behaviour by eliciting people's opinions, explanations and attitudes about a particular theme. Written answers are collected by the use of survey questionnaires where the same questions often provided with possible answers are administered to a selected sample of respondents. Three methods of collecting written answers are most commonly used (Schroeder et al., 2010): (1) mail-out and mail-back form; (2) hand-out and mail-back form; and (3) hand-out and hand-back form. With the spread of information technology (e.g. internet), online surveys (i.e. mail-out and mail-back forms) are becoming popular nowadays.

Time and practical constraints meant that mail-surveys were considered inappropriate in this study and online technology was also eliminated because access would be limited for many pedestrians. As a result the decision was made to concentrate on face-to-face surveys where respondents were asked a series of questions with limited option responses.

4.4. Methodology

4.4.1. Instrumentation

Instruments used for manual data collection include measuring tape, measuring wheel, a stopwatch, field data sheets, a map of selected sites, a clipboard, pens and umbrella (when the weather was wet). Image videotaping required a video camera and a lap-top computer with enough disk space. The video camera used was the DRIFT HD170 extreme sports camera enabling a maximum rate of 60 frames per seconds. The survey technique used printed sheets with anticipated answers to a set of questions administered to respondents.

4.4.2. Data collection procedures

4.4.2.1. Manual data collection

Operational and design characteristics of the selected site were recorded manually on field data sheets during the period of the image videotaping. These characteristics included: the date, start time and end time of data recording, weather conditions, type of crossing facility, roadway and pedestrian crossing characteristics (type of crossing marking, presence/absence of pedestrian refuge, presence/absence of kerb ramps, width of crossing and roadway, presence/absence and state of road signage, signal timing, speed limit and other particular traffic or roadway characteristics). Recording of geometric dimensions of the selected site was supplemented by a hand-drawn sketch of the geometric configuration of the site. Comments on particular pedestrian behaviour exhibited during the recording period were also recorded manually on field data sheets. This information was generally collected during the image videotaping process. However, in some circumstances where the manual data collection could not be done by still keeping an eye on the camera (for its safety), manual information was collected after the videotaping.

4.4.2.2. Image videotaping

The first step of data collection took place in the observer's office where a checklist of field data collection was done. At this stage, the time and the day of data collection were selected by the observer and the instruments needed were prepared. The site was accessed at least 10 minutes before the start of data recording, in order to assess conditions, positions and to install the video camera. The video camera was mounted

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inconspicuously on an existing tree, a signpost, a traffic light post or a public light post, at an elevated height in order to obtain a sufficiently wide field of view.

For the sake of image quality, the direction of sun glare was checked and avoided while installing the video camera. The unobtrusive roadside video camera was adjusted in such a way that the field of view overlapped with the targeted zone of interest. The field of view of the video camera provided a wide view of pedestrians using a crossing and the area around the crossing under observation. At signalised crossings, great care was taken so that the state of traffic signals for both motorists and pedestrians could be seen. Pictures illustrating the site configuration and unusual traffic flow or geometric characteristics were taken using a digital camera to complement the hand-drawn sketches. Pedestrian crossing data was recorded in 15-minute periods during weekdays, covering peak hours in the morning (07:30-09:00) and in the afternoon (16:00-18:00) as well as off-peak hours. Weekend recordings were done for crossing behaviour patterns for which the effect of day of week was in target.

Videotaped data was also recorded at three sidewalks with the purpose of comparing pedestrian crossing speed and pedestrian normal walking speed. Physical objects such as trees, public light posts or other were selected to be the bench marks and the segment marked off by the two selected bench marks were measured. The measured distances for the three selected sites varied from 16 m to 36 m.

4.4.2.3. On-street personal surveys

On–street personal surveys took place at five signalised intersections and one informal crossing in the month of November 2012. On-street personal surveys were conducted with the purpose to supplement the video observations. The video observations revealed common unsafe road-crossing behaviour exhibited by pedestrians. Such unsafe road-crossing behaviour includes crossing during the red man phase and crossing outside the crossing (jaywalking). The on-street personal surveys were designed to reveal motivational factors determining the performed unsafe road-crossing behaviour.

The site selection for the surveys was based on the observed frequency of a particular unsafe road-crossing behaviour at the site. The selected sites include the crossings located at signalised intersections (Adam Tas/Bird Street, Bird Street/Jan Celliers Road, Bird Street/ Merriman, Merriman/Andriga Street and Merriman/Ryneveld Street) and one informal crossing located at Merriman Avenue. Pedestrians were observed from the time they arrived at the kerbs until they completed the crossing. Those who exhibited the two types of unsafe-road crossing behaviour above-mentioned were approached and asked the reason for their crossing preferences. They were also asked their age (or age category), whether they have a driving license and whether they drive a car. A list of anticipated answers to the asked questions was included in printed questionnaires and the researcher ticked the corresponding answer in the questionnaire or wrote down the answer if it had not been anticipated by the researcher.

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4.4.3. Sample selection

A minimum sample size of 100 pedestrian crossing events was targeted to be adequate for statistical significance. Non-random sampling was used for on-street personal surveys. In the non-random sampling method, each member of the population of interest does not have an established probability of being selected (Schroeder et al., 2010). That is, the researcher decided a fixed number of subjects to be interviewed for each selected site. This sampling method is much more convenient to the designer than other sampling methods because it does not require drawing of a random sample. However, the major disadvantage of the non-random sampling methods is that their validity cannot be proved mathematically and consequently the generalization of their findings to the whole population may lead to biased estimates.

Within this sampling method, quota sampling was adopted to be appropriate. The quota sampling is the non-random sampling method where the population is divided into non-overlapping groups called “strata”. The required number of subjects for each stratum is determined based on convenience or judgement of the researcher (Schroeder et al., 2010). Relevant strata in the present study include pedestrians crossing against the red man signal, pedestrians crossing outside the crossing and pedestrians crossing between and behind stopped cars. The selected sample was made of 231 respondents involved in all three targeted unsafe road-crossing behaviours.

4.4.4. Data reduction

4.4.4.1. Required data variables

Videotaped data was downloaded from the video camera and stored in a database file on the basis of the number of the crossing facility. Video data was displayed on a screen of a computer and coded by the researcher. The coded data was recorded on paper sheets and transferred to Microsoft Excel spreadsheets to expedite calculations and the statistical analysis. The information collected manually on site was copied from handwritten sheets to the corresponding Microsoft Excel spreadsheet file. Each pedestrian was viewed in slow motion to allow the record of all necessary information. The video camera used has the capacity to provide a maximum rate of 60 frames per second. The coded information was documented in six categories:

- General information, such as the date, recording starting and ending time, weather conditions and type of land use.
- Crossing facility and roadway characteristics: This category includes attributes such as number of pedestrian crossing, crossing type, type of traffic control, location (road or street, intersection name), width of crossing, width of pedestrian refuge, speed limit, type of crossing marking, signal timing, presence/absence of on-street parking, presence/absence of bicycle lanes and presence/absence of kerb ramps.
- Traffic flow conditions, namely pedestrian arrival rate and vehicle arrival rate.
- Pedestrian characteristics: Variables such as age, gender, group size, level of mobility, and type of distraction are included in this category.

- Crossing behaviour patterns: This category includes variables such as movement direction, pedestrian crossing tactics, pedestrian and vehicular phase during which the pedestrian arrived at the kerb and stepped off the kerb, start-up time, type of vehicle while accepting a lag or a gap, type of accepted gap, waiting time, crossing time, kerb delay, signal calling time and number of head movements before and while crossing.
- Pedestrian-vehicle conflicts: This category includes pedestrian evasive actions (i.e. running in the crossing, stopping in the crossing, aborting the crossing, slowing down while crossing and asking for priority by using hand sign) and motorist evasive actions (i.e. stopping for the pedestrian, slowing down to allow the pedestrian to pass first, refusing to yield to the pedestrian who waiting at the kerb, refusing to yield to the pedestrian who is approaching the conflict point, refusing to yield to the pedestrian who is leaving the conflict point, turning vehicle yielding to pedestrian and turning vehicle refusing to yield to the pedestrian).

The data variables adduced from the videotaped data and those recorded manually are presented in the observation grid as illustrated in Table 4-1.

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Table 4-1: Observation grid of reduced data variables

1. General information:

- Date
- Recording starting time
- Recording ending time
- Land use type
- Weather conditions

2. Crossing facility and roadway characteristics:

- Pedestrian crossing N°
- Location
- Type of Crossing Facility:
  - – Crossing at unsignalised intersection:
    - Crossing at T-junction
    - Crossing at four-way stop
  - – Unsignalised midblock crossing:
    - Zebra crossing:
      - 2-lane road
      - 4-lane undivided road
    - Raised pedestrian crossing
  - – Crossing at signalised intersections:
    - 4-lane undivided road/2-lane road
    - 4-lane divided road/2-lane road
    - 2-lane road/2-lane road
  - – Signalised midblock crossing:
    - 2-lane road
    - 4-lane undivided road
- Speed limit
- Crossing width:
  - – Width of the 1st half
  - – Width of the 2nd half
- Presence of on-street parking
- Refuge width
- Type of crossing marking
- Presence of bicycle lanes
- Presence of yielding lines
- Presence of zigzag lines
- Presence of refuge
- Presence of kerb ramps:
  - – At kerbs
  - – At refuge
- Traffic control:
  - – Traffic sign

- Traffic signal
- State of pushbuttons
- Presence of audible pedestrian signal

• Signal timing:
- Duration of green man signal
- Duration of flashing red man signal
- Duration of steady red man signal
- Signal cycle length (for vehicles)

3. Traffic conditions:

• Pedestrian arrival rate:
- direction 1
- direction 2

• Vehicle arrival rate

4. Pedestrian characteristics:

• Pedestrian No

• Movement direction

• Demographic characteristic:
- Gender:
  Male
  Female
- Age:
  Young
  Middle age
  Elderly

• Group size:
- Single
- Couple
- Group of 3+over

• Level of mobility:
- Unencumbered
- Encumbered:
  Pedestrian with a pram
  Pedestrian with a trolley
  Pedestrian with a bag in one hand
  Pedestrian with a bag in two hands
  Pedestrian with a backpack
  Pedestrian with a handbag
  Pedestrian with 2 handbags
  Pedestrian with a baby in the back
  Pedestrian carrying a baby in the arms
  Pedestrian with a child:
    Holding hand
    Not holding hand

- Pedestrian with a load on the head
- Pedestrian with an umbrella
- Pedestrian pushing a bicycle
- Any kind of combination

– Pedestrian with disabilities:
  - Mobility impairment:
    - Cane or crutch
    - Wheelchair
  - Visual impairment

– On small wheel:
  - Skateboard
  - Kick scooter

• Distraction:
- – Using a cell phone
- – Listening to the music
- – Eating
- – Talking

5. Crossing behaviour patterns:

• Arrival time at Kerb1
• Departure time from Kerb1
• Waiting time at Kerb1

Applicable to signalised pedestrian crossings only:

• Signal calling time
• Start-up time
• Pedestrian signal on arrival at Kerb1:
- – Green man
- – Flashing red man
- – Red man

• Pedestrian signal on departure from Kerb1:
- – Green man
- – Flashing red man
- – Red man

• Vehicle signal on arrival at Kerb1:
- – Green phase
- – Red phase

• Vehicle signal on departure from Kerb1:
- – Green phase
- – Red phase

- Kerb2 arrival time
- Arrival time at Kerb3
- Departure time from Kerb3
- Waiting time at Kerb3
- Start-up time
- Pedestrian signal on arrival at Kerb3:
  - Green man
  - Flashing red man
  - Red man
- Pedestrian signal on departure from Kerb3:
  - Green man
  - Flashing red man
  - Red man
- Vehicle signal on arrival at Kerb3:
  - Green phase
  - Red phase
- Vehicle signal on departure from Kerb3

(Items from "Arrival time at Kerb3" to "Vehicle signal on departure from Kerb3": Applicable to signalised pedestrian crossings located on divided roads)

- Arrival time at Kerb4
- Crossing time
- Observational behaviour:
  - Head movements at kerbs:
    - Right
    - Left
    - Back
    - Ahead
  - Head movements while crossing:
    - Right
    - Left
    - Back
    - Ahead

- Gap-acceptance:
  - Rejected lag:
    - Near-side direction:
      - Lane 1
      - Lane 2
    - Far-side direction:
      - Lane 3
      - Lane 4
  - Accepted lag:
    - Near-side direction:
      - Lane 1
      - Lane 2
    - Far-side direction:
      - Lane 3
      - Lane 4
  - Rejected gap:
    - Near-side direction:
      - Lane 1
      - Lane 2
    - Far-side direction:
      - Lane 3
      - Lane 4
  - Accepted gap:
    - Near-side direction:
      - Lane 1
      - Lane 2
    - Far-side direction:
      - Lane 3
      - Lane 4

Applicable to 4-lane undivided roads. For a 2-lane road, each direction corresponds to one lane only

  - Vehicle category while lag/gap is accepted:
    - Motorcycle
    - Cars
    - Mini-bus
    - Bus
    - Bakkie
    - Light Good Vehicle
    - Medium Good Vehicle
    - Heavy Good Vehicle
  - Type of gap:
    - Normal gap
    - Rolling gap

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- Crossing tactics:
  - – Straight
  - – Diagonal
  - – Half straight and half diagonal
  - – In V path
  - –Behind stopped vehicle
  - – Through stopped vehicles
  - – Pushing button
  - – Pushing button but crossing during the red man signal
  - – Starting the crossing in the marked area
  - – Ending the crossing in the marked area
  - – Cross outside the crossing

6. Pedestrian-vehicle conflicts:

- Pedestrian evasive actions:
  - – Running
  - – Stepping back to the kerb (aborting crossing)
  - – Stopping in the crossing
  - – Slowing down while crossing
  - – Asking for priority by using hand sign
- Motorist evasive actions:
  - – Stopping to allow the pedestrian to pass first
  - – Slowing down to allow the pedestrian to pass first
  - – Refusing to yield to the pedestrian when s/he is at the kerb
  - – Refusing to yield to the pedestrian while s/he is approaching the conflict point
  - – Refusing to yield to the pedestrian while s/he is leaving the conflict point
  - – Turning vehicle yielding to the pedestrian who has crossed in green man signal
  - – Turning vehicle refusing to yield to the pedestrian who has crossed in green man signal

7. Comments

4.4.4.2. Data coding procedures

Each pedestrian was viewed in slow motion while approaching the kerb to start crossing the road until the crossing is completed. Microsoft Excel spreadsheets including all data variables above-mentioned were prepared. Apart from numerical data (e.g. data in time units and number of head movement) other remaining data was qualitative. The coding of qualitative data was done by filling 1 in the cell corresponding to the data variable if the same variable was viewed and by filling 0 if it was not present.

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i. Pedestrian characteristics

The demographic variables (age and gender), movement direction and level of mobility were recorded when the pedestrian reached the kerb to start the crossing. The type of distraction was observed at the kerb and while the pedestrian was crossing. A group size was taken as the number of pedestrians constituting a group of pedestrians crossing a road together usually involuntarily, as a result of signal control or insufficient gaps in the traffic stream.

ii. Crossing behavioural patterns

- **Number of head movements**

Head movement was monitored and counted from the time the pedestrian started checking the oncoming traffic until he or she completed the crossing. A distinction was made between the number of head movements when the pedestrian was waiting at the kerbs and when the pedestrian was crossing the road.

- **Crossing time and waiting time**

The pedestrian arrival time at the kerb and the time he or she stepped onto the road with the purpose of crossing were recorded separately. The pedestrian was watched until he or she reached the opposite kerb after completing the crossing (or the half-crossing). The waiting time was obtained by subtracting the pedestrian arrival time at the kerb from the time the pedestrian stepped of the same kerb. The crossing time was obtained by subtracting the pedestrian stepped off the kerb from the time he or she reached the opposite kerb.

- **Pedestrian compliance with the traffic signals**

Pedestrian compliance with the traffic signals was monitored from the time the pedestrian arrived at the waiting area. The time the pedestrian used the pushbutton to activate the green man signal was recorded together with the time the green man signal was displayed. The difference between these two time records was termed the “signal calling time”. The pedestrian traffic signal during which the pedestrian arrived at and stepped off the kerb were recorded together with the traffic signal for vehicles. The “start-up time” was defined as the time between the time the pedestrian stepped off the kerb to cross the road and the time the green man signal was displayed.

- **Gap-acceptance behaviour**

Since the available gaps at signalised crossings and unsignalised intersections are affected by traffic controls, the gap-acceptance behaviour was observed only at unsignalised mid-block crossings. The gap-acceptance behaviour was coded from the time the pedestrian reached the kerb. A distinction was made between a “lag” and a “gap”. A lag was defined as the time between the pedestrian arrival at the kerb and the time the first oncoming vehicle crossed the pedestrian’s path. A gap was defined as the time elapsed between the time the rear of a vehicle passed a pedestrian crossing and the time the front of the next arriving vehicle passed the same point. Crossing a multiple-lane road (e.g. four-lane undivided road) required that the pedestrian accepted multiple gaps in the near-side and far-side traffic streams. In such a case, larger gaps in far-side lanes were needed to accommodate walking times until the pedestrian reached a considered lane. Therefore, gaps in far-side lanes were converted into effective gap. The effective gap was defined as the normal gap minus the expected walking time to reach a considered lane (Cherry et al. 2011). As an example, Figure 4-3 illustrates a pedestrian crossing a three-lane road. The width of each lane is W_l and the pedestrian speed is symbolized by S_p. The effective gaps in lane 1, lane 2 and lane 3 are symbolised by g_1, g_2 and g_3, respectively. The effective gaps g_2 and g_3 in far-side lanes were obtained by subtracting the respective walking time W_l/S_p and $2W_l/S_p$. The walking speed S_p is the calculated average speed that emerged from this study. The duration times of accepted and rejected gaps and lags for each lane were recorded separately.

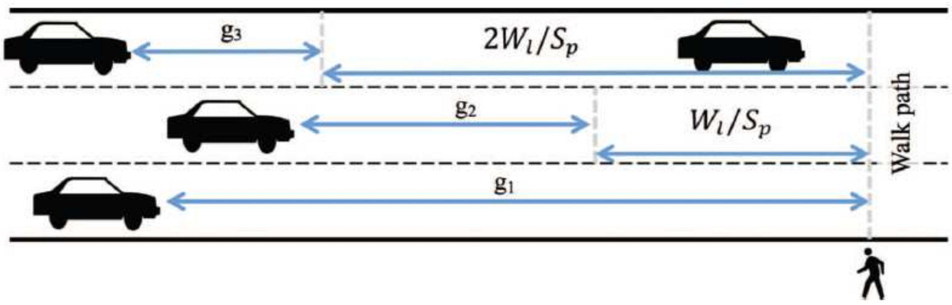

Figure 4-3: Multi-lane effective gap measurement (Cherry et al., 2011)

When the pedestrian accepted a certain gap, the category of the next arriving vehicle was recorded. Vehicles were subdivided into 8 categories: Motorcycles, cars, mini-bus, bus, bakkie, light good vehicle (LGV), medium good vehicle (MGV) and heavy good vehicle (HGV). A distinction of accepted gaps was also made into normal gaps and rolling gaps. A normal gap was recorded when the pedestrian crossed the road after all lanes had been completely clear. A rolling gap was recorded for the pedestrian who did not wait for all lanes to be completely clear, rather he or she searched for a gap in the far-lanes while crossing.

- **Crossing tactics**

Pedestrian exhibited different tactics when they were crossing. Ten crossing tactics were considered while coding the data variables. It was recorded while the pedestrian crossed straight, diagonally or a combination of the two (crossing the first half straight and the second half diagonally or the inverse). Crossing in V path was recorded for pedestrians who started the crossing in the marked area but deviated the straight crossing by passing behind or between stopped cars and then finished the crossing in the marked area. Activating the traffic signal was also recorded and a distinction was made between those who pushed the button and complied with the traffic signal and those who pushed the button but crossed against the red man signal. Other crossing tactics identified and recoded included crossing behind or through stopped vehicles, starting the crossing in the marked area, ending the crossing in the marked area and crossing outside the marked area.

- **Pedestrian-vehicle conflicts**

Conflicts were categorised into two groups: pedestrian evasive actions and motorist evasive actions. With regards to pedestrian evasive actions, it was recorded if the pedestrian ran, aborted the crossing by stepping back to the kerb, stopped in the crossing, slowed down while crossing and when he or she asked for priority by using hand sign. Motorist evasive actions included stopping or slowing down to allow the pedestrian to pass first. It was also noted whether the motorist stopped (or not) for the pedestrian who was still waiting at the kerb. At signalised intersections, conflicts with turning vehicles were carefully observed. Turning motorists yielding to the pedestrian who had crossed during the green man signal were recorded. Similarly, those who refused to yield to the compliant pedestrian were also recorded separately. Refusing to yield to the pedestrian who is approaching the conflict point, together with refusing to yield to the pedestrian who is leaving the conflict point was recorded at unsignalised mid-block crossings.

- **Pedestrian crossing speed and normal walking speed**

Pedestrian crossing speed was deduced from crossing time and crossing distance recorded manually at the field. The crossing speed was calculated by dividing the crossing distance (crossing width) by the crossing time. The time-mean speed (TMS) approach was adopted to calculate the average crossing speed. The TMS refers to the basic arithmetic mean of speeds recorded at a segment (i.e. pedestrian crossings). The formula used for this approach is as follows:

$$TMS_{seg} = \frac{\sum_{i=0}^{n}\left(\frac{d_i}{t_i}\right)}{n}$$

Where:

TMS_{seg} =Time-mean crossing speed;

d_i =Crossing width;

t_i =Crossing time for a pedestrian i;

n = Number of observed pedestrians.

The TMS was calculated for all observed pedestrians and for non-conflicting pedestrians. Non-conflicting pedestrians were those who crossed the road without any evasive actions (e.g. running, slowing down, stopping, etc.). The normal walking speed was also calculated in the same manner. Pedestrians who did not perform a straight

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crossing were excluded in speed calculation because their crossing distance could not be determined from the video observations.

- **Pedestrian delay**

Pedestrian delay was determined in such a way to include also the delay experienced by pedestrians while crossing (e.g. delay resulting from stopping or slowing down in the crossing). The pedestrian delay was determined by summing the kerb delay (or waiting times at the kerbs) and the crossing delay. The crossing delay was taken as the difference between the ideal crossing time and the actual crossing time. The actual crossing time is the recorded crossing time for each observed pedestrian, whereas the ideal crossing time was taken as the calculated average crossing time of non-conflicting pedestrians. This approach can be summarized as follows:

$$d_{total} = d_{kerb} + d_{crossing}$$

Where:

d_{total} = Total delay experienced by a pedestrian;

d_{kerb} =Delay experienced by a pedestrian at a kerb or at a refuge;

$d_{crossing}$ =Delay experienced by a pedestrian while crossing, or:

$$d_{crossing} = t_{actual} - t_{ideal}$$

$Where$:

t_{actual} =Actual crossing time;

t_{ideal} =Ideal crossing time.

4.4.4.3. Analysis of on-street personal surveys

Answers collected from the surveys were classified by similarity and then converted into Microsoft Excel spreadsheets for the purpose of analysis.

4.4.5. Limitations

The method used in this study presented some limitations. While coding videotaped data, the observer's vision was blocked for short periods by queuing or passing vehicles at pedestrian crossings. Possible errors would also happen while estimating demographic variables, especially for age. The pedestrian age was estimated on the basis of a combination of their height, facial features, deportment and their attire. In some instances, the video camera was not able to capture the pedestrians' facial features and the age estimation was done on the basis of the remaining characteristics. For some pedestrian crossing types, time constraints hindered the researcher from fulfilling the minimum sample size requirement (e.g. signalised mid-block crossings).

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The initial attempt for on-street personal surveys was to investigate pedestrians' beliefs, motivational factors and attitudes toward unsafe road-crossing behaviour exhibited from the video observations. A questionnaire included closed questions intending to investigate those determinants of unsafe road-crossing behaviour. Closed questions are those that present a fixed set of alternate answers to the respondent. The closed questions provided 5 Likert scales ranging from "strongly agree" through "neither agree nor disagree" to "strongly disagree". These Likert scales intended to measure the degree at which pedestrians agree with presented statements related with unsafe road-crossing behaviour. Unfortunately, the use of this questionnaire presented many difficulties. Firstly, pedestrians who were asked to participate in the survey were not willing to answer by reasoning that the questions took too long to answer. Secondly, the reliability of the few answers obtained was deemed by the researcher to be uncertain. Further, questions were found taxing mentally to respondents and consequently, respondents often gave confusing answers such as "yes" or "no" or tended to choose the first Likert scale "strongly agree" regardless of the sense of the statement. Given these challenges it was recognised that, it would take a significant amount of time to achieve the targeted minimum sample size of 200 respondents. Therefore, the researcher decided to bring some modifications to the first questionnaire in order to make it simpler. The first questionnaire is presented in Appendix A.

The alternative option was to formulate a short questionnaire including only 3 open-ended questions. Open-ended questions are those that enable respondents to create their own answers. However, the technique objectives were reduced. Whereas the first questionnaire was intended to reveal pedestrians' beliefs, motivational factors and attitudes towards unsafe road-crossing behaviour, the objectives in the second questionnaire were reduced only to motivational factors of unsafe road-crossing behaviour. The modified questionnaire is presented in Appendix B.

Chapter 5. RESULTS PRESENTATION AND DISCUSSION

5.1 Introduction

This chapter presents the research findings and the discussions thereof. The results presented in this chapter are broken down into six sections according to the patterns of the road-crossing behaviour investigated throughout this research. These patterns of pedestrian road-crossing behaviour include pedestrian speed, pedestrian delay, observational behaviour, pedestrian-vehicle conflicts, pedestrian compliance with traffic rules and gap-acceptance. For the ease of the results presentation and discussions, 17 pedestrian crossings selected for the study are grouped into 6 categories defined on the basis of their physical aspects and operational similarities. Three sidewalks selected for the investigation of the normal walking speed constitutes another additional category of facilities. These categories are thus as follows:

- Category No 1 (signal-actuated crossings located on four-lane divided roads): This category includes the pedestrian crossing No 1.
- Category No 2 (signal-actuated crossings located on four-lane undivided roads): This category includes the pedestrian crossings No 3, No 4 and No 5.
- Category No 3 (unsignalised crossings located on T-junctions): This category includes the pedestrian crossings No 9 and No 10.
- Category No 4 (unsignalised crossings located on two-way and four-way-stop intersections): This category includes the crossings No 6 and No 7.
- Category No 5 (unsignalised mid-block crossings located on two-lane roads): The pedestrian crossings No 15, No16 and No 17 are included in this category.
- Category No 6 (unsignalised mid-block crossings located on four-lane undivided roads): The pedestrian crossings No 8 and No 14 are included in this category.
- Category No 7 (sidewalks).

5.2. Pedestrian walking speeds

5.2.1. Values of pedestrian walking speeds

The calculated values of the time-mean speed (TMS) for pedestrians who completed a perpendicular (straight) crossing at every category of pedestrian facility are presented in Table 5-1. The calculated walking speed is presented in terms of the mean walking speed, 15th percentile walking speed, 50th percentile walking speed (or median) and standard deviation. These walking speed variables are calculated directly from the reduced speed data or from the frequency and cumulative distribution tables. The mean walking speed is a measure describing the central tendency of a walking speed distribution. It represents the walking speed at which the half of the observed pedestrians are below and half of the observed pedestrians are above. The 15th percentile of walking speed represents the speed at which 15 percent of the observed pedestrians are walking at or below or the walking speed exceeded by 85 percent of all observed pedestrians. The 15th percentile walking speed is the slowest walking speed

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adopted for design purposes. The standard deviation is a measure of dispersion of the walking speed dataset.

The dataset for walking speed comprised a total number of 1285 pedestrians. Of them, 753 pedestrians (59 percent) were males and 532 pedestrians (41 percent) were females. Young pedestrians (under 26 years old) were the majority of the dataset, accounting for 58 percent of the total number. Middle-aged pedestrians accounted for 39 percent and elderly pedestrians were the minority comprising only 2 percent of the total number.

Table 5-1: Pedestrian walking speeds per pedestrian facility category

Category No	Category of crossing facility	Number of pedestrians	Pedestrian walking speed (m/s)			
			15th percentile speed	Mean speed	Average speed	Standard deviation
1	Signal-actuated crossings on four-lane divided roads	236	1.24	1.56	1.66	0.53
2	Signal-actuated crossings on four-lane undivided roads	157	0.94	1.33	1.34	0.38
3	Unsignalised crossings on T-junctions	138	1.00	1.25	1.25	0.29
4	Unsignalised crossings on two-way and four-way-stop intersections	115	1.25	1.43	1.49	0.36
5	Unsignalised mid-block crossings on two-lane roads	316	1.20	1.47	1.48	0.30
6	Unsignalised mid-block crossings on four-lane undivided roads	142	1.32	1.47	1.54	0.35
7	Sidewalks	181	1.18	1.33	1.41	0.37

Figure 5-1 presents the 15th percentile speed, mean speed and average speed of pedestrians crossing or walking at different categories of pedestrian facilities. The highest walking speed was found at Category No 1 (signal-actuated crossings on four-lane divided roads), followed by Category No 6 (unsignalised mid-block crossings on four-lane undivided roads). The lowest walking speed was recorded at Category No 3 (unsignalised crossings on T-junctions). The lowest 15th percentile speed (0.94 m/s) was found at Category No 2 (signal-actuated crossings on four-lane undivided roads). Contrary to what was expected, the pedestrian mean normal walking speed (Category No 7) was found to be higher than the mean crossing speed at T-junctions (Category No 3) and at signal-actuated crossings on four-lane undivided roads (Category No 2).

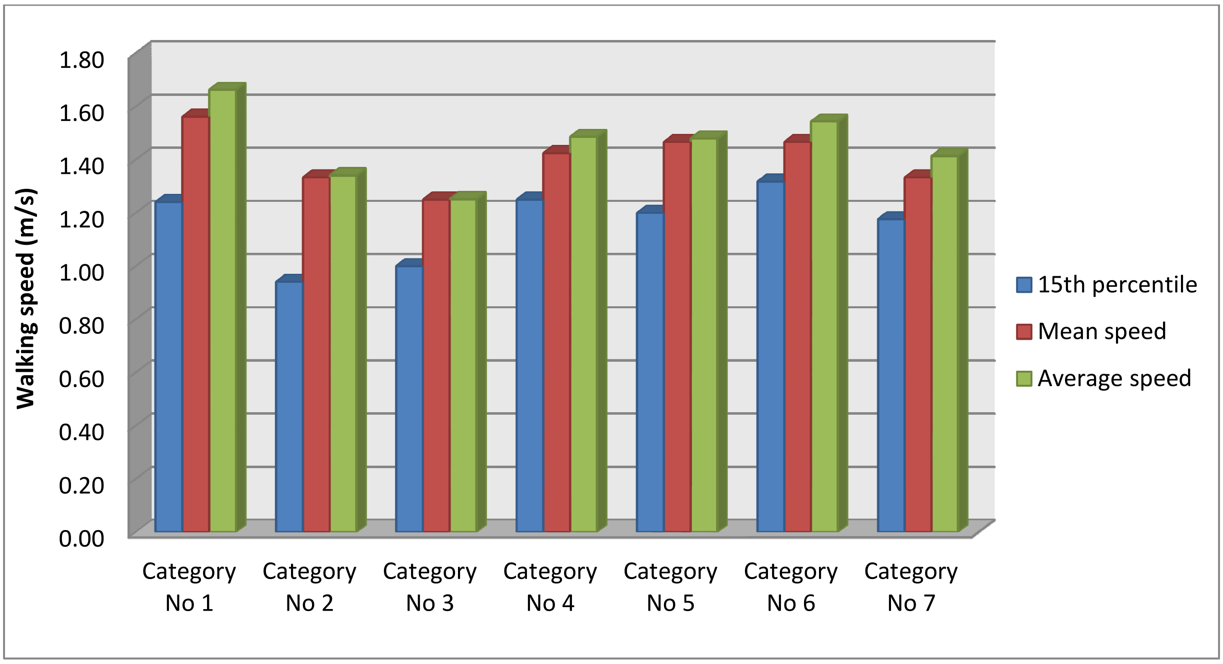

Figure 5-1: Pedestrian walking speed per pedestrian facility type

5.2.2. Effect of pedestrian gender on walking speed

Table 5-2 presents the walking speed values by gender at every pedestrian facility category. It is clearly seen from Figure 5-2 that male pedestrians walk faster than female pedestrians. However, an interesting exception was found at Category No 2 (signal-actuated crossings on four-lane undivided roads). Higher values of standard deviation were found amongst male pedestrians as illustrated in Table 5-2. The lower values of standard deviations for female pedestrians presented in Table 5-2 explain that the walking speed of female pedestrians is tightly grouped around the mean. A marked gender difference in walking speed can be seen from the S-cumulative distribution curves at Category No 3 (unsignalised crossings on T-junctions) and Category No 4 (unsignalised crossings on two-way and four-way-stop intersections) (see Figure 5-5 and Figure 5-6).

Table 5-2: Pedestrian walking speed by gender

Category No	Pedestrian gender	Number of pedestrians	%	Pedestrian walking speed (m/s)			
				15th percentile speed	Mean speed	Average speed	Standard deviation
Category No 1	Male	168	71	1.27	1.62	1.72	0.56
	Female	68	29	1.24	1.46	1.53	0.43
Category No 2	Male	92	59	0.94	1.27	1.32	0.36
	Female	65	41	0.94	1.42	1.37	0.41
Category No 3	Male	72	52	1.07	1.28	1.38	0.30
	Female	66	48	0.93	1.13	1.11	0.19
Category No 4	Male	68	59	1.26	1.56	1.58	0.34
	Female	47	41	1.12	1.39	1.35	0.33
Category No 5	Male	163	52	1.25	1.50	1.54	0.33
	Female	153	48	1.20	1.42	1.42	0.26
Category No 6	Male	74	52	1.32	1.60	1.60	0.39
	Female	68	48	1.32	1.45	1.48	0.29
Category No 7	Male	116	64	1.25	1.43	1.49	0.42
	Female	65	36	1.09	1.25	1.28	0.21

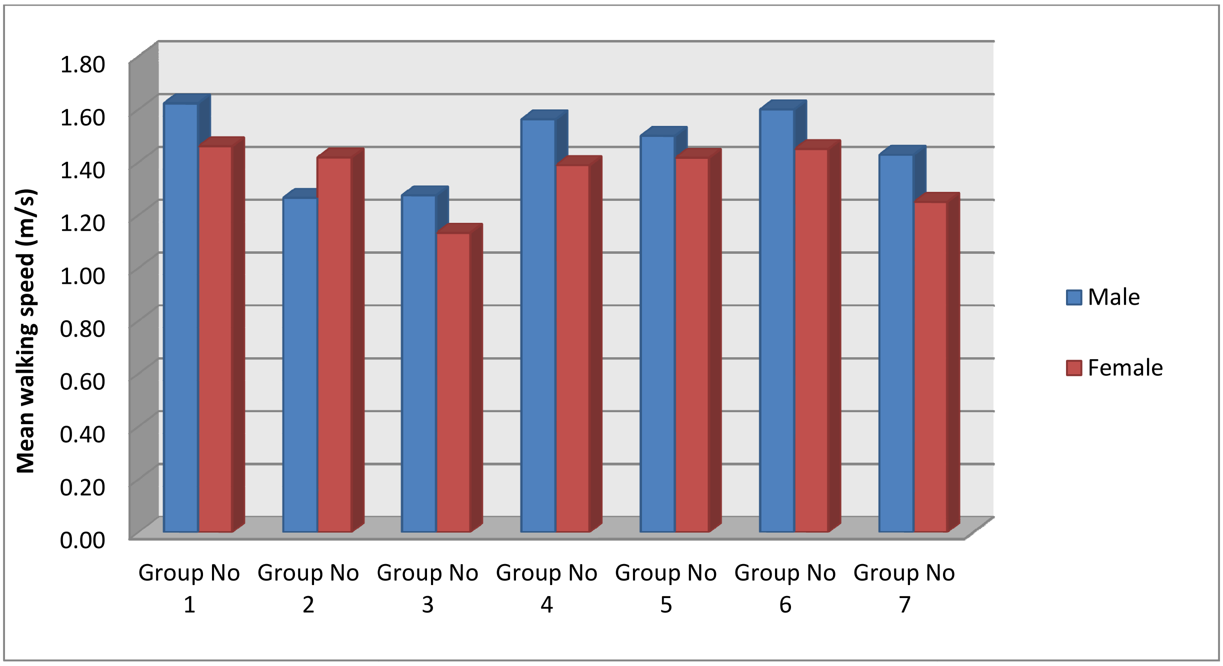

Figure 5-2: Pedestrian mean walking speed by gender

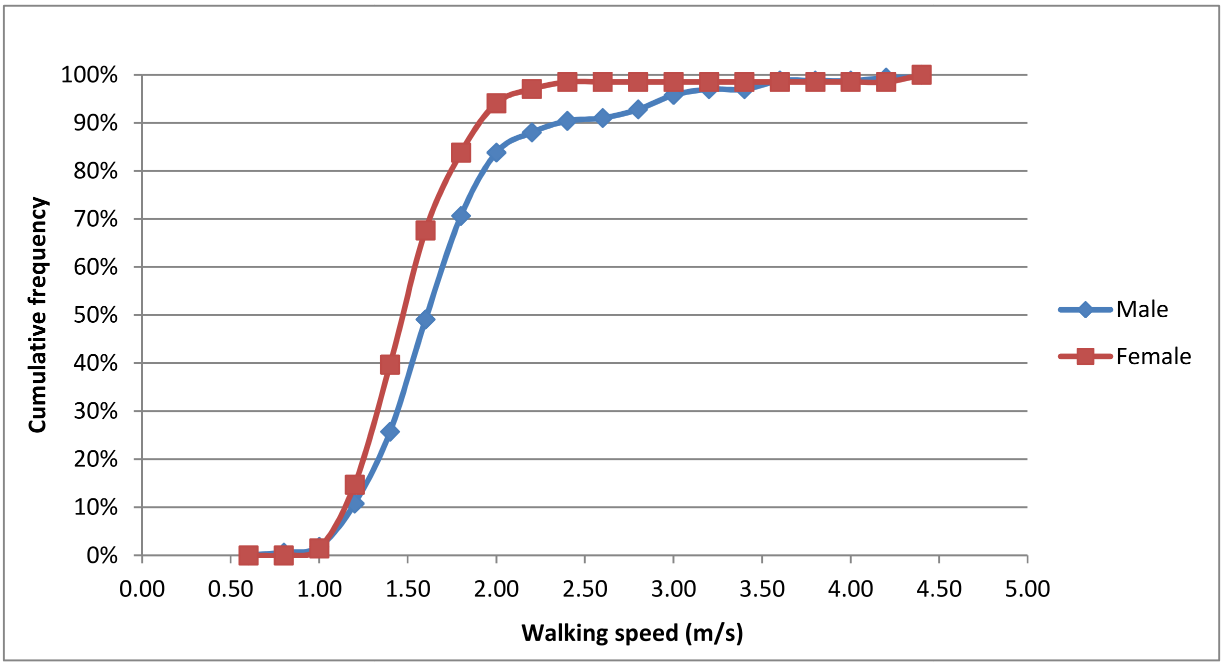

Figure 5-3: Cumulative distribution of pedestrian walking speed by gender at signal-actuated crossings on four-lane divided roads

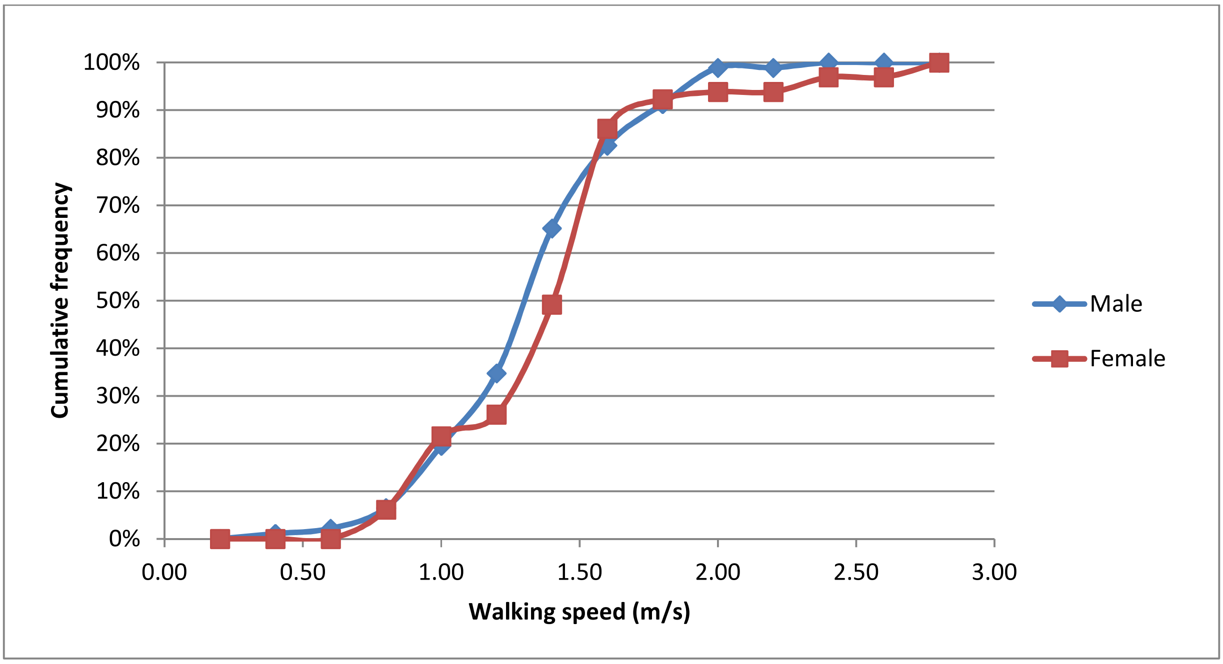

Figure5-4: Cumulative distribution of pedestrian walking speed by gender at signal-actuated crossings on four-lane undivided roads

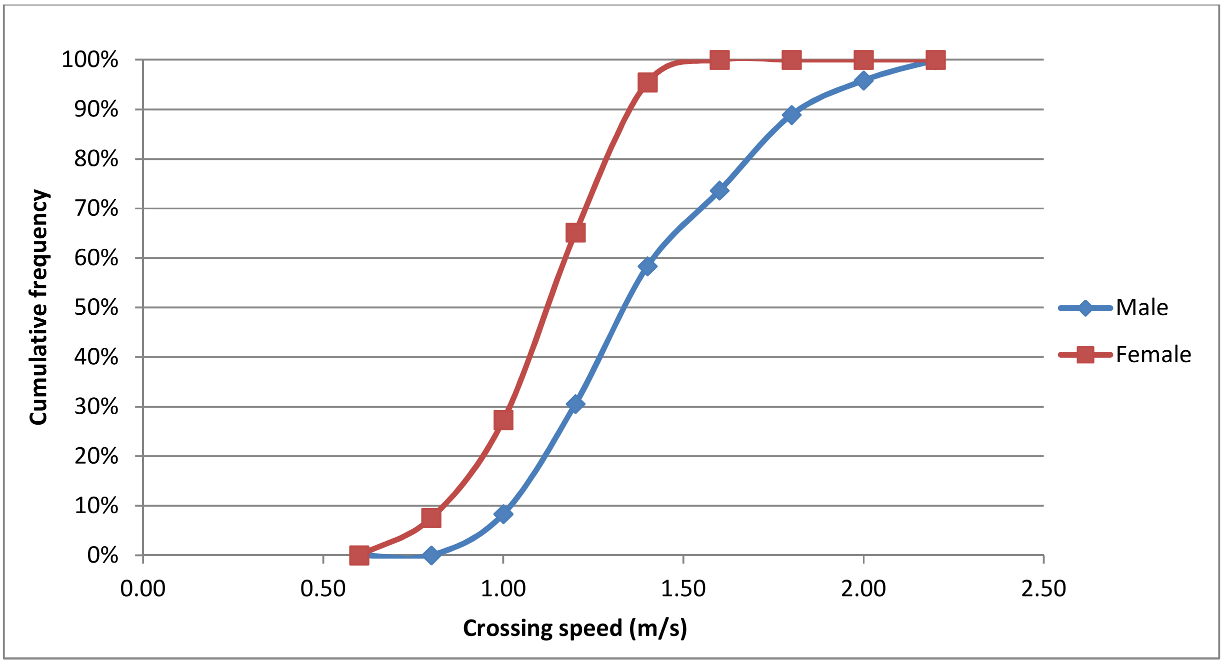

Figure 5-5: Cumulative distribution of pedestrian walking speed by gender at unsignalised crossings on T-junctions

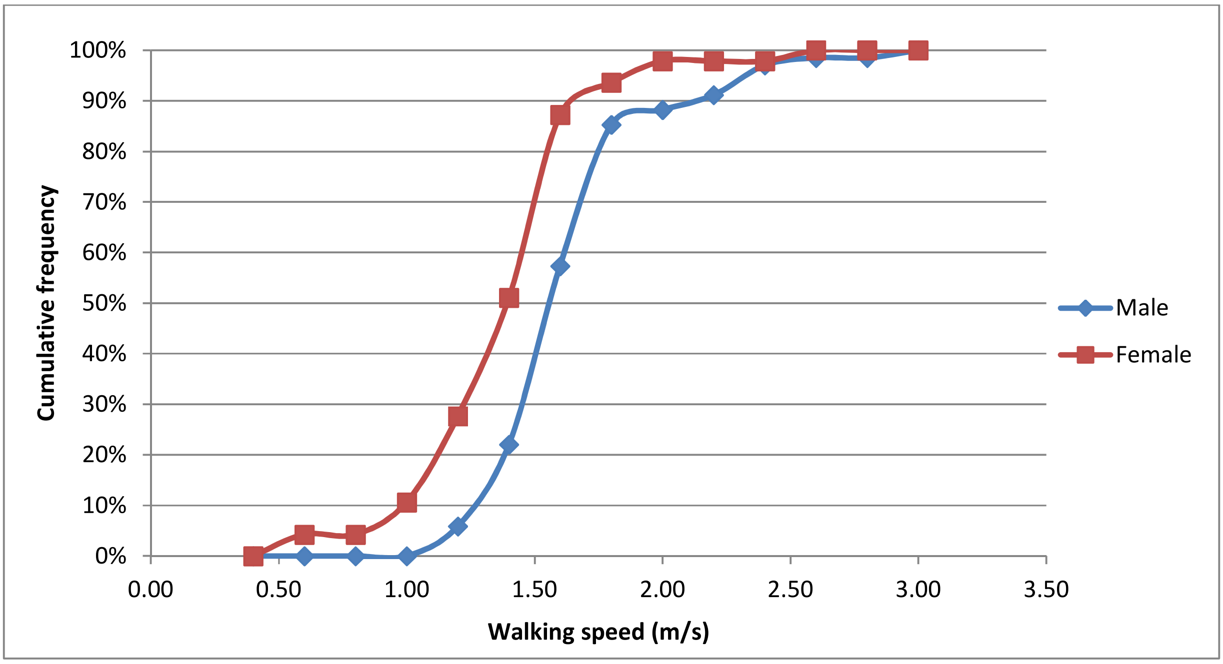

Figure 5-6: Cumulative distribution of pedestrian walking speed by gender at unsignalised crossings on two-way and four-way-stop intersections

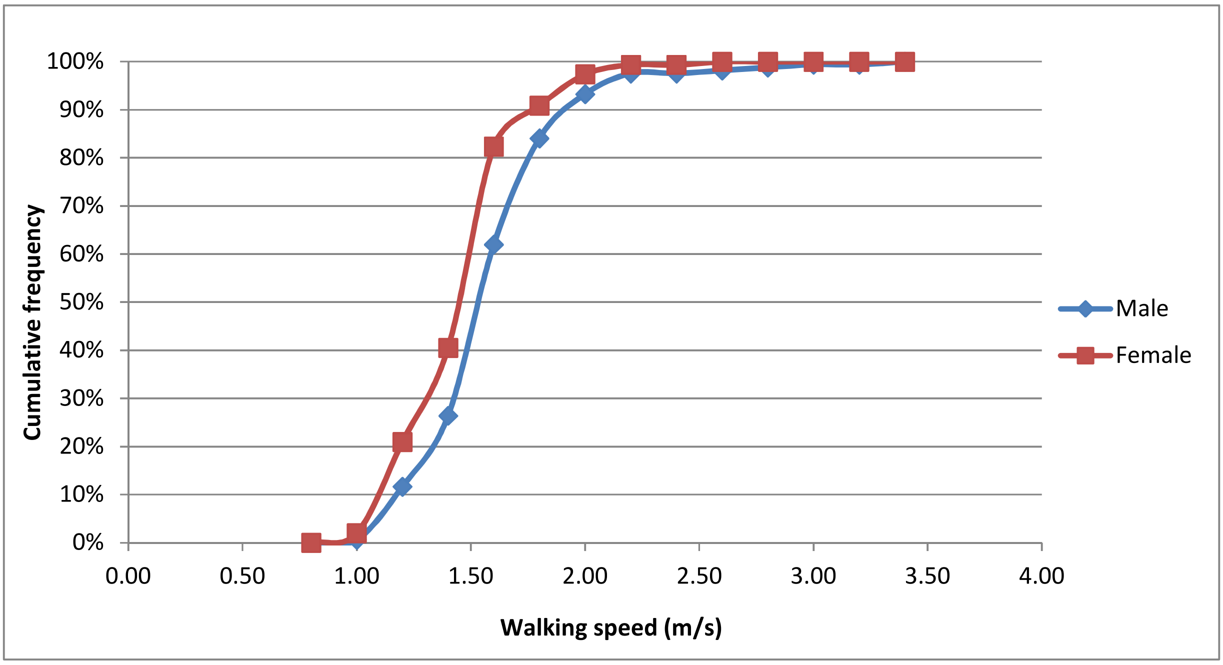

Figure 5-7: Cumulative distribution of pedestrian walking speed by gender at unsignalised mid-block crossings on two-lane roads

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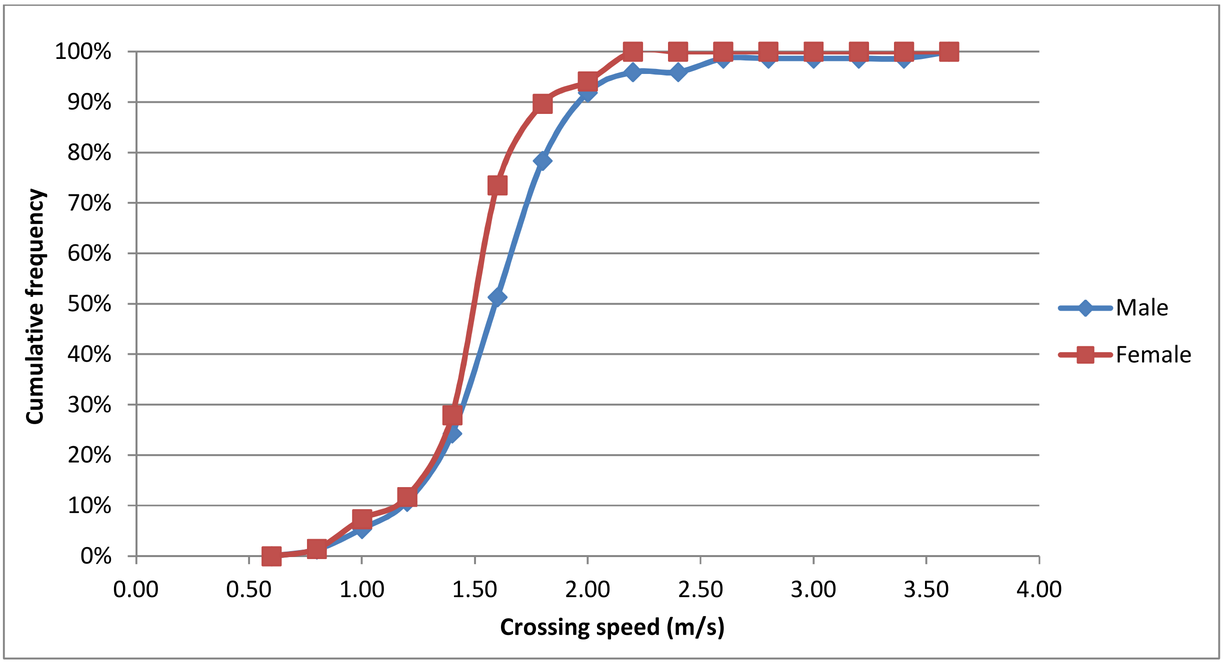

Figure 5-8: Cumulative distribution of pedestrian walking speed by gender at unsignalised mid-block crossings on four-lane undivided roads

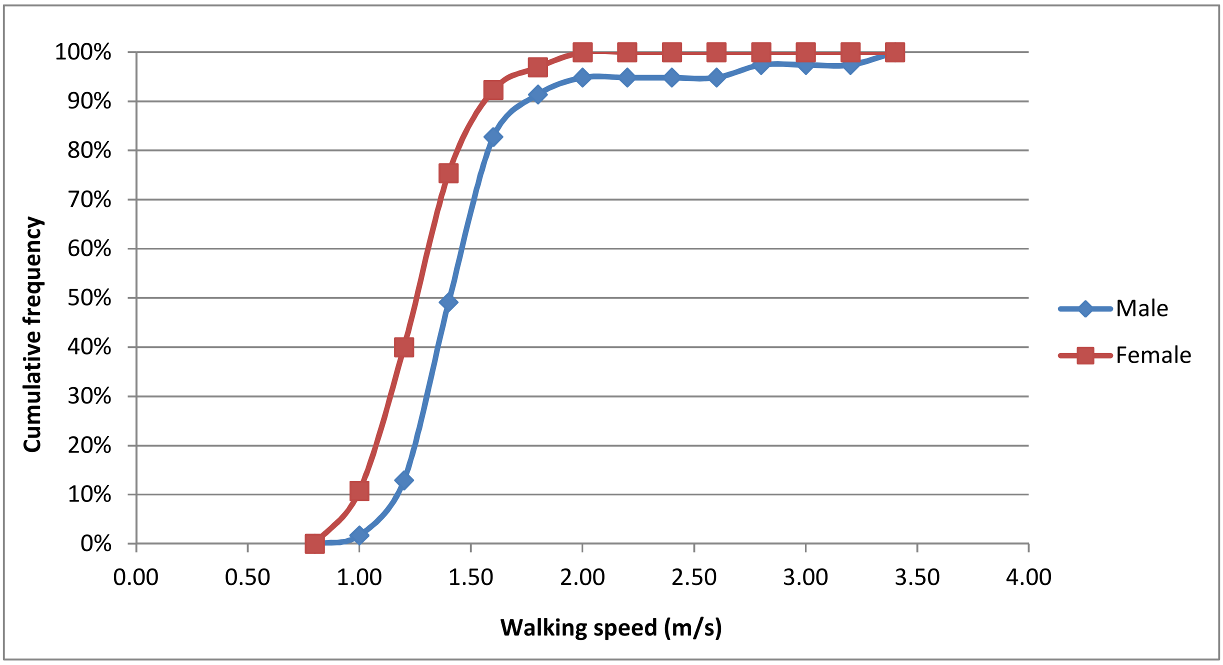

Figure 5-9: Cumulative distribution of pedestrian normal walking speed by gender at sidewalks

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5.2.3. Effect of age on pedestrian walking speed

Table 5-3 presents the distribution of observed pedestrians by age category. The definition of age groups was included in the methodology section. Except in Category No 1 (signal-actuated crossings on four-lane divided roads) young pedestrians were found in higher proportions than other age groups. The highest proportion of young pedestrians emerged in Category No 4 (unsignalised crossings on two-way and four-way-stop intersections), followed by Category No 6 (unsignalised mid-block crossings on four-lane undivided roads) and Category No 5 (unsignalised mid-block crossings on two-lane roads). The lowest percentage of young pedestrians was observed in Category No 1 (signal-actuated crossings on four-lane divided roads) along Bird Street. Elderly pedestrians were found in insignificant proportions at all pedestrian facilities varying from 1 percent to 5 percent of the total observed pedestrians.

Table 5-3: Age group distribution per pedestrian facility type

Category No	Age category	Number of pedestrians	%
Category No 1	Young	78	33
	Middle age	146	62
	Elderly	12	5
Category No 2	Young	83	53
	Middle age	73	46
	Elderly	1	1
Category No 3	Young	87	63
	Middle age	49	36
	Elderly	2	1
Category No 4	Young	82	71
	Middle age	29	25
	Elderly	4	3
Category No 5	Young	206	65
	Middle age	106	34
	Elderly	4	1
Category No 6	Young	94	66
	Middle age	46	32
	Elderly	2	1
Category No 7	Young	121	67
	Middle age	57	31
	Elderly	3	2

Given the small number of elderly pedestrians, and in order to facilitate the descriptive statistics, two age groups were considered instead of three age groups defined in the methodology section. “Younger” pedestrians were taken as those who appeared to be 25 years or below and “older” pedestrians those who appeared to be aged above 25 years.

From Table 5-4, older pedestrians outnumbered younger pedestrians only in Category No 1 (signal-actuated crossings on four-lane divided roads) with 67 percent of the total number. Higher proportions of younger pedestrians were found in Category No 4 (unsignalised crossings on two-way and four-way-stop intersections), Category No 7 (sidewalks), Category No 5 (unsignalised mid-block crossings on two-lane roads) and Category No 6 (unsignalised mid-block crossings on four-lane undivided roads). Age differences in walking speed are clearly illustrated by Figure 5-3; younger pedestrians walk faster than older pedestrians at all pedestrian facilities. Higher values of standard deviations emerged amongst the younger group, meaning that walking speeds of this age group are more widely distributed than those for older pedestrians. S-shaped cumulative distributions curves illustrated by Figure 5-14 and Figure 5-12 highlight a marked difference in walking speed between the two age categories.

Table 5-4: Pedestrian walking speed by age group

Category No	Type of delay	Number of pedestrians	%	Pedestrian walking speed (m/s)			
				15th percentile speed	Mean speed	Average speed	Standard deviation
Category No 1	Younger	78	33	1.24	1.62	1.84	0.72
	Older	158	67	1.24	1.51	1.58	0.38
Category No 2	younger	83	53	1.16	1.42	1.45	0.38
	Older	74	47	0.84	1.23	1.22	0.34
Category No 3	younger	87	63	1.02	1.25	1.29	0.30
	Older	51	37	0.93	1.25	1.19	0.26
Category No 4	younger	82	71	1.27	1.49	1.58	0.35
	Older	33	29	1.03	1.25	1.26	0.25
Category No 5	younger	206	65	1.25	1.50	1.52	0.31
	Older	110	35	1.10	1.42	1.40	0.28
Category No 6	younger	94	66	1.35	1.60	1.62	0.34
	Older	48	34	1.04	1.45	1.40	0.33
Category No 7	younger	121	67	1.19	1.39	1.44	0.36
	Older	60	33	1.05	1.27	1.36	0.40

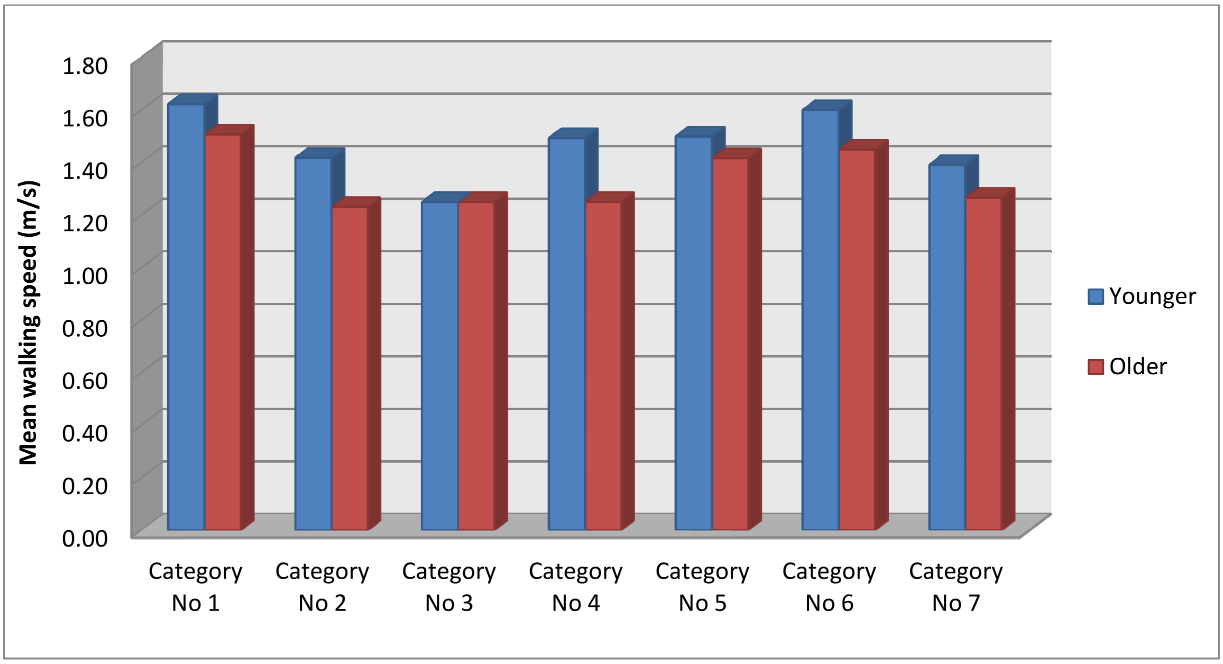

Figure 5-10: Pedestrian mean walking speed by age group

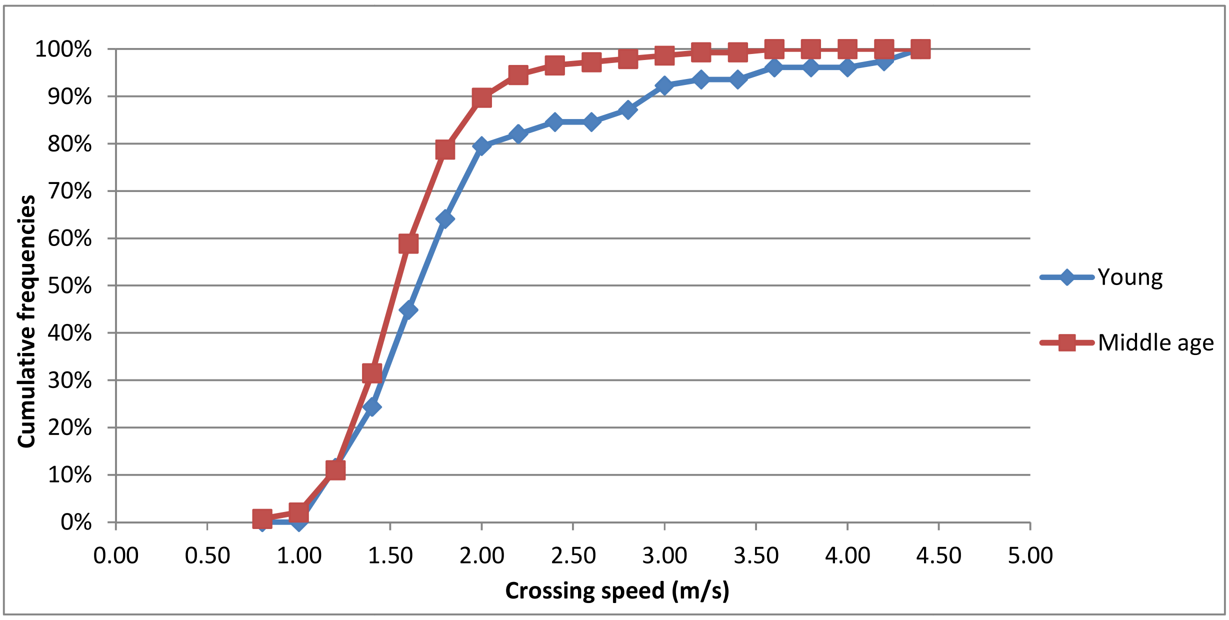

Figure 5-11: Cumulative distribution of pedestrian walking speed by age group at signal-actuated crossings on four-lane divided roads

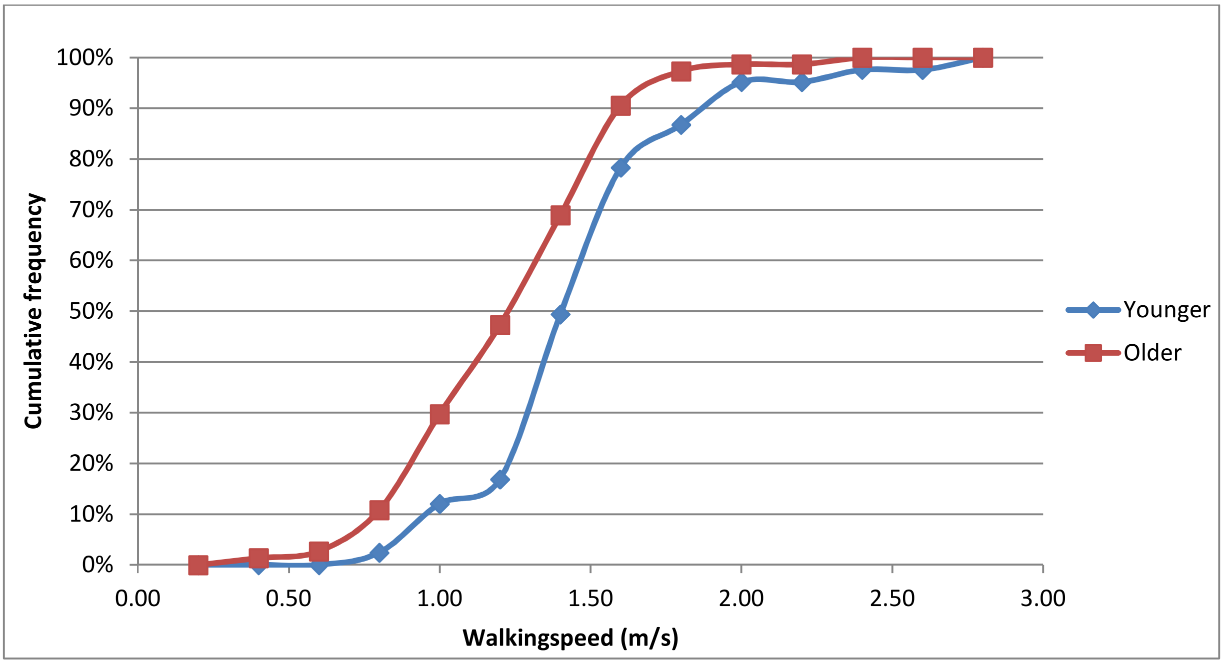

Figure 5-12: Cumulative distribution of pedestrian walking speed by age group at signal-actuated crossings on four-lane undivided roads

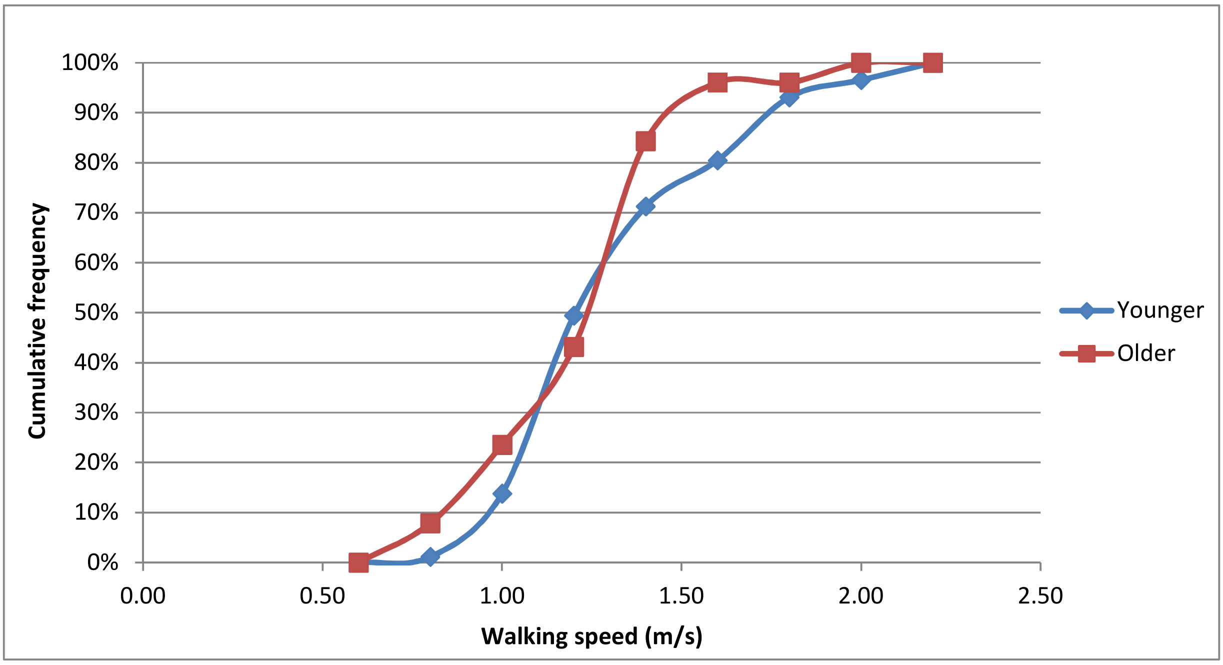

Figure 5-13: Cumulative distribution of pedestrian walking speed by age group at unsignalised crossings on T-junctions

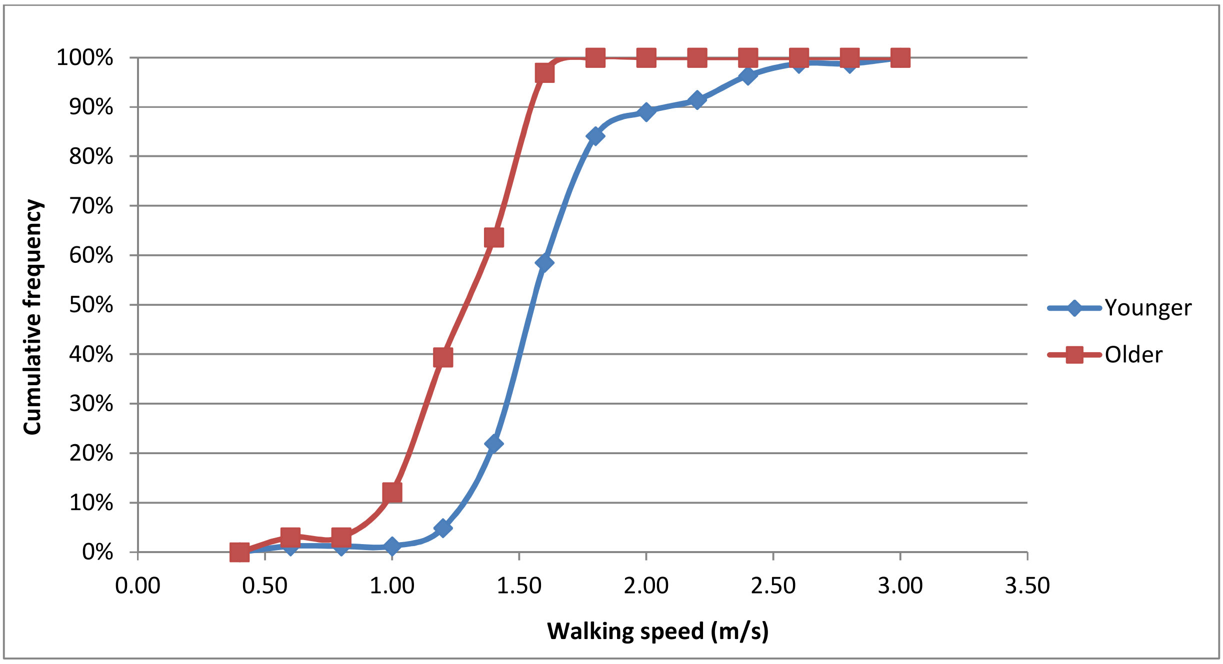

Figure 5-14: Cumulative distribution of pedestrian walking speed by age group at unsignalised crossings on two-way and four-way-stop intersections

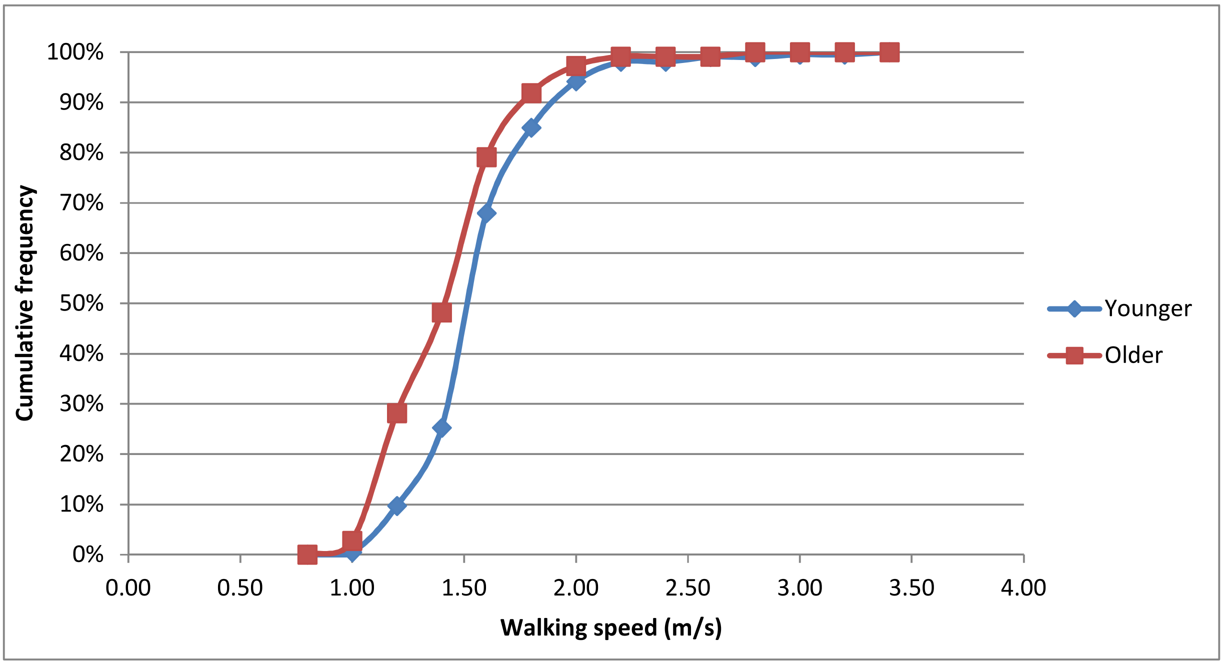

Figure 5-15: Cumulative distribution of pedestrian walking speed by age group at unsignalised mid-block crossings on two-lane roads

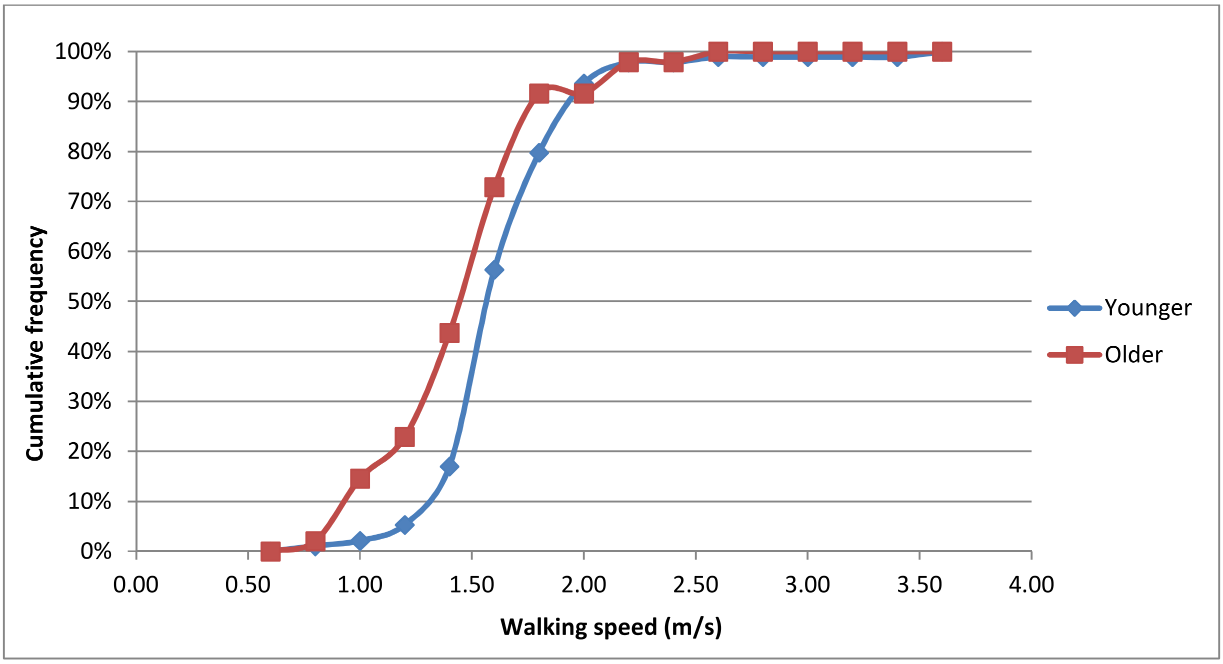

Figure 5-16: Cumulative distribution of pedestrian walking speed by age group at unsignalised mid-block crossings on four-lane undivided roads

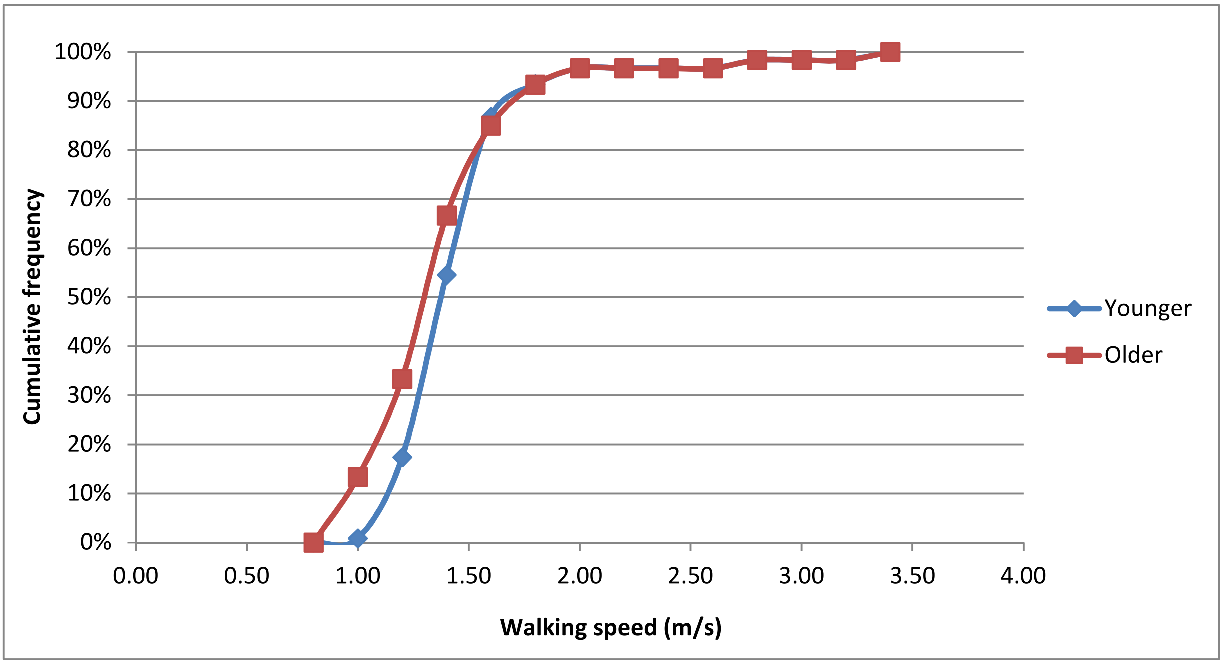

Figure 5-17: Cumulative distribution of pedestrian walking speed by age group at sidewalks

5.2.4. Effect of Group size

Pedestrian group size was classified into three categories; single pedestrians, pedestrians walking in groups of two pedestrians (pair) and pedestrians walking in groups of 3 pedestrians or over (3+over). Single pedestrians outnumbered other group size categories at every pedestrian crossing category. The lowest percentages were found among pedestrians who walked in groups of 3 pedestrians or over (see Table 5-5). Figure 5-18 presents the mean walking speeds by group size at each pedestrian facility category. Single pedestrians were generally found to be faster than other group size categories, followed by pedestrians walking in pairs. However, an exception was found in Category No 4 (unsignalised crossings on two-way and four-way-stop intersections) where pedestrians in groups of 3 pedestrians or over walked faster than other groups. Little difference in walking speed among the three group sizes was found in Category No 6 (unsignalised mid-block crossings on four-lane undivided roads) and Category No 7 (sidewalks). Similar distributions of walking speeds among age groups emerged in these groups as illustrated by Figure 5-24 and Figure 5-25.

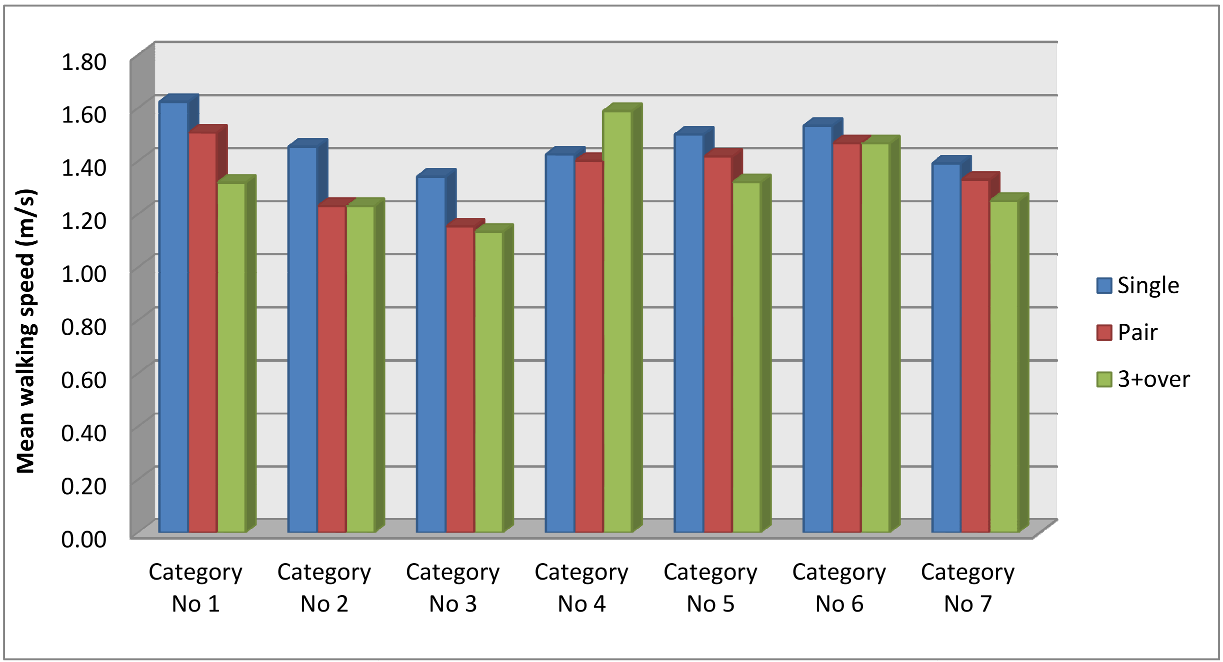

Figure 5-18: Pedestrian mean walking speed by group size

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Table 5-5: Pedestrian walking speed by group size

Category No	Group size	Number of pedestrians	%	Pedestrian walking speed (m/s)			
				15th percentile speed	Mean speed	Average speed	Standard deviation
Category No 1	Single	127	54	1.32	1.62	1.79	0.63
	Pair	74	31	1.24	1.51	1.58	0.37
	3+over	35	15	1.19	1.32	1.40	0.22
Category No 2	Single	63	40	0.98	1.45	1.44	0.45
	Pair	48	31	0.94	1.23	1.29	0.28
	3+over	46	29	0.84	1.23	1.26	0.33
Category No 3	Single	46	33	1.13	1.34	1.35	0.29
	Pair	62	45	1.00	1.15	1.21	0.23
	3+over	30	22	0.93	1.13	1.19	0.35
Category No 4	Single	75	65	1.26	1.43	1.54	0.32
	Pair	34	30	1.03	1.40	1.35	0.42
	3+over	6	5	1.41	1.59	1.53	0.11
Category No 5	Single	182	58	1.25	1.50	1.56	0.33
	Pair	100	32	1.07	1.42	1.38	0.21
	3+over	34	11	1.10	1.32	1.34	0.22
Category No 6	Single	66	46	1.26	1.53	1.61	0.42
	Pair	55	39	1.32	1.47	1.49	0.28
	3+over	21	15	1.32	1.47	1.49	0.25
Category No 7	Single	113	62	1.18	1.39	1.48	0.43
	Pair	44	24	1.13	1.33	1.29	0.18
	3+over	24	13	1.18	1.25	1.31	0.19

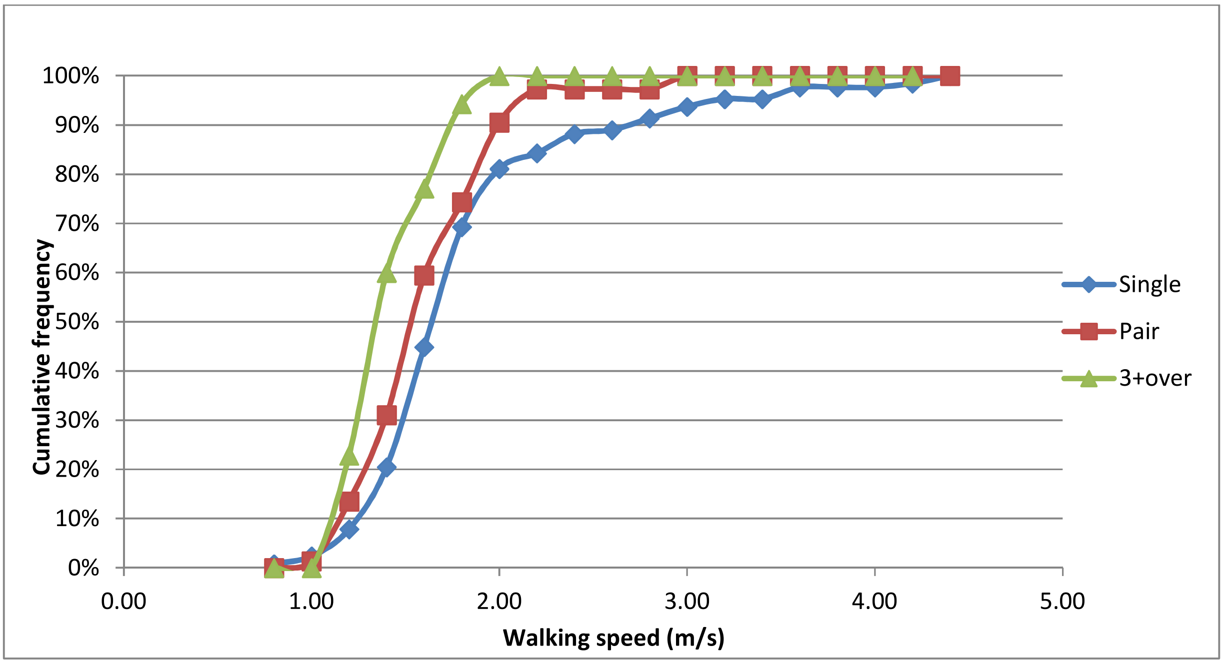

Figure 5-19: Cumulative distribution of pedestrian walking speed by group size at signal-actuated crossings on four-lane divided roads

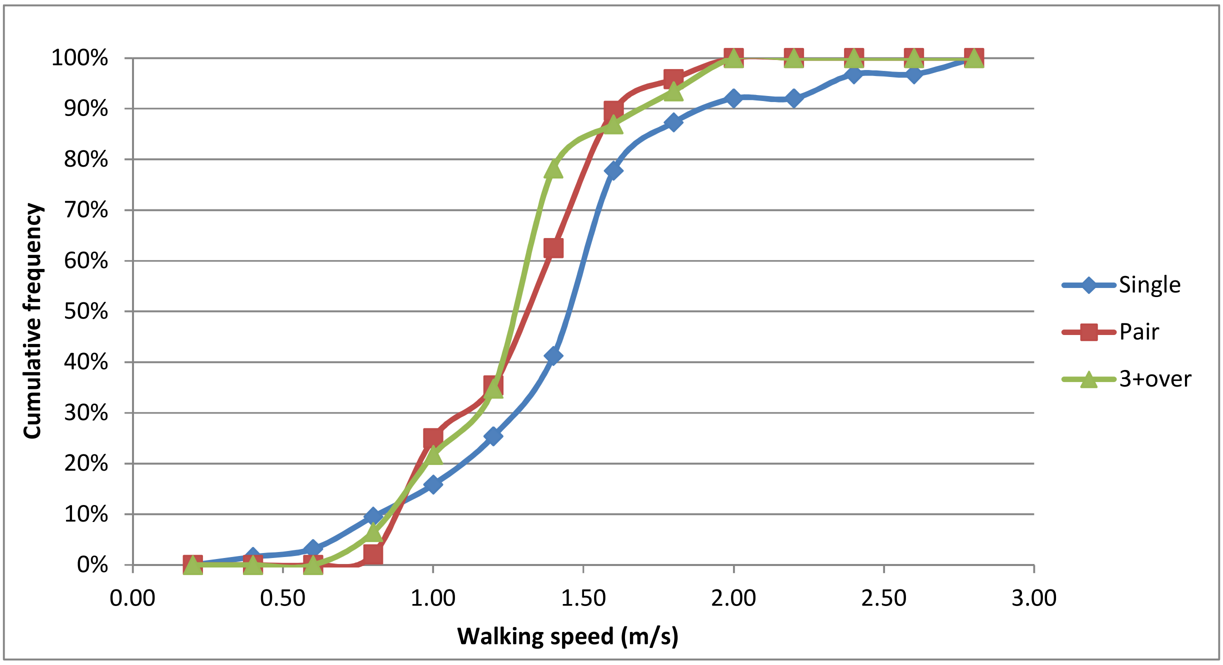

Figure 5-20: Cumulative distribution of pedestrian walking speed by group size at signal-actuated crossings on four-lane undivided roads

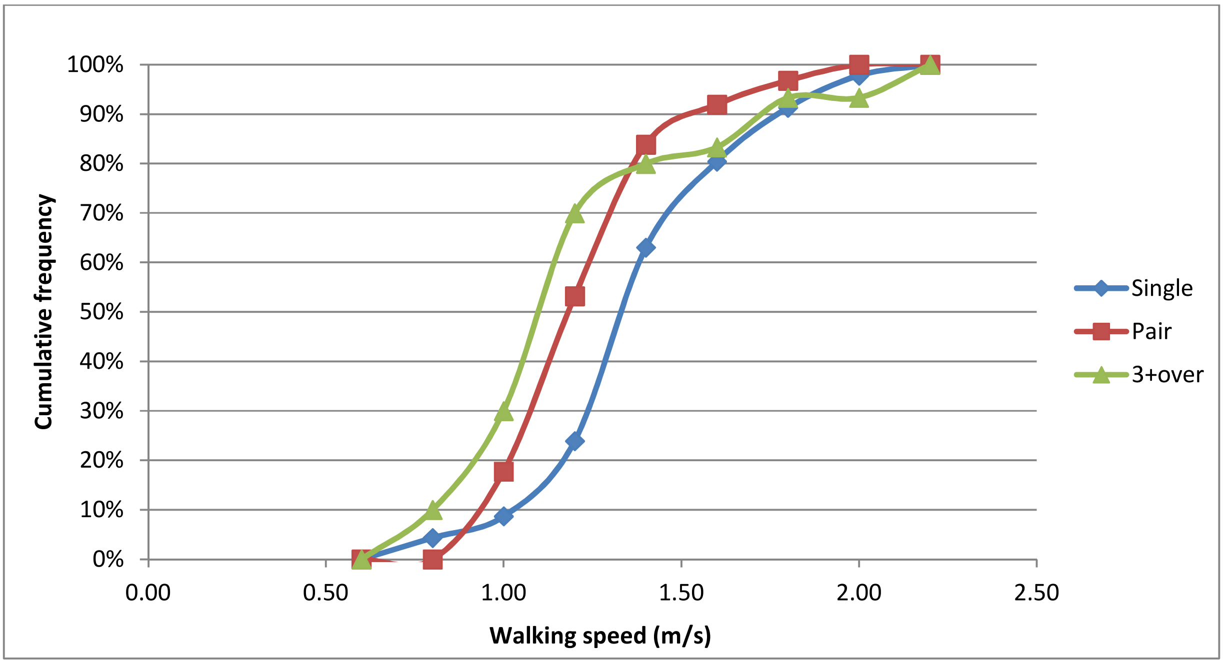

Figure 5-21: Cumulative distribution of pedestrian walking speed by group size at unsignalised crossings on T-junctions

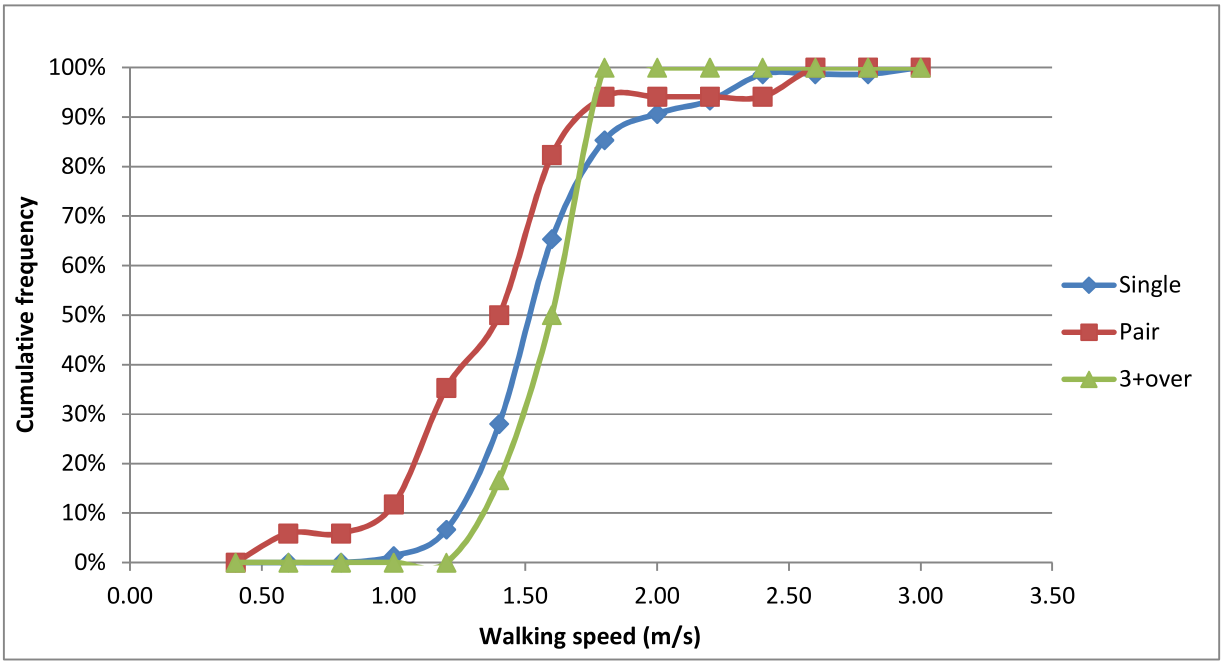

Figure 5-22: Cumulative distribution of pedestrian walking speed by group size at unsignalised crossings on two-way and four-way-stop intersections

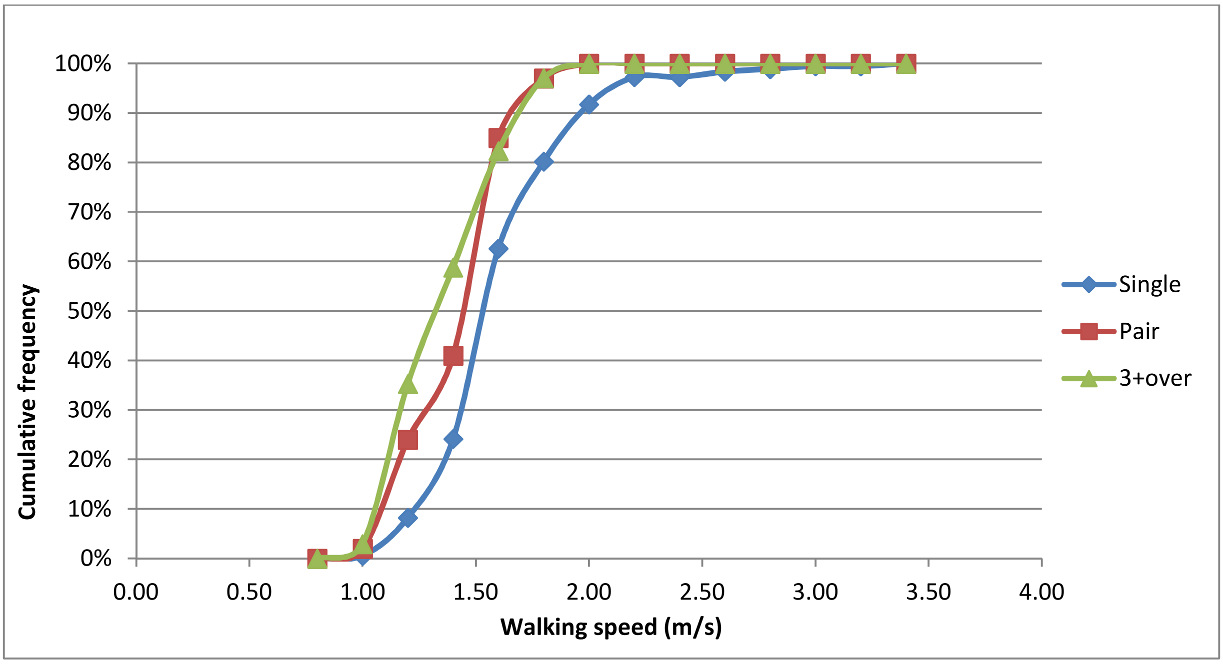

Figure 5-23: Cumulative distribution of pedestrian walking speed by group size at unsignalised mid-block crossings on two-lane roads

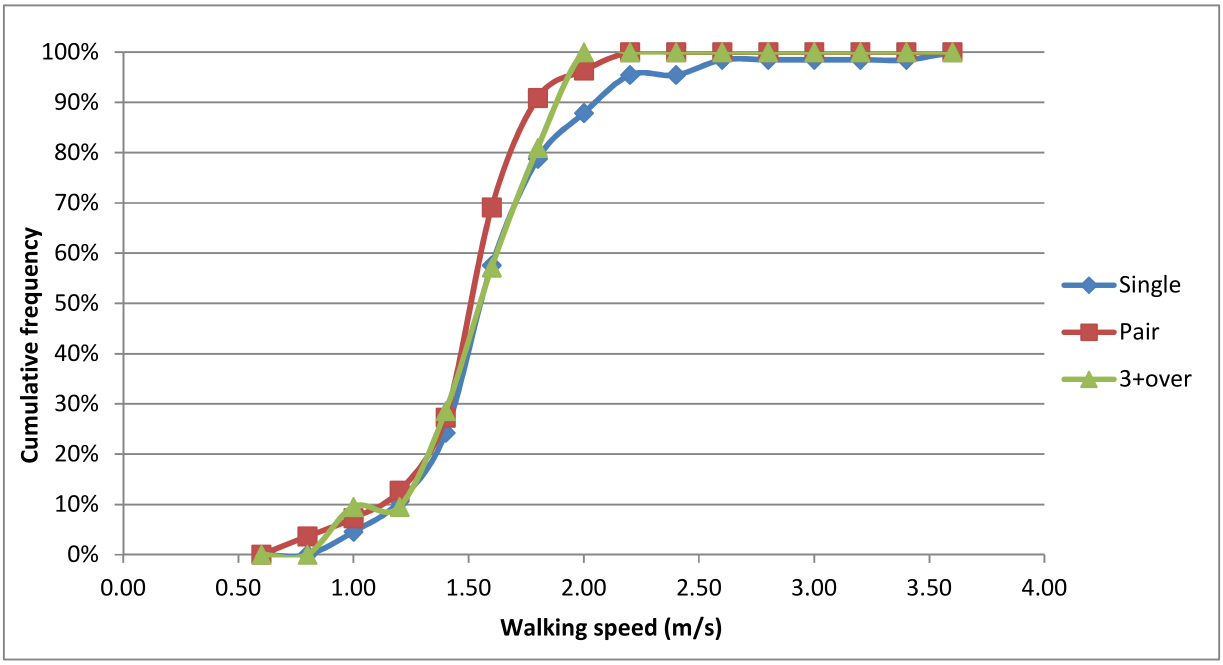

Figure5-24: Cumulative distribution of pedestrian walking speed by group size at unsignalised mid-block crossings on four-lane undivided roads

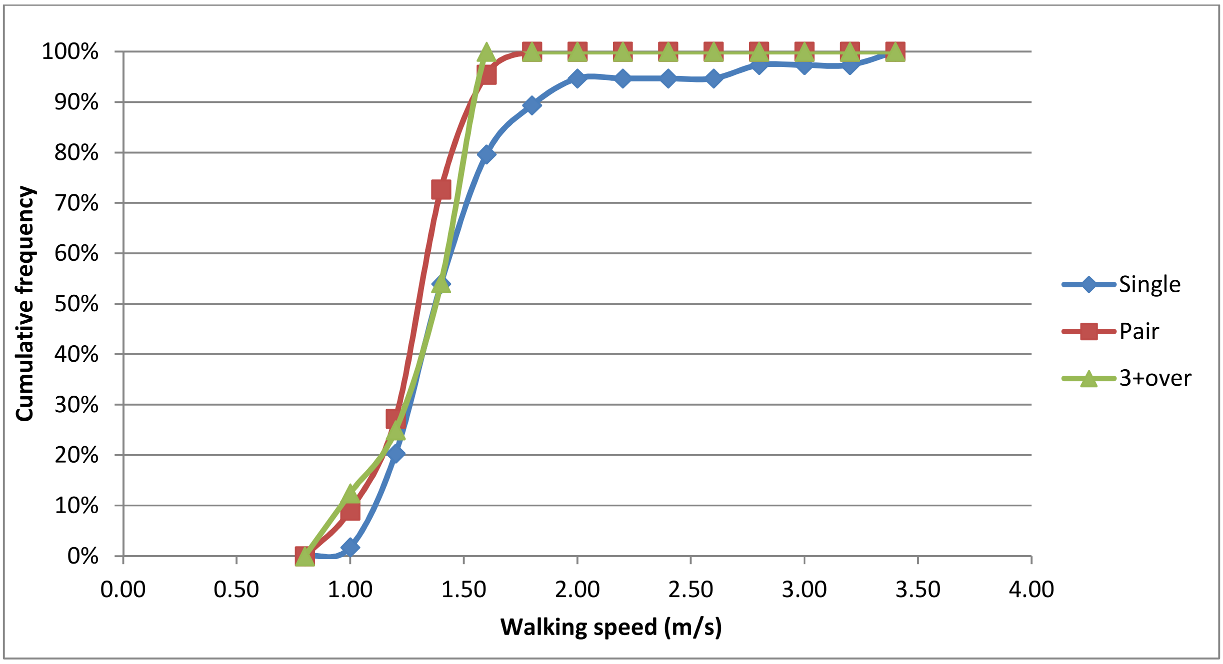

Figure 5-25: Cumulative distribution of pedestrian walking speed by group size at sidewalks

5.2.5. Effect of encumbrance on pedestrian walking speed

As it can be seen from Table 5-6, pedestrians were generally found to be walking with a load. More than half of pedestrians were encumbered. An exception was recorded, however, for pedestrians in Category No 1 (signal-actuated crossings on four-lane divided roads). The highest proportion of encumbrance was observed in Category No 6 (unsignalised mid-block crossings on four-lane undivided roads) and Category No 4 (unsignalised crossings on two-way and four-way-stop intersections). The lowest rate of encumbrance was observed in Category No 1 (signal-actuated crossings on four-lane divided roads). The S-shaped cumulative curves exhibit little difference between walking speeds of encumbered and unencumbered pedestrians, except in Category No 1 (signal-actuated crossings on four-lane divided roads) and in Category No 3 (unsignalised crossings on T-junctions) as shown by Figure 5-27 and Figure 5-29. Carrying a bag or an article in one or both hands, together with carrying a handbag and a backpack were the forms of encumbrance significantly predominant at all pedestrian facility categories (see Figure 5-34 to Figure 5-39).

Table 5-6: Pedestrian walking speed by encumbrance

Category No	Encumbrance	Number of pedestrians	%	Pedestrian walking speed (m/s)			
				15th percentile speed	Mean speed	Average speed	Standard deviation
Category No 1	Unencumbered	129	55	1.32	1.63	1.78	0.60
	Encumbered	107	45	1.19	1.47	1.52	0.40
Category No 2	Unencumbered	71	45	0.94	1.30	1.32	0.36
	Encumbered	86	55	0.94	1.33	1.36	0.40
Category No 3	Unencumbered	68	49	1.02	1.28	1.34	0.30
	Encumbered	70	51	0.93	1.15	1.17	0.24
Category No 4	Unencumbered	31	27	1.19	1.56	1.50	0.36
	Encumbered	84	73	1.25	1.43	1.48	0.36
Category No 5	Unencumbered	110	35	1.21	1.47	1.50	0.31
	Encumbered	206	65	1.20	1.47	1.47	0.30
Category No 6	Unencumbered	26	18	1.12	1.45	1.49	0.38
	Encumbered	116	82	1.32	1.47	1.56	0.34
Category No 7	Unencumbered	82	45	1.19	1.43	1.48	0.42
	Encumbered	99	55	1.11	1.33	1.36	0.32

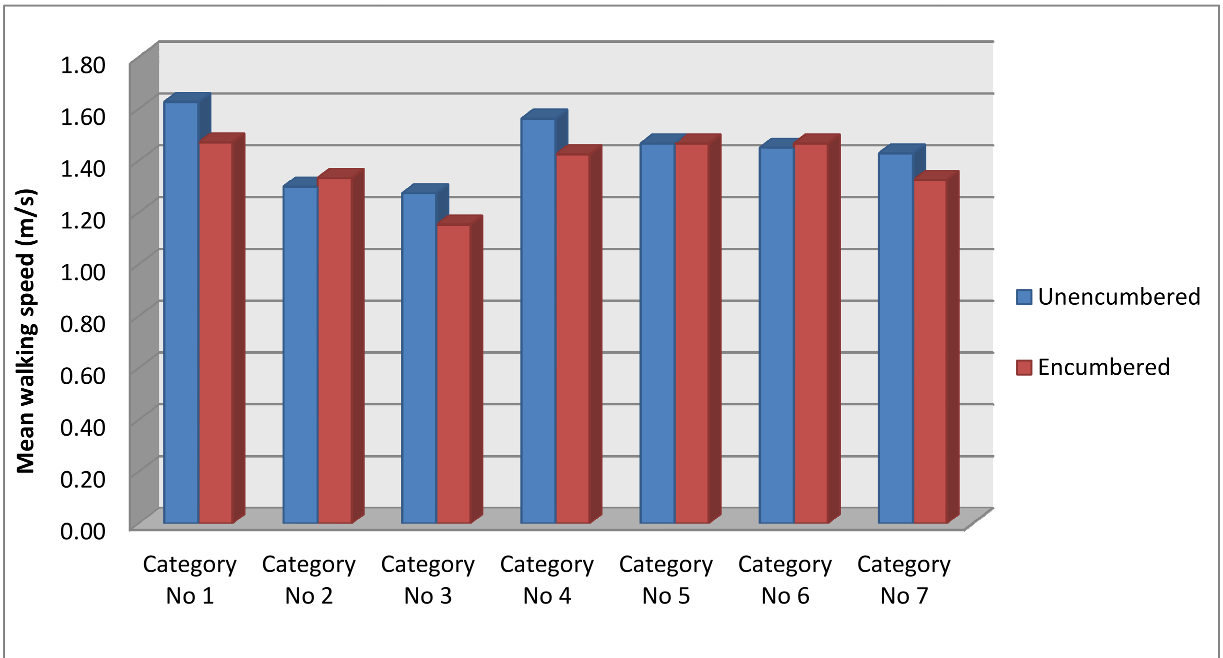

Figure 5-26: Pedestrian mean walking speed by encumbrance

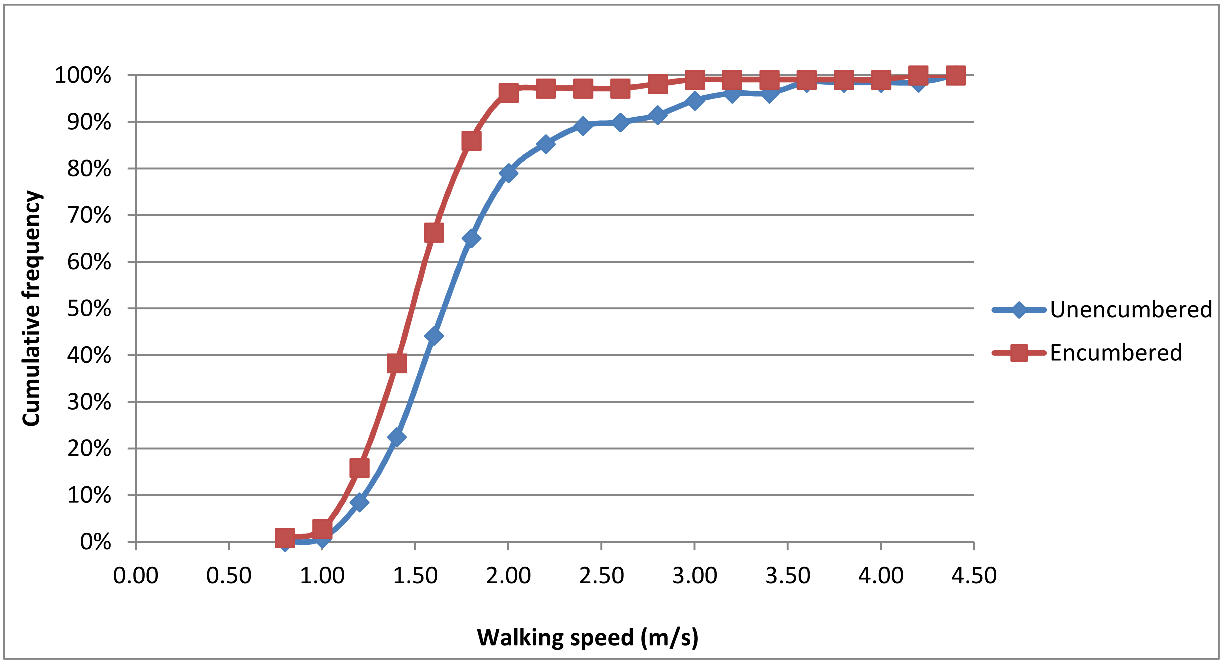

Figure 5-27: Cumulative distribution of pedestrian walking speed by encumbrance at signal-actuated crossings on four-lane divided roads

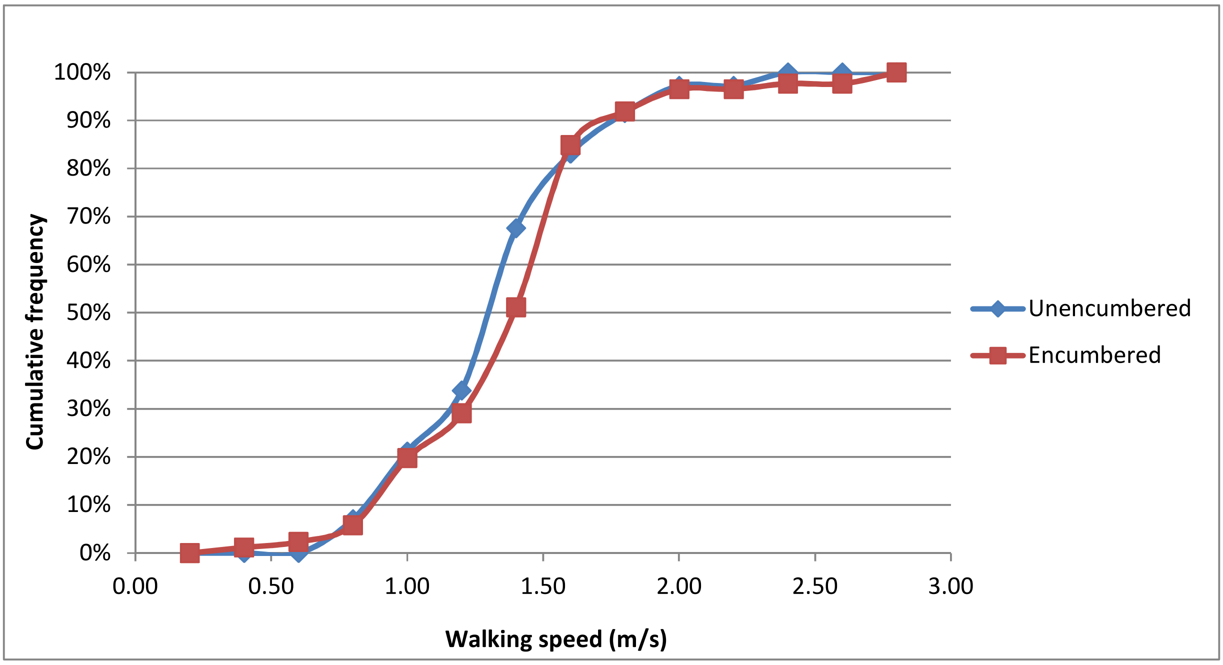

Figure 5-28: Cumulative distribution of pedestrian walking speed by encumbrance at signal-actuated crossings on four-lane undivided roads

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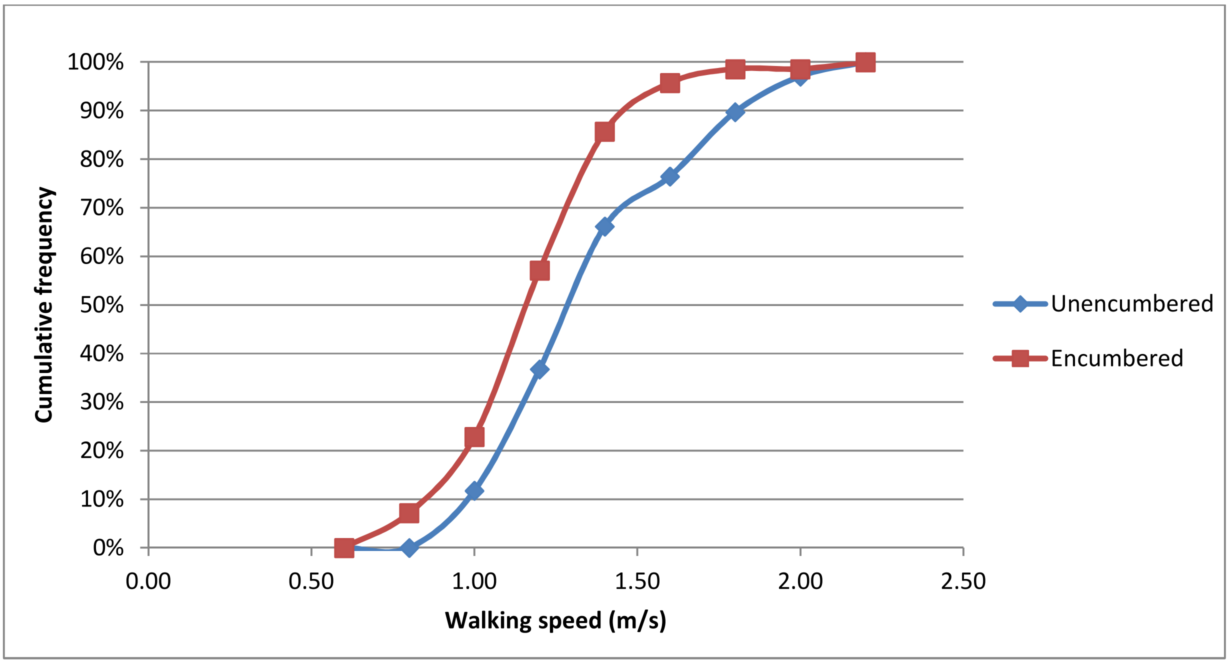

Figure5-29: Cumulative distribution of pedestrian walking speed by encumbrance at unsignalised crossings on T-junctions

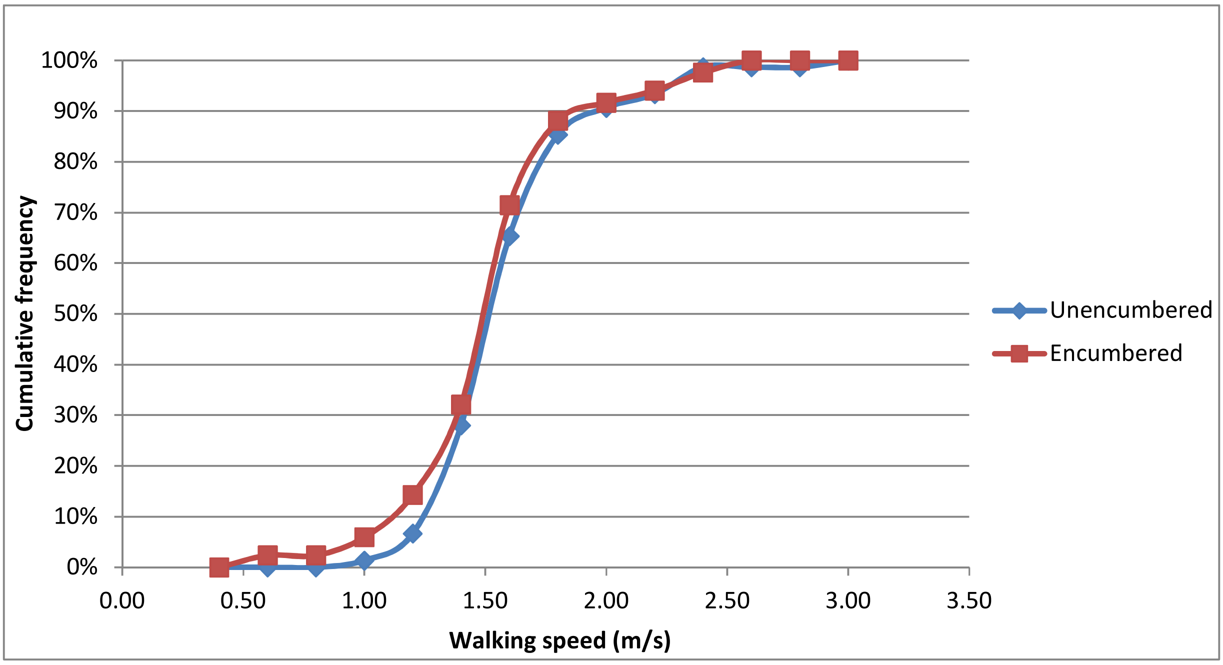

Figure 5-30: Cumulative distribution of pedestrian walking speed by encumbrance at unsignalised crossings on two-way and four-way-stop intersections

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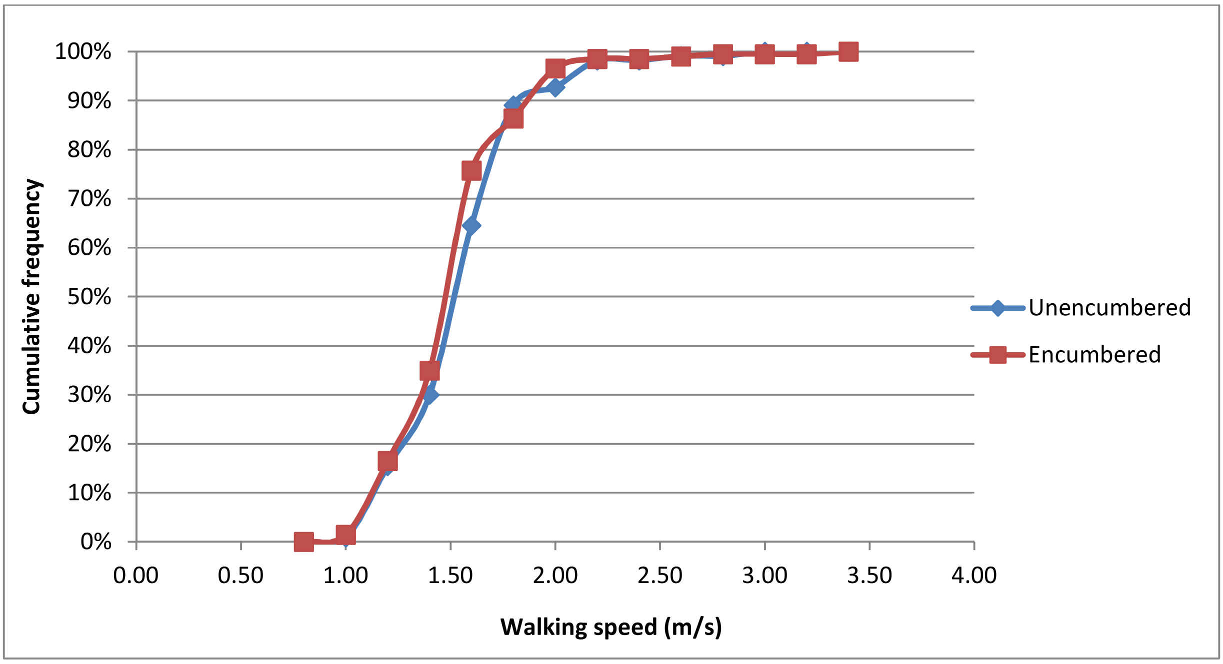

Figure 5-31: Cumulative distribution of pedestrian walking speed by encumbrance at unsignalised mid-block crossings on two-lane roads

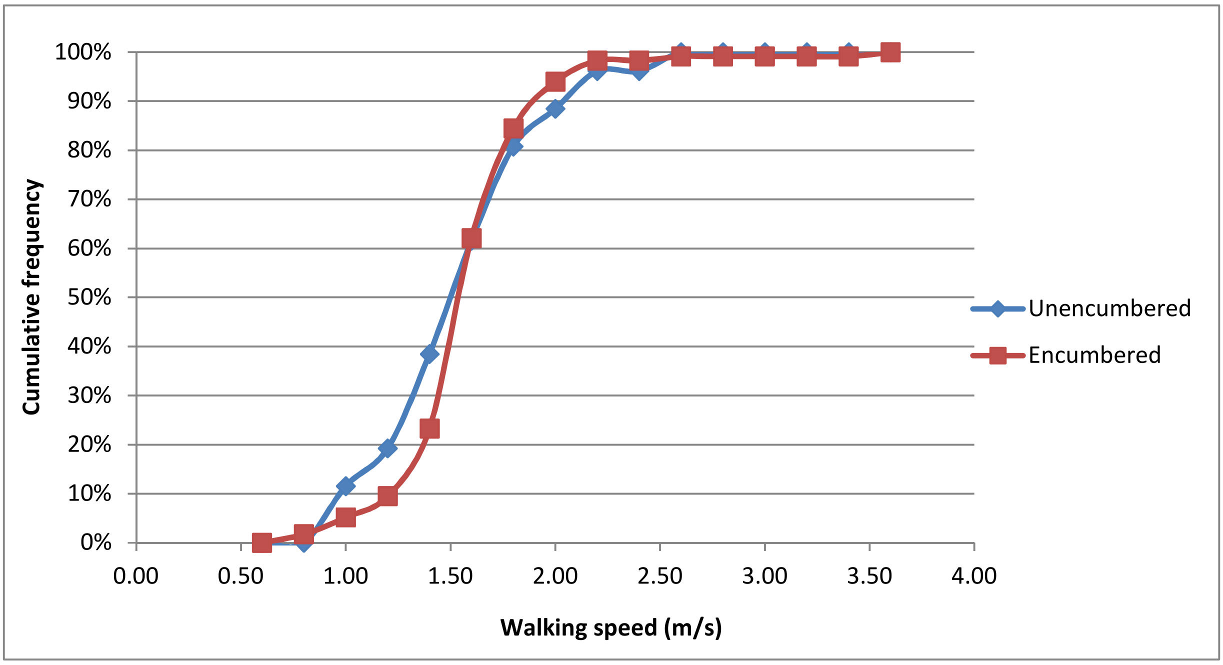

Figure5-32: Cumulative distribution of pedestrian walking speed by encumbrance at unsignalised mid-block crossings on four-lane undivided roads

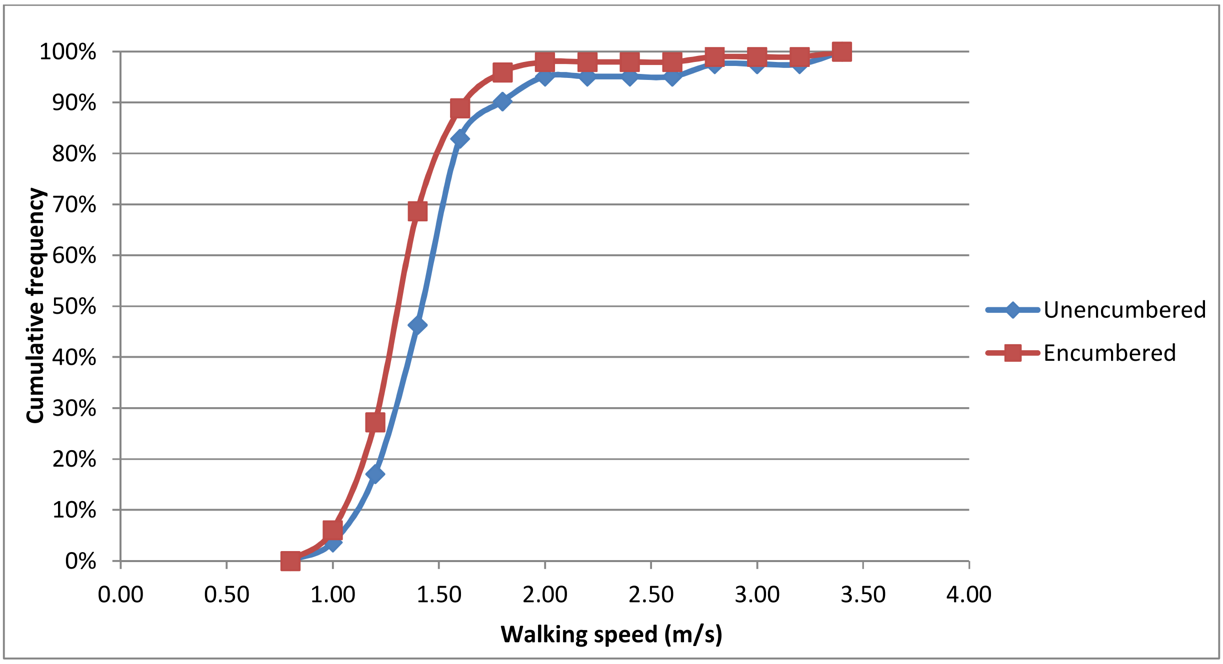

Figure 5-33: Cumulative distribution of pedestrian walking speed by encumbrance at sidewalks

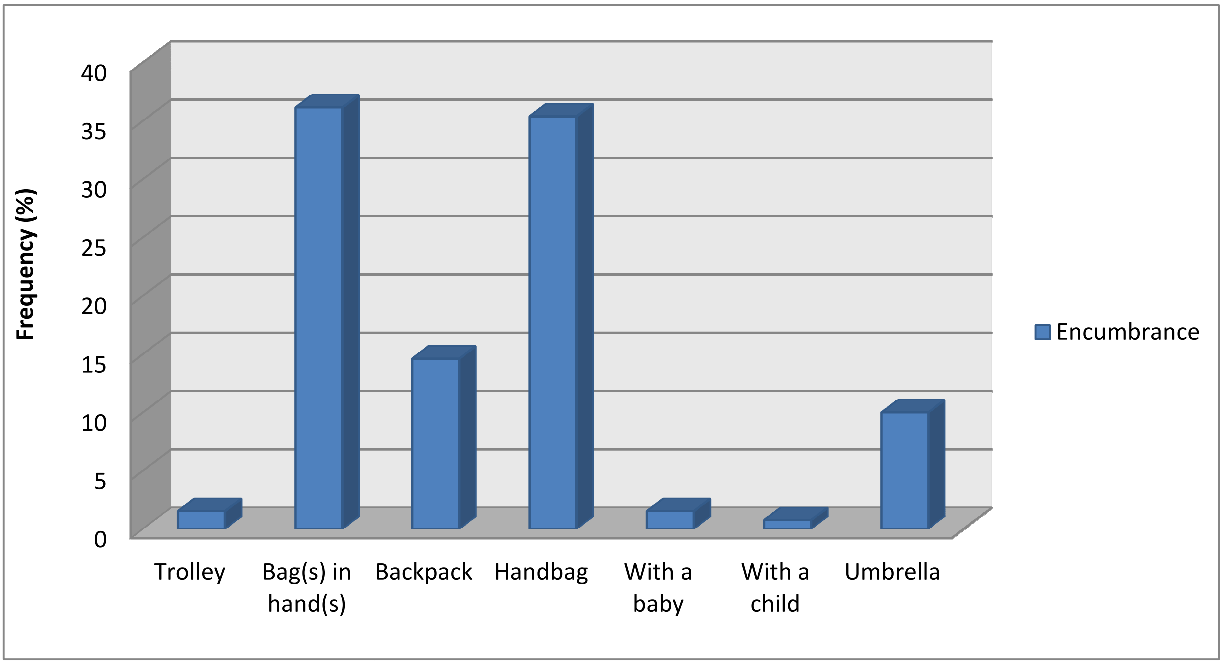

Figure 5-34: Frequency distribution of encumbrance at signal-actuated crossings on four-lane divided roads

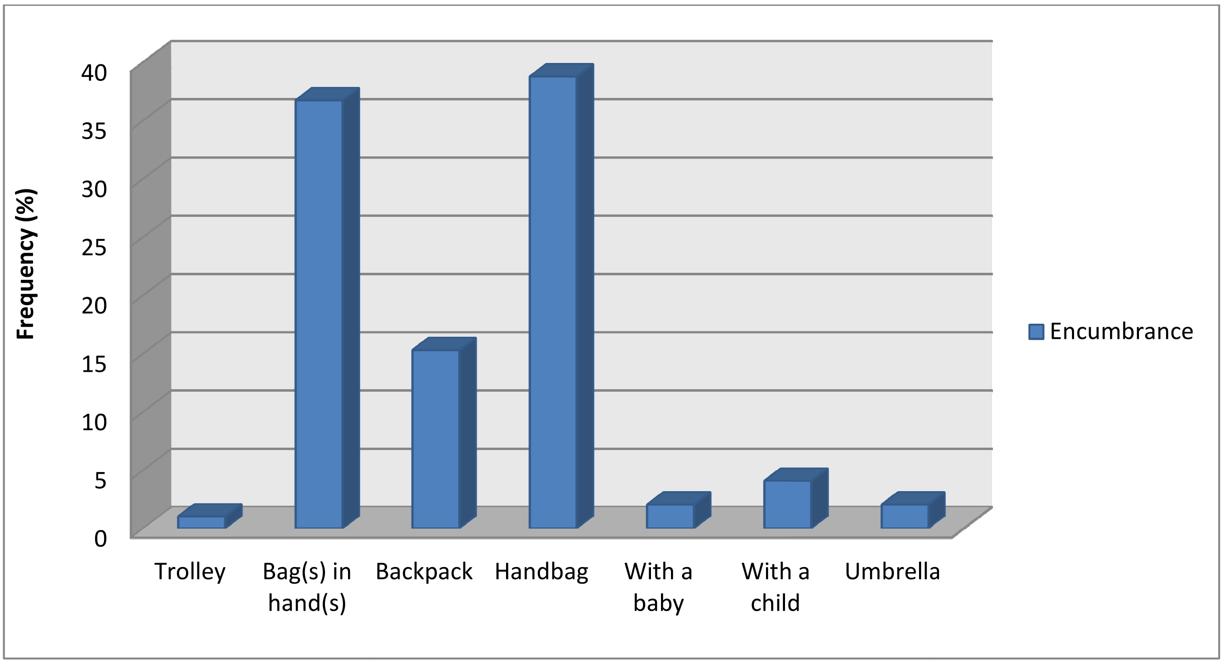

Figure 5-35: Frequency distribution of encumbrance at signal-actuated crossings on four-lane undivided roads

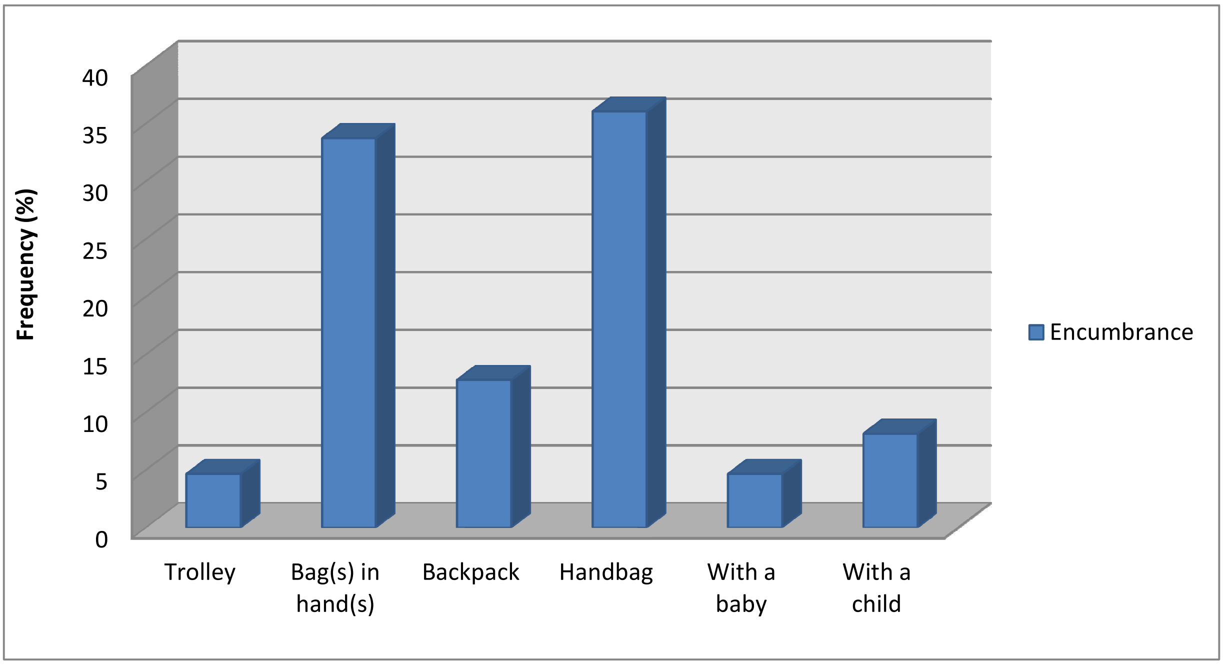

Figure 5-36: Frequency distribution of encumbrance at unsignalised crossings on T-junctions

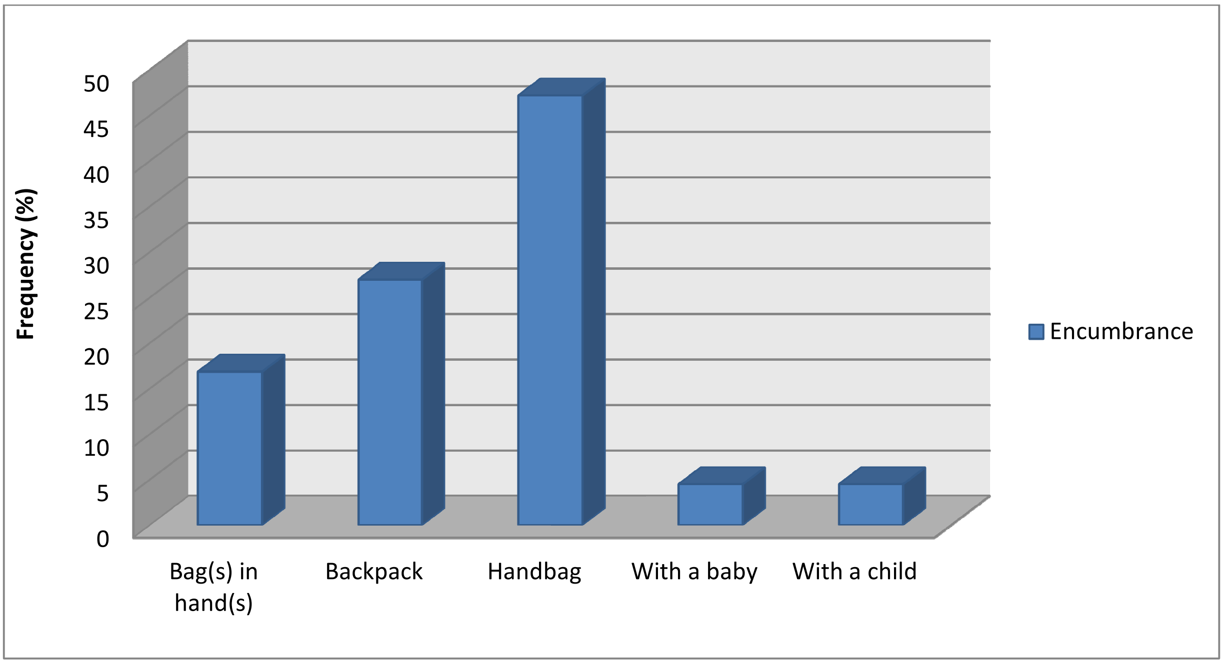

Figure 5-37: Frequency distribution of encumbrance at unsignalised crossings on two-way and four-way-stop intersections

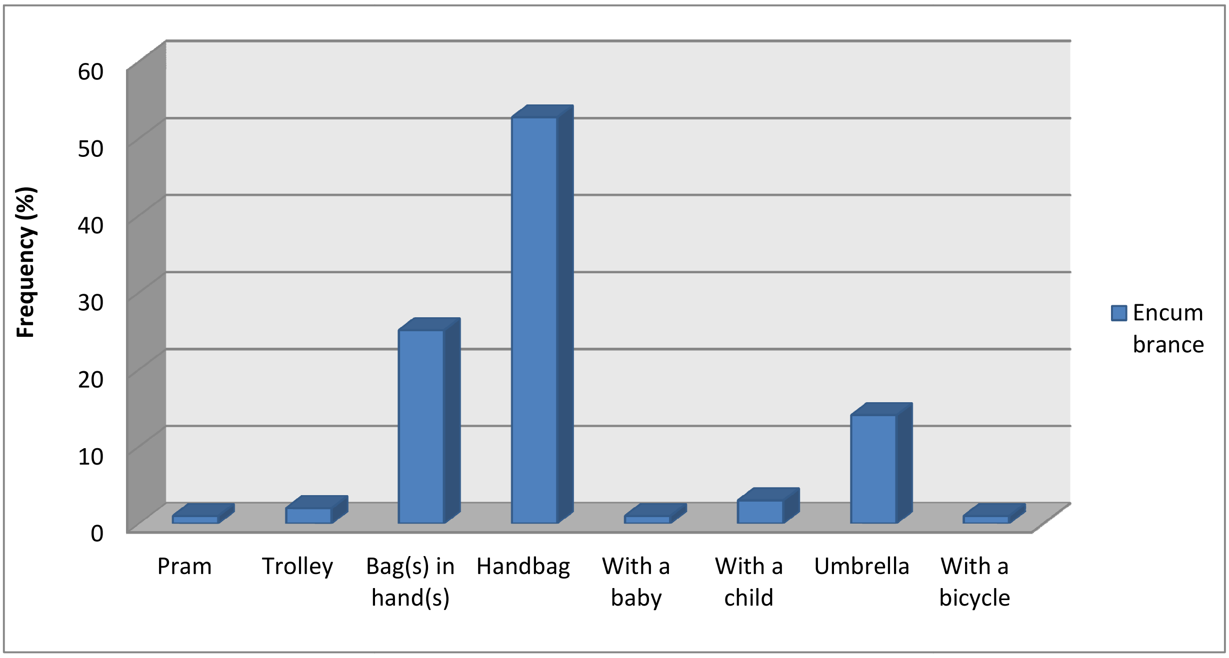

Figure 5-38: Frequency distribution of encumbrance at unsignalised mid-block crossings on two-lane roads

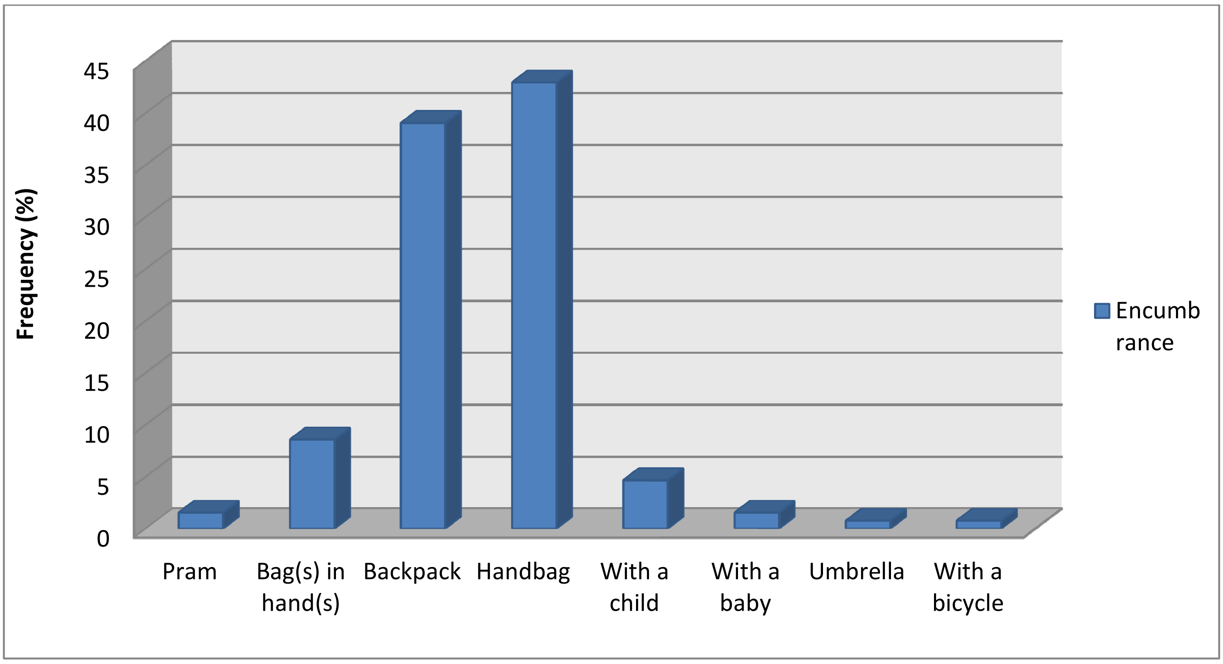

Figure 5-39: Frequency distribution of encumbrance at unsignalised mid-block crossings on four-lane undivided roads

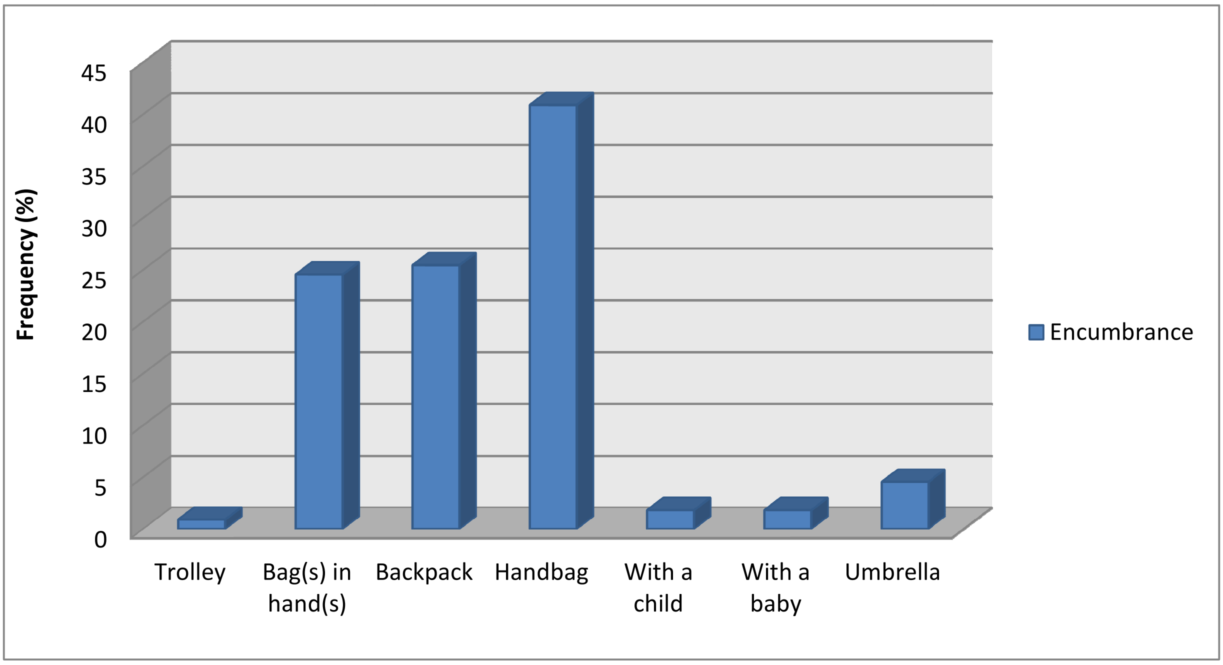

Figure 5-40: Frequency distribution of encumbrance at sidewalks

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5.2.6. Effect of distraction on pedestrian walking speed

In general, little difference in walking speed was found between distracted and non-distracted pedestrians, with two exceptions. Distracted pedestrians were those who were using a mobile phone, those who were listening to the music, those who were eating and those who were talking while crossing. The first exception was with e Category No 3 (unsignalised crossings on T-junctions) as illustrated by Figure 5-41 and Figure 5-44. Here, distracted pedestrians were found to be walking at lower speeds than non-distracted pedestrians. The other exception arose in Category No 2 (signal-actuated crossings on four-lane undivided roads) where distracted pedestrians walked faster than non-distracted pedestrians.

Table 5-7: Pedestrian walking speed by distraction

Category No	Distraction	Number of pedestrians	%	Pedestrian walking speed (m/s)			
				15th percentile speed	Mean speed	Average speed	Standard deviation
Category No 1	Non-distracted	149	63	1.27	1.62	1.69	0.53
	Distracted	87	37	1.24	1.51	1.62	0.54
Category No 2	Non-distracted	67	43	0.94	1.23	1.29	0.29
	Distracted	90	57	0.93	1.42	1.38	0.43
Category No 3	Non-distracted	59	43	1.07	1.28	1.35	0.31
	Distracted	79	57	0.95	1.13	1.18	0.24
Category No 4	Non-distracted	75	65	1.25	1.43	1.52	0.34
	Distracted	40	35	1.13	1.41	1.43	0.38
Category No 5	Non-distracted	197	62	1.25	1.50	1.54	0.33
	Distracted	119	38	1.10	1.42	1.37	0.23
Category No 6	Non-distracted	80	56	1.25	1.47	1.58	0.41
	Distracted	62	44	1.32	1.47	1.50	0.25
Category No 7	Non-distracted	122	67	1.18	1.38	1.47	0.42
	Distracted	59	33	1.14	1.28	1.30	0.19

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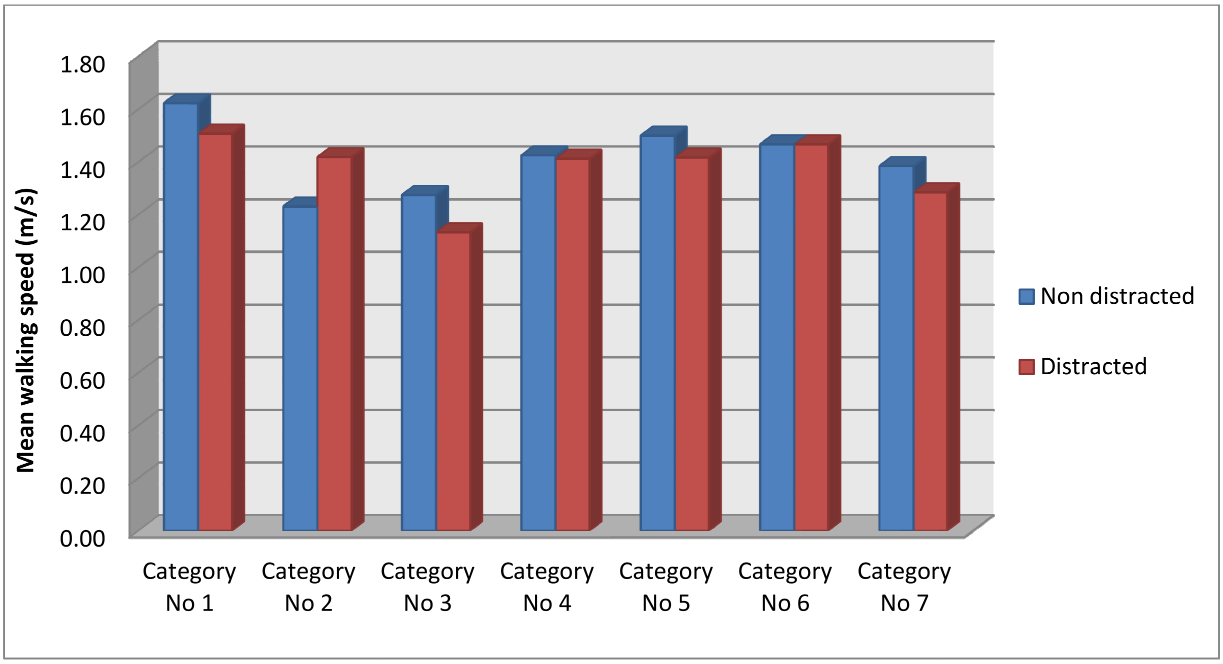

Figure 5-41: Pedestrian mean walking speed by distraction

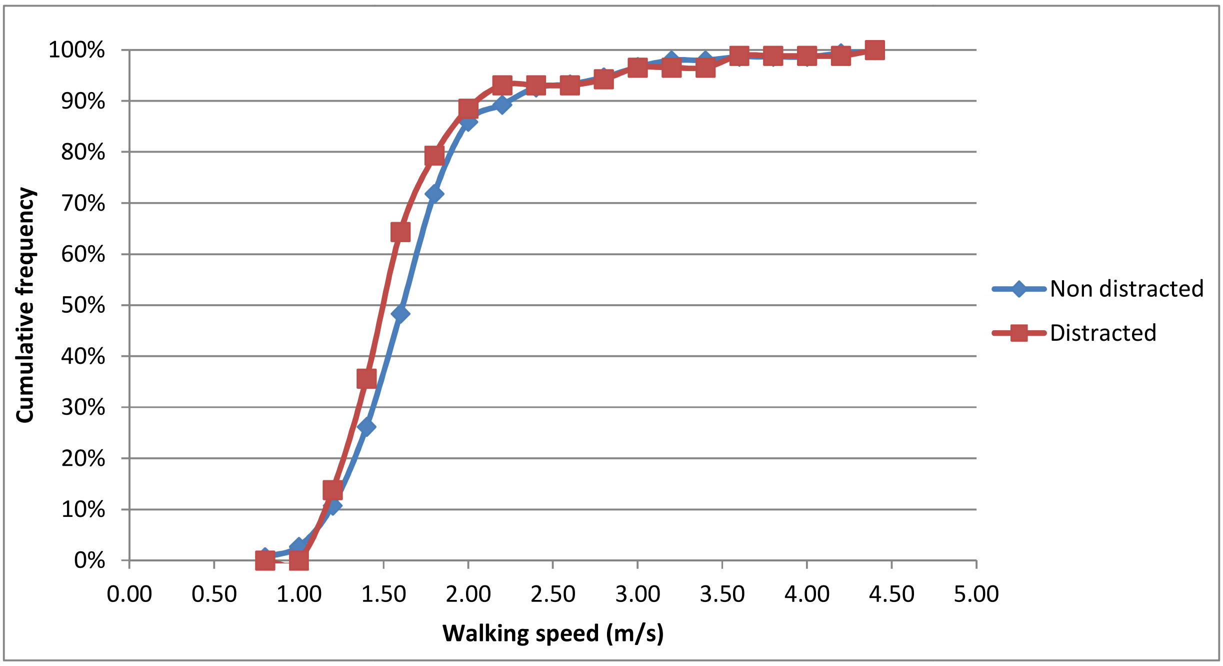

Figure 5-42: Cumulative distribution of pedestrian walking speed by distraction at signal-actuated crossings on four-lane divided roads

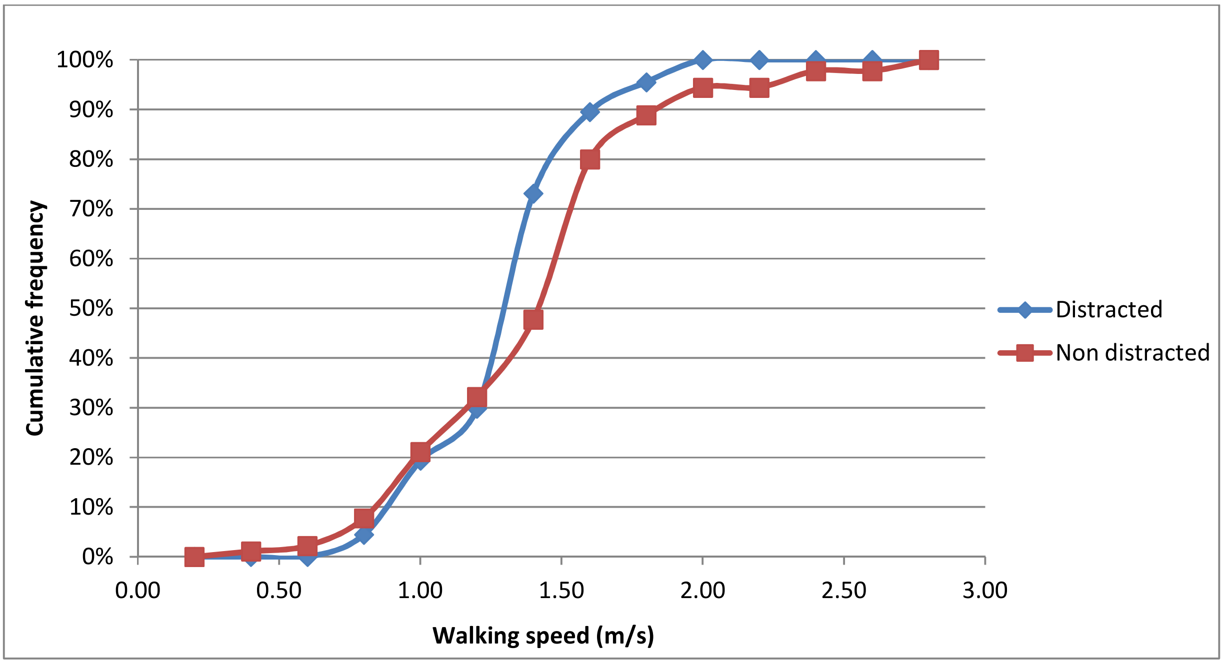

Figure 5-43: Cumulative distribution of pedestrian walking speed by distraction at signal-actuated crossings on four-lane undivided roads

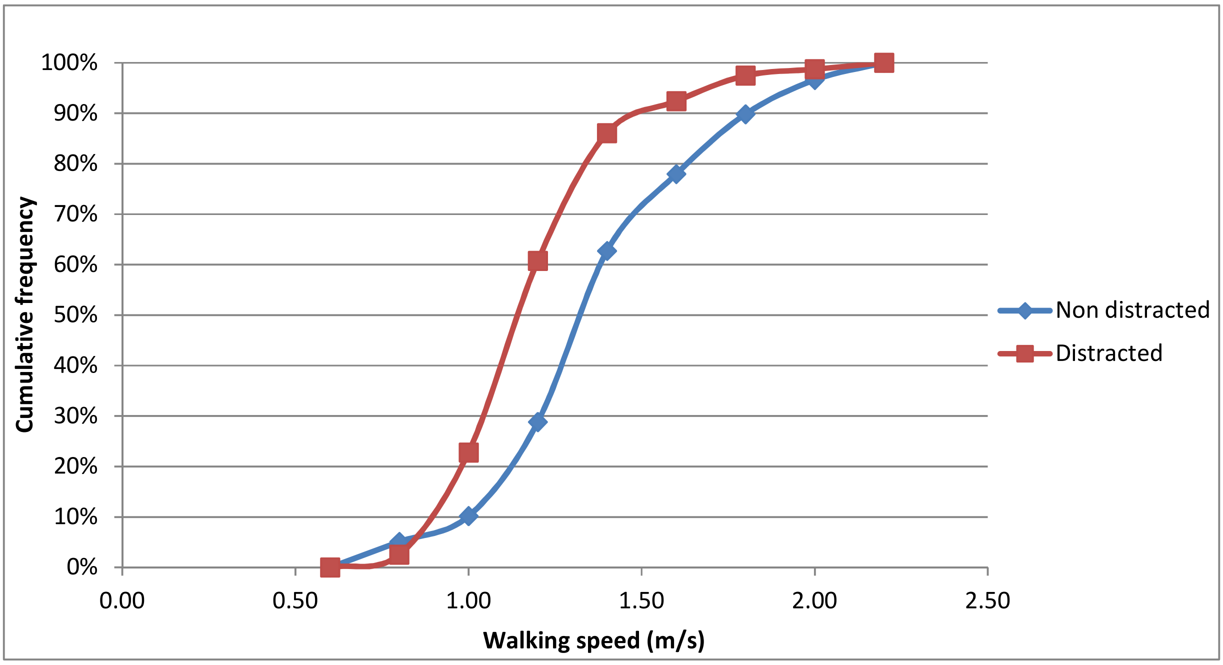

Figure 5-44: Cumulative distribution of pedestrian walking speed by distraction at unsignalised crossings on T-junctions

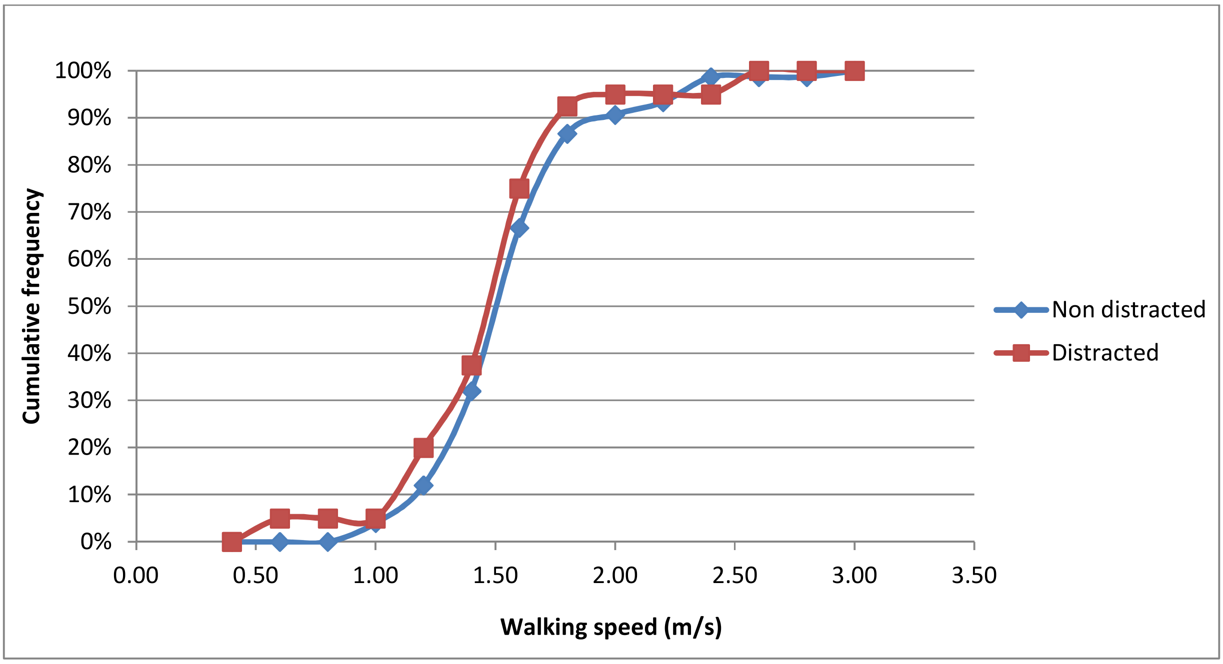

Figure 5-45: Cumulative distribution of pedestrian walking speed by distraction at unsignalised crossings on two-way and four-way-stop intersections

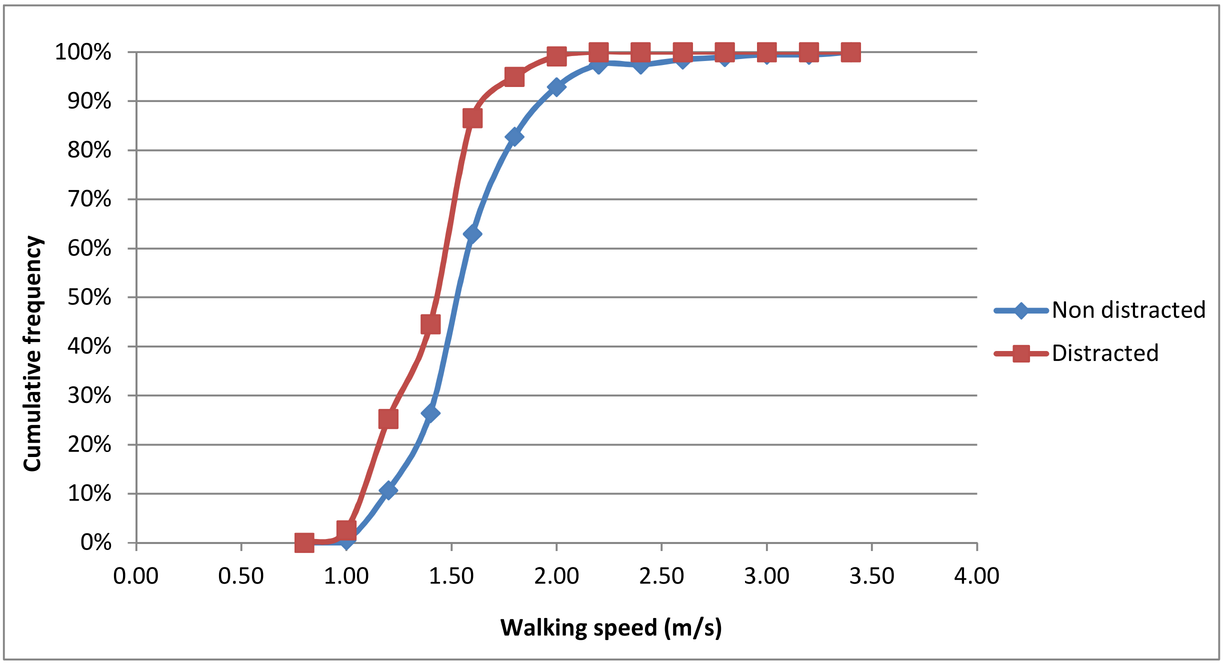

Figure 5-46: Cumulative distribution of pedestrian walking speed by distraction at unsignalised mid-block crossings on two-lane roads

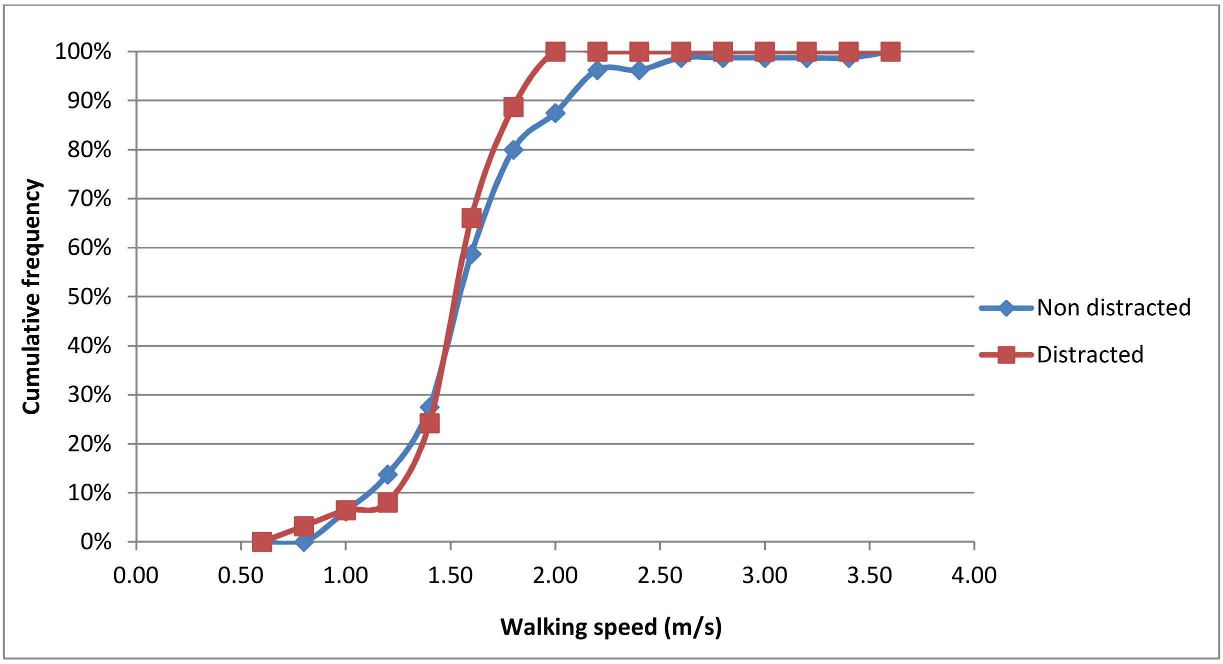

Figure 5-47: Cumulative distribution of pedestrian walking speed by distraction at unsignalised mid-block crossings on four-lane undivided roads

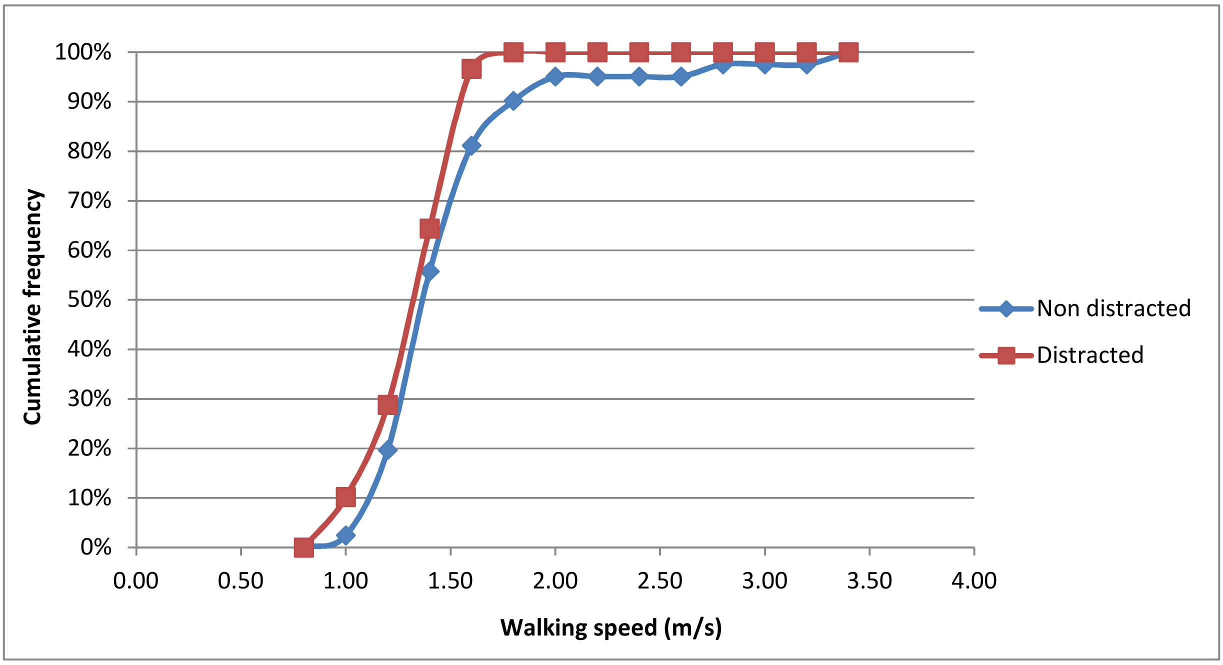

Figure5-48: Cumulative distribution of pedestrian walking speed by distraction at sidewalks

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5.2.7. Effect of conflicts on pedestrian walking speed

Conflicting pedestrians were those who stopped in the street, those who slowed down to take an evasive action, those who run and those who requested priority by using a hand sign. Table 5-8 shows varying proportions of conflicts according to the type of crossing facility. Conflict rate peaked in Category No 2 (signal-actuated crossings on four-lane undivided roads) with a score of 51 percent, followed by Category No 1 (signal-actuated crossings on four-lane divided roads) with a score of 51 percent. The lowest rate of conflicts was found in Category No 3 (unsignalised crossings on T-junctions). Conflicting pedestrians were found to walk slower than non-conflicting pedestrians, except in Category No 1 (signal-actuated crossings on four-lane divided roads). Difference in walking speed between conflicting and non-conflicting pedestrians is generally noticeable in all pedestrian facility categories (see Figure 5-50 to Figure 5-54).

Table 5-8: Pedestrian walking speed by conflict

Category No	Conflict	Number of pedestrians	%	Pedestrian walking speed (m/s)			
				15th percentile speed	Mean speed	Average speed	Standard deviation
Category No 1	Non-conflicting	115	49	1.24	1.47	1.50	0.23
	Conflicting	121	51	1.19	1.69	1.82	0.68
Category No 2	Non-conflicting	71	45	1.23	1.42	1.46	0.23
	Conflicting	86	55	0.84	1.23	1.24	0.44
Category No 3	Non-conflicting	112	81	1.02	1.25	1.28	0.28
	Conflicting	26	19	0.82	1.06	1.11	0.28
Category No 4	Non-conflicting	99	86	1.26	1.43	1.51	0.32
	Conflicting	16	14	1.05	1.25	1.34	0.50
Category No 5	Non-conflicting	238	75	1.21	1.47	1.47	0.25
	Conflicting	78	25	1.09	1.42	1.50	0.44
Category No 6	Non-conflicting	94	66	1.35	1.60	1.56	0.22
	Conflicting	48	34	0.97	1.46	1.50	0.52

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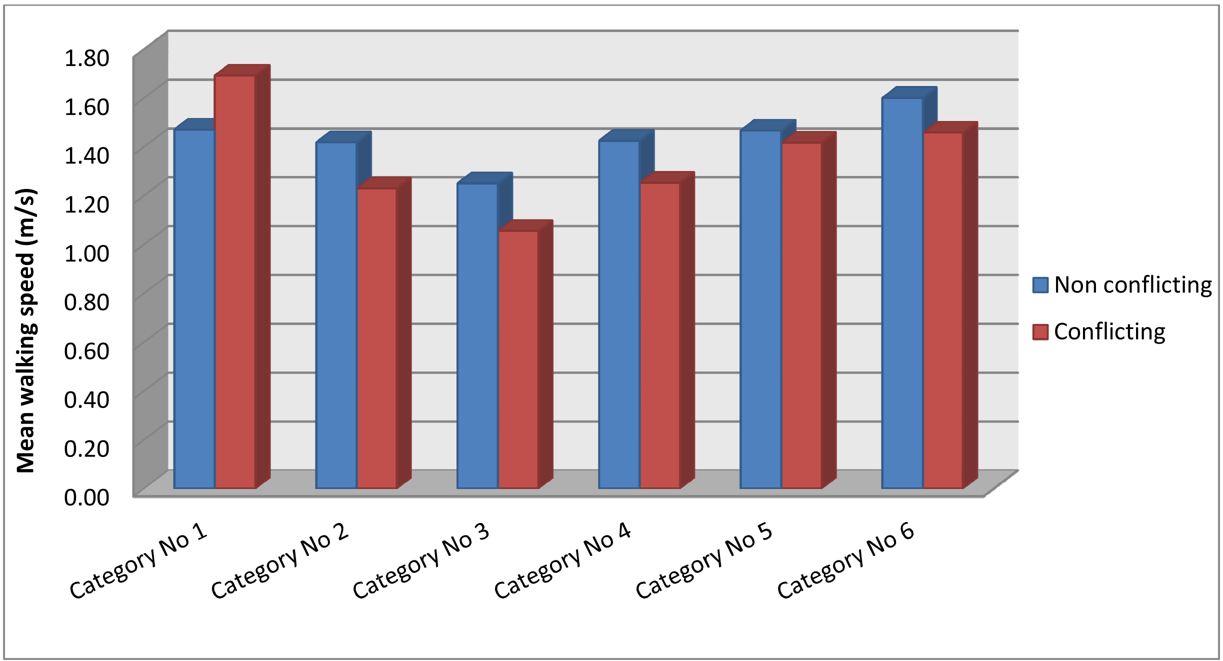

Figure 5-49: Pedestrian mean walking speed by conflicts

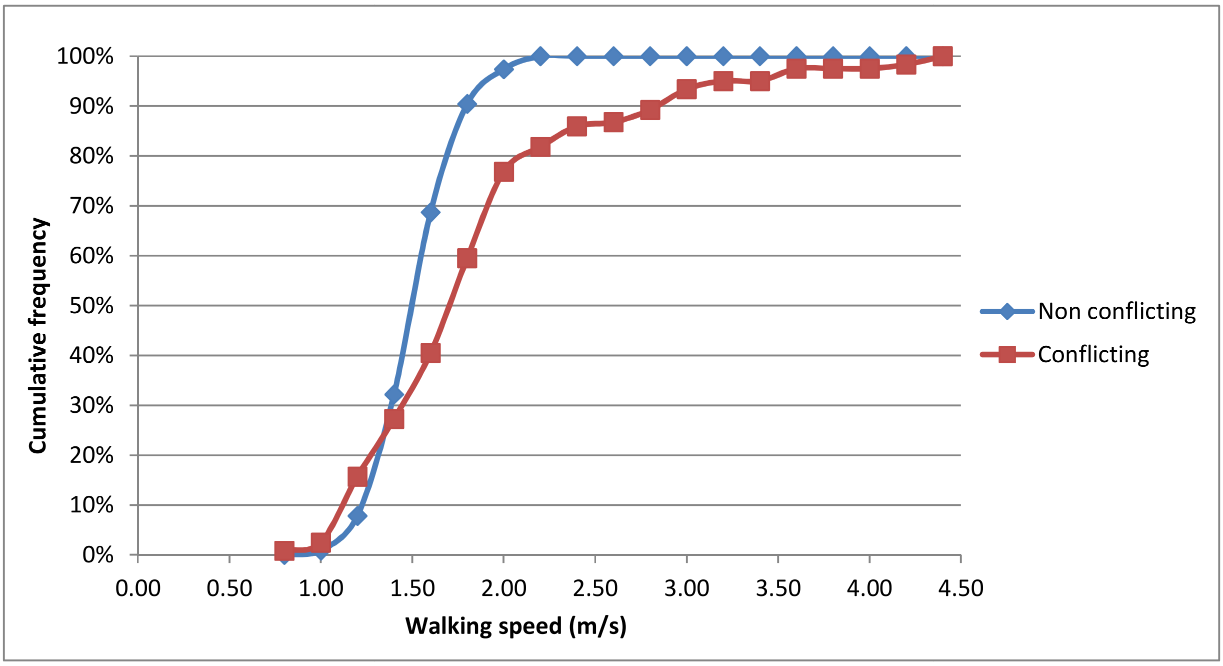

Figure 5-50: Cumulative distribution of pedestrian walking speed by conflict at signal-actuated crossings on four-lane divided roads

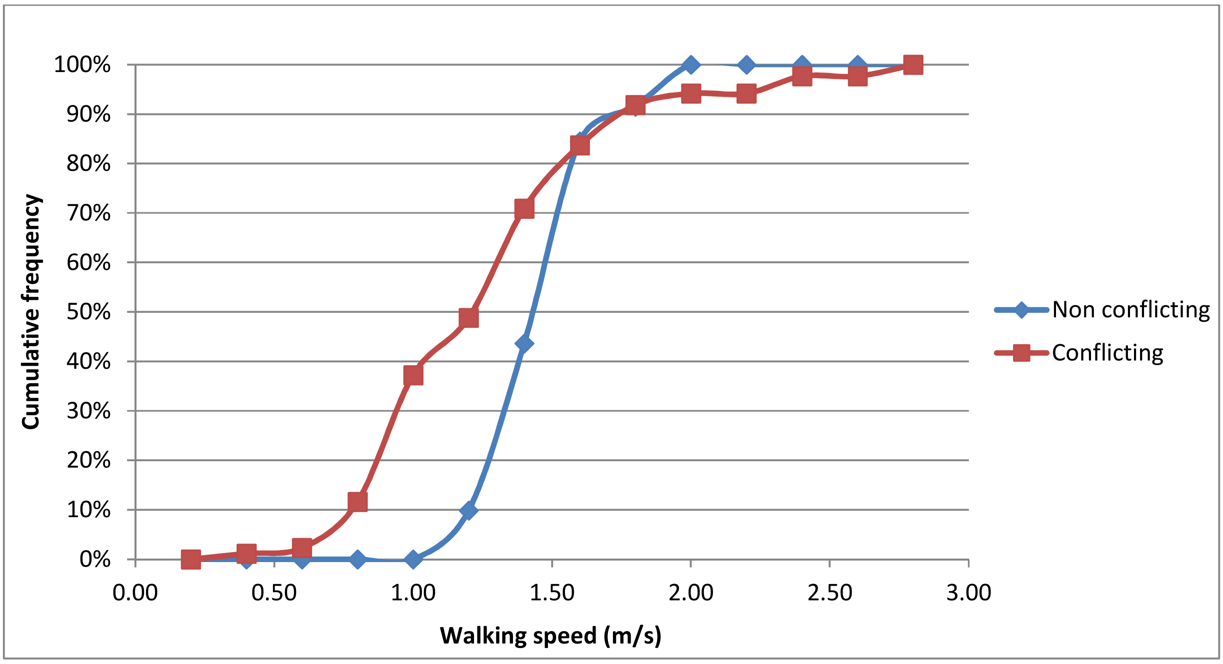

Figure 5-51: Cumulative distribution of pedestrian walking speed by conflict at signal-actuated crossings on four-lane undivided roads

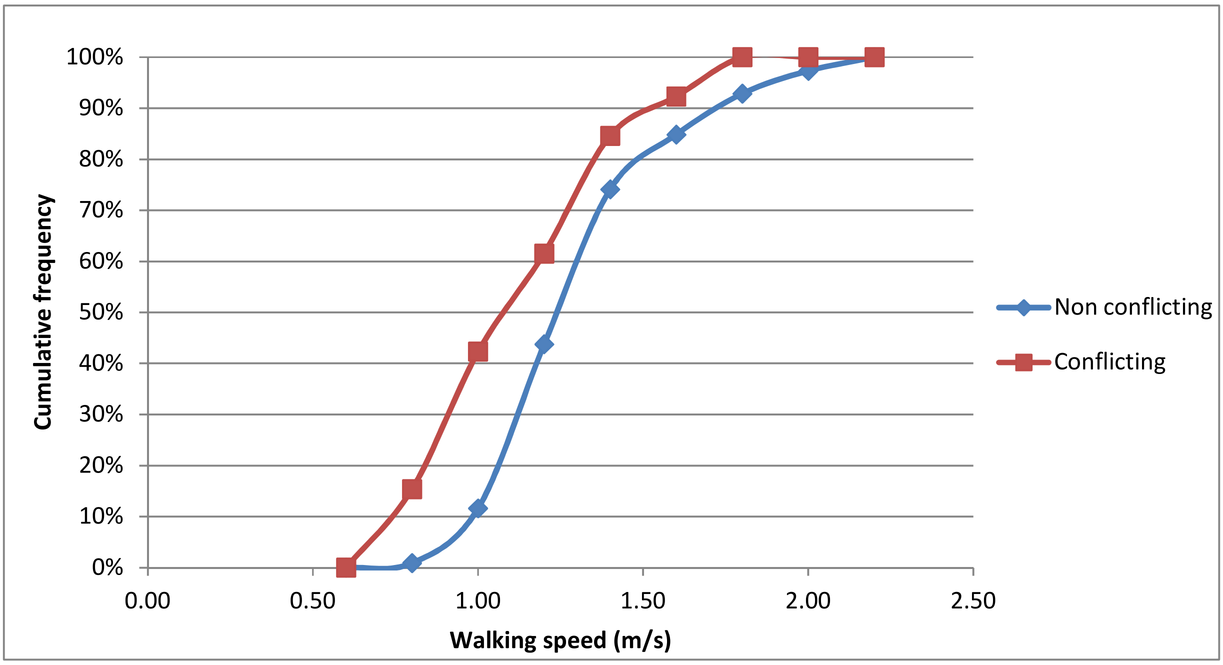

Figure 5-52: Cumulative distribution of pedestrian walking speed by conflict at unsignalised crossings on T-junctions

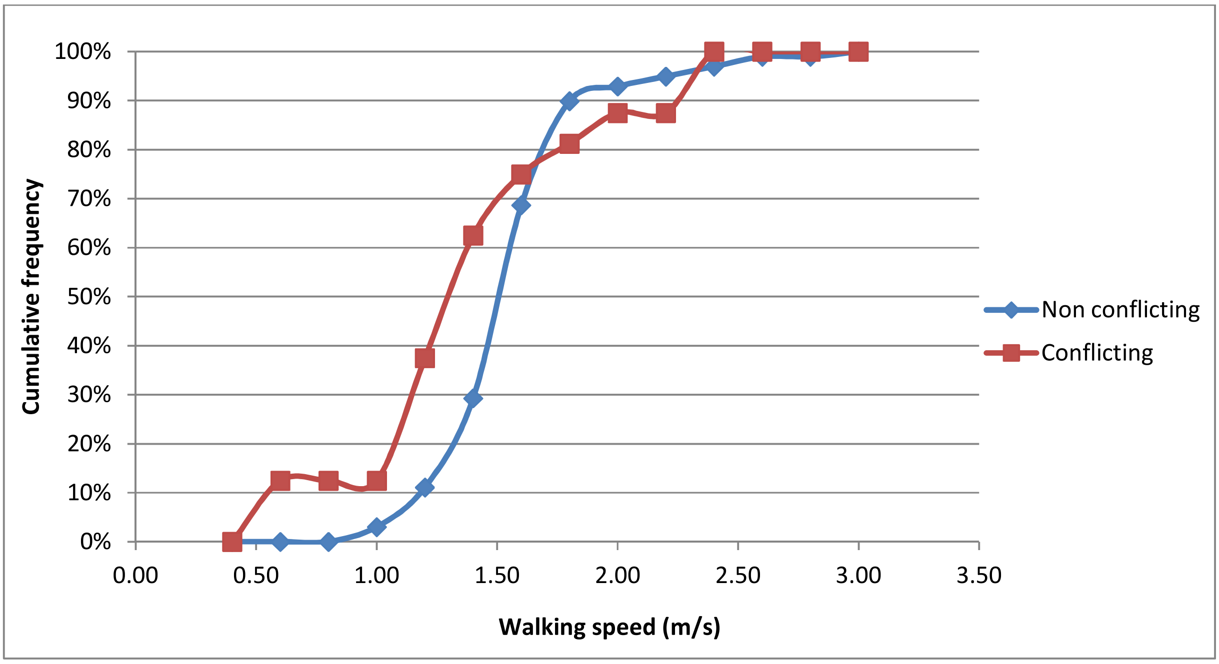

Figure 5-53: Cumulative distribution of pedestrian walking speed by conflict at unsignalised crossings on two-way and four-way-stop intersections

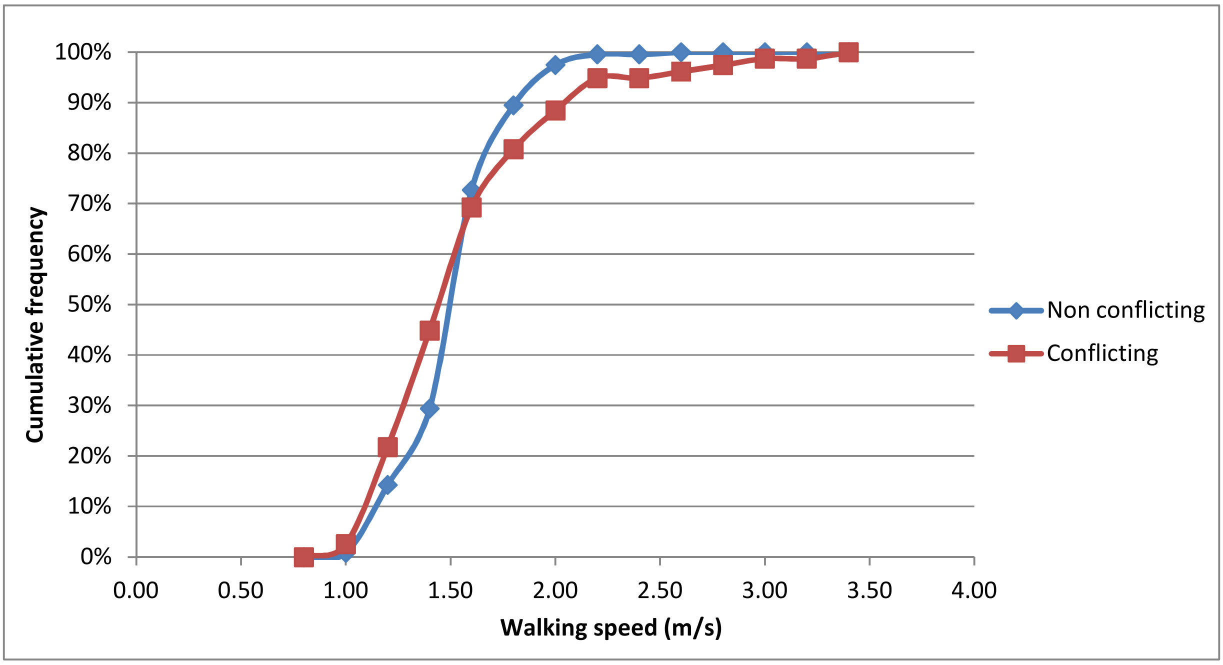

Figure 5-54: Cumulative distribution of pedestrian walking speed by conflict at unsignalised mid-block crossings on two-lane roads

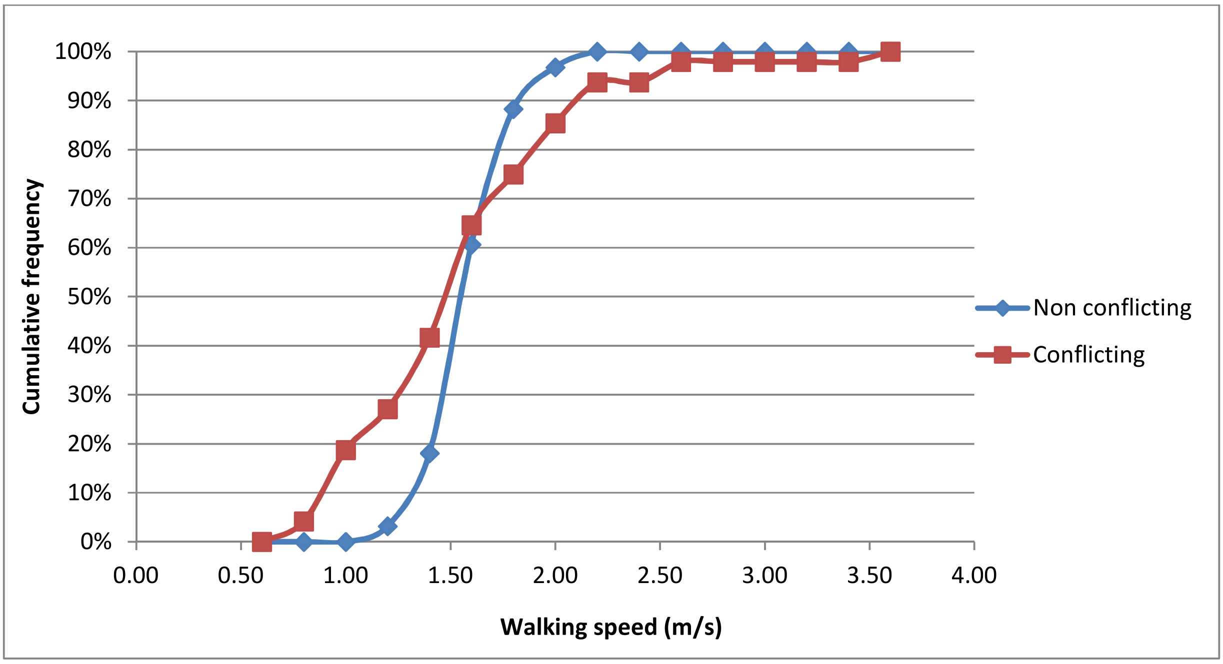

Figure 5-55: Cumulative distribution of pedestrian walking speed by conflict at unsignalised mid-block crossings on four-lane undivided roads

5.2.8. Discussion-Walking speeds

As illustrated by Figure 5-1, the 15th percentile walking speed per pedestrian facility category varies between 0.94 m/s and 1.32 m/s. In three pedestrian crossing categories, namely Category No 2 (signal-actuated crossings on four-lane undivided roads), Category No 3 (unsignalised crossings on T-junctions) and Category No 7(sidewalks), the values of the 15th percentile speed were found to be lower than the design walking speed of 1.2 m/s recommended in most design manuals. The mean walking speed varies between 1.25 m/s and 1.56 m/s.

The higher values of walking speed were found in t Category No 1 (signal-actuated crossings on four-lane divided roads) and Category No 6 (unsignalised mid-block crossings on four-lane undivided roads). Category No 1 includes two signal-actuated crossings located at the intersection of Adam Tas and Bird Street). Category No 6 includes two unsignalised mid-block crossings (Zebra crossings) located on Merriman Avenue and Helshoogte Road. The common characteristics of these pedestrian crossings are wide roads (four-lane roads), high traffic volume and fast moving vehicles. This suggests that pedestrians generally tend to reduce the risk associated with crossing at these pedestrian crossings by shortening the crossing time.

Running is the common strategy of shortening the crossing time and this behaviour was predominantly observed in Category No 1 (signal-actuated crossings on four-lane divided roads) as illustrated by Figure 5-83. Running behaviour in turn may be associated with several factors such as pedestrian non-compliance with the traffic signals and motorists' failure to yield to pedestrians at unsignalised crossings. Pedestrians who fail to wait for the green man signal choose to find a gap through the traffic stream. In high traffic volume and high vehicular speed conditions, available gaps become shorter and acceptance of shorter gaps involves also an evasive action such as running. This was the situation frequently observed at Adam Tas/ Bird Street intersection. Motorists' failure to yield to pedestrians was commonly observed at unsignalised mid-block crossings especially on wide roads (e.g. four-lane roads). It can be surmised that crossing the road at these crossing facilities involves the readiness to take an evasive action in the case the conflicting motorist is not willing to yield to pedestrians. This situation may be the reason of higher walking speeds and also explain higher rates of running behaviour observed in Category No 6 (unsignalised mid-block crossings on four-lane undivided roads) as illustrated by Figure 5-1 and Figure 5-83.

Demographic variables may also influence the walking speed at these crossing facilities. As men generally walk faster than women, observed high proportions of male pedestrians at these crossing facilities may also explain the higher walking speeds observed in Category No 1 (signal-actuated crossings on four-lane divided roads) and Category No 6 (unsignalised mid-block crossings on four-lane undivided roads).

The slowest observed walking speed was found at the pedestrian crossings located at T-junctions. The effect of encumbrance and low traffic volumes at intersecting minor roads (Crozier Street and Kromrivier Street) may influence walking speed at these crossings. The higher rates of pedestrians walking with a child, with a baby and with a trolley were observed at these crossing facilities, especially at Bird Street/Crozier (see Figure 5-39). The Bird Street/Crozier T-intersection is located in the CBD of the town and is used mainly by shoppers carrying bags in their hands or in trolleys. Demographic variables may also influence walking speed at these crossing facilities. The highest percentage of female pedestrians emerged at these crossing facilities (see Table 5-2). The effect of traffic volume, crossing distance and the number of conflicts on pedestrian walking speed was shown in this study. Conflict rates peaked at 4-lane roads (Category No 1 and Category No 6) as shown in Figure 5-49. In the absence of conflict situations, pedestrians tended to cross at their normal walking speed which was found in this study to be lower than the crossing speed (see Figure 5-1). The normal walking speed was expected to be the lowest walking speed in this study. However, the effect of encumbrance at T-junctions on the one hand, and the presence of pedestrians travelling on skateboards at the sidewalks on the other hand may explain the unexpected outcome from this study.

Although the female population outnumbers the male population in Stellenbosch (Stellenbosch Municipality, 2012), the findings from Table 5-2 showed that male pedestrians outnumber female pedestrians. This suggests that generally males walk more than females in Stellenbosch. In line with the international literature, male pedestrians were found to walk faster than female pedestrians. The effect of encumbrance was more predominantly observed in females than in males and this may be owing to innate differences between the sexes with regard to walking differences.

Females were more likely to be encumbered by carrying a handbag or walking with children.

The higher percentages of younger pedestrians were found at the pedestrian crossings located near the Stellenbosch University and other educational institutions (e.g. Category No 4, Category No 5, Category No 6 and Category No7). Proportions of young pedestrians found in this study are proportional to the demographic composition of the population in Stellenbosch. According to Stellenbosch Municipality annual reports, children and youth represent 66.1 percent of the total population (Stellenbosch Municipality, 2012). Elderly pedestrians were found in higher proportions at one sidewalk along Bird Street and in Category No 1 (signal-actuated crossings on four-lane divided roads). The type of land use may also be associated with demographic differences at pedestrian facilities. Whereas the majority of the pedestrian crossings investigated in this study are located in the town CBD and around the Stellenbosch University, Category No 1 (signal-actuated crossings on four-lane divided roads) serve as a route towards the suburban settlements located in the north of Stellenbosch. The active population whose majority component are young and middle-aged people may be expected more frequently around the CBD and the academic area.

Apart from the exception found in Category No 4 (unsignalised crossings on two-way and four-way-stop intersections), single pedestrians were observed to walk faster than pedestrians walking in groups. Similarly, pedestrians who walked in couples walked faster than those who walked in groups of more than 2 pedestrians. It can thus be concluded that the higher the number of pedestrians in the group, the slower the walking speed. Social influence may help to explain the reduced walking speeds recorded for pedestrians who walked in groups: pedestrians tend to feel safer when they cross the road in groups than when they walk alone and tend to be less cautious in these situations. The interrelationship may thus exist between distraction, group effect and reduced walking speed.

A little effect of encumbrance on walking speed has emerged in this study. The possible reason for this outcome may be a significant predominance of bags, handbags and backpacks as the forms of encumbrance. These loads are relatively too small to deter pedestrians from walking at their normal walking speeds. Carrying a certain load may be associated with the pedestrian trip purpose and the type of the land use. As an example, a high proportion of pedestrians with trolleys were found in Category No 3 (unsignalised crossings on T-junctions). One pedestrian crossing of this group is located in the town CBD and most of the facility users are shoppers. Handbags and backpacks peaked in Category No 4 (unsignalised crossings on two-way and four-way-stop intersections) and in the Category No 5 (unsignalised mid-block crossings on two-lane roads). These pedestrian crossings are located in the academic area and are frequently used by students walking with their books and their lap-tops in the handbags and backpacks.

Distraction was found to be associated with reduced walking speeds at 6 of the 7 pedestrian facilities. The distraction form most frequently observed at all pedestrians facilities was talking. Talking is associated with walking in groups and as it was discussed early, the walking speed reduced with increasing group size.

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While conflicts peaked in Category No 2 (signal-actuated crossings on four-lane undivided roads), the walking speed at the same crossing facilities reduced (see Table 5-8 and Figure 5-49). Contrary to this situation, the higher rates of conflicts in Category No 1 (signal-actuated crossings on four-lane divided roads) were found to be associated with higher walking speeds at the same crossing facility. This suggests that conflicts reduced the walking speed in Category No 2 whereas they increased the walking speed in Category No 1. This situation could be clearly seen from Figure 5-83; running was the most frequent conflict type in Category No 1 whereas stopping and slowing down were the most predominant conflicts observed in Category No2.

5.3. Pedestrian delay

5.3.1. Pedestrian delay values

Pedestrian delays were investigated as two distinct components. The delay pedestrians experienced while waiting at the kerb is referred as “kerb delay” and the delay experienced during the actual crossing of the road is referred as “crossing delay”. The values of the kerb delay were the calculated difference between the arrival time at the kerb and the departure time from the kerb. Crossing delay was calculated by subtracting the ideal crossing time from the actual crossing time. The ideal crossing time was calculated by multiplying the width of the crossing by the calculated average walking speed of non-conflicting pedestrians. A negative value of crossing time explains that a pedestrian gained time by walking at higher walking speed than the non-conflicting speed. The total pedestrian delay was taken as the sum of the kerb delay and the crossing delay.

Values of kerb delay, crossing delay and total delay are presented in Table 5-9 and plotted in Figure 5-56. Kerb delays were found to be significantly higher in Category No 2 (signal-actuated crossings on four-lane undivided roads), followed by Category No 1 (signal-actuated crossings on four-lane divided roads). However, the crossing delay peaked in Category No 2 and the lowest value, which is negative, was found in Category No 1. The total delay peaked in Category No 2, followed by Category No 1 and Category No 6 (unsignalised mid-block crossings on four-lane undivided roads). At all crossing facilities, the kerb delay significantly exceeded the crossing delay.

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Table 5-9: Pedestrian delays per crossing facility type

Category No	Category of crossing facility	Type of delay	Pedestrian delay (s)		
			Mean delay	Average delay	Standard deviation
Category No 1	Signal-actuated crossings on four-lane divided roads	Kerb delay	3.00	9.23	11.52
		Crossing delay	-0.80	-0.74	3.45
		Total delay	4.20	8.49	12.70
Category No 2	Signal-actuated crossings on four-lane undivided roads	Kerb delay	6.00	11.54	13.98
		Crossing delay	0.72	1.76	4.60
		Total delay	8.72	13.29	15.15
Category No 3	Unsignalised crossings on T-junctions	Kerb delay	1.00	1.40	1.38
		Crossing delay	0.00	0.42	2.32
		Total delay	1.84	1.81	2.98
Category No 4	Unsignalised crossings on two-way and four-way-stop intersections	Kerb delay	1.00	2.00	0.90
		Crossing delay	0.00	0.16	2.56
		Total delay	1.00	1.45	2.85
Category No 5	Unsignalised mid-block crossings on two-lane roads	Kerb delay	1.00	1.24	0.96
		Crossing delay	0.00	0.23	1.37
		Total delay	1.20	1.47	1.68
Category No 6	Unsignalised mid-block crossings on four-lane undivided roads	Kerb delay	1.00	3.82	5.76
		Crossing delay	0.94	0.82	2.54
		Total delay	2.00	4.63	7.06

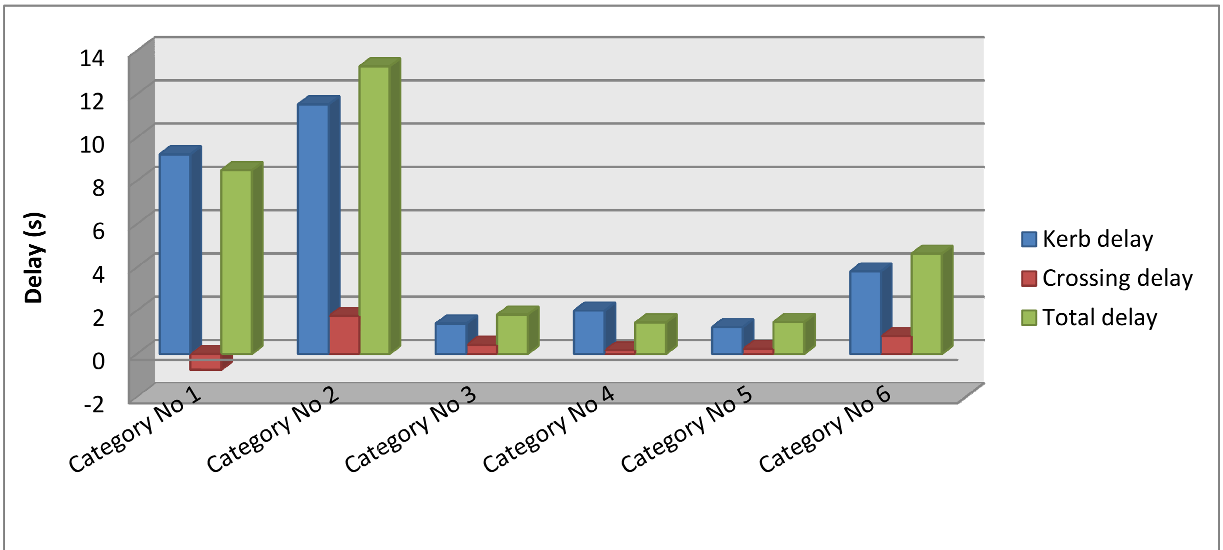

Figure 5-56: Average pedestrian delays at different pedestrian crossing types

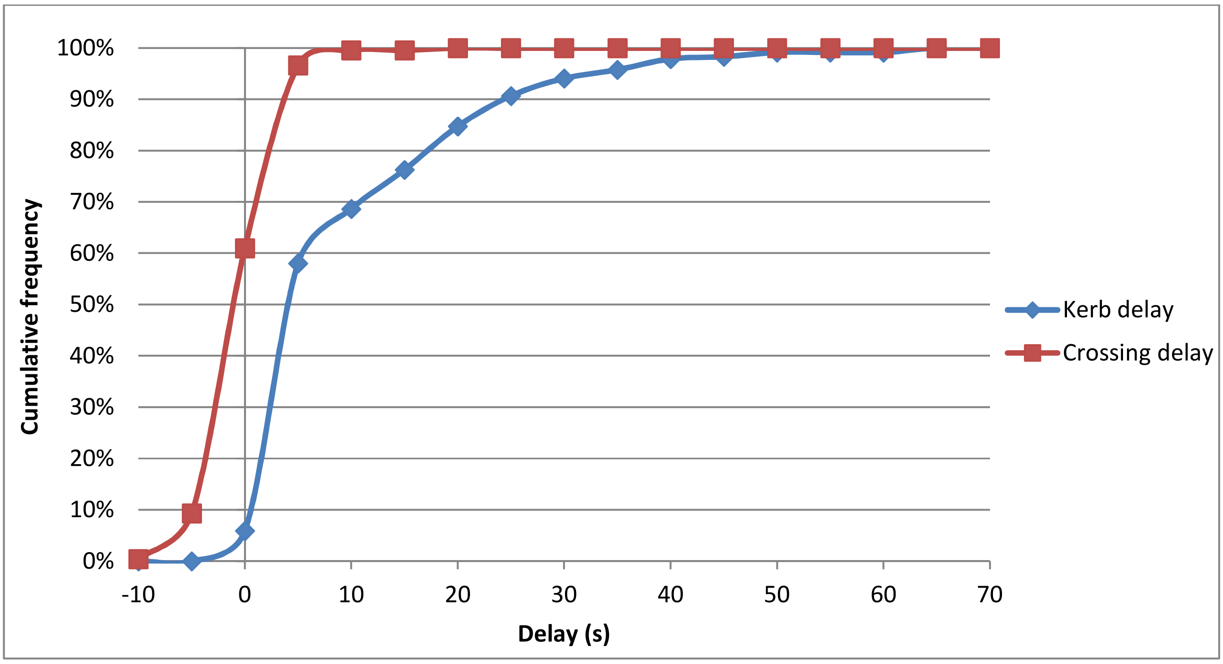

Figure 5-57: Cumulative distribution of kerb delay and crossing delay at signal-actuated crossings on four-lane divided roads

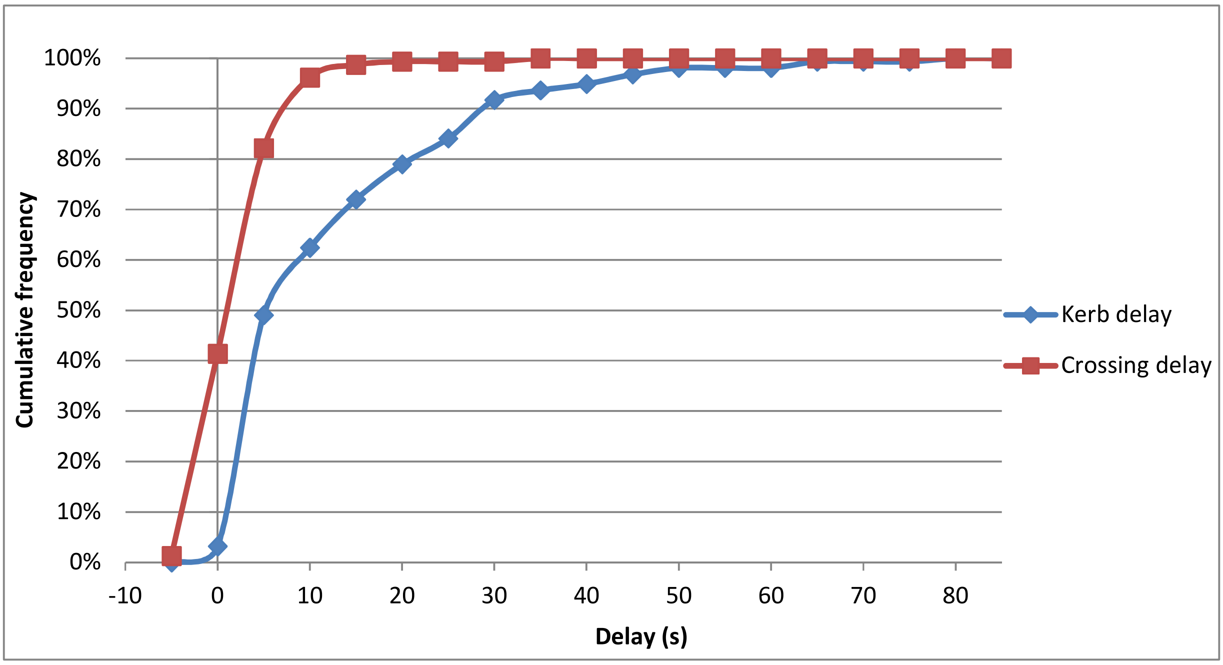

Figure5-58: Cumulative distribution of kerb delay and crossing delay at signal-actuated crossings on four-lane undivided roads

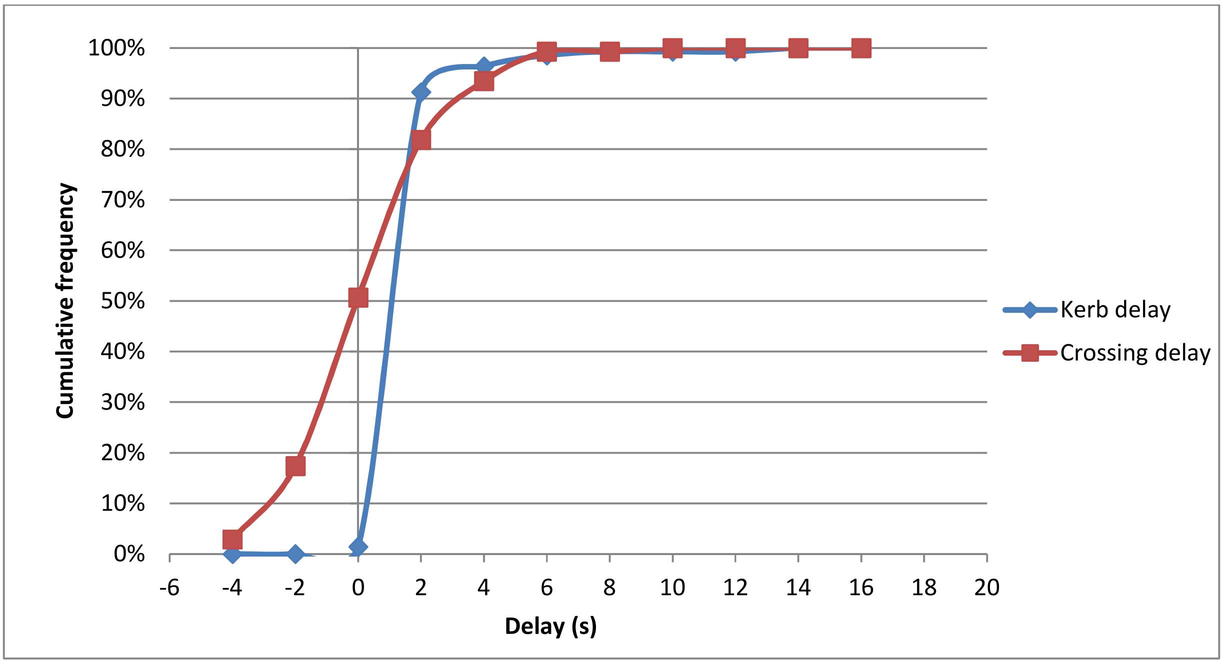

Figure 5-59: Cumulative distribution of kerb delay and crossing delay at unsignalised crossings on T-junctions

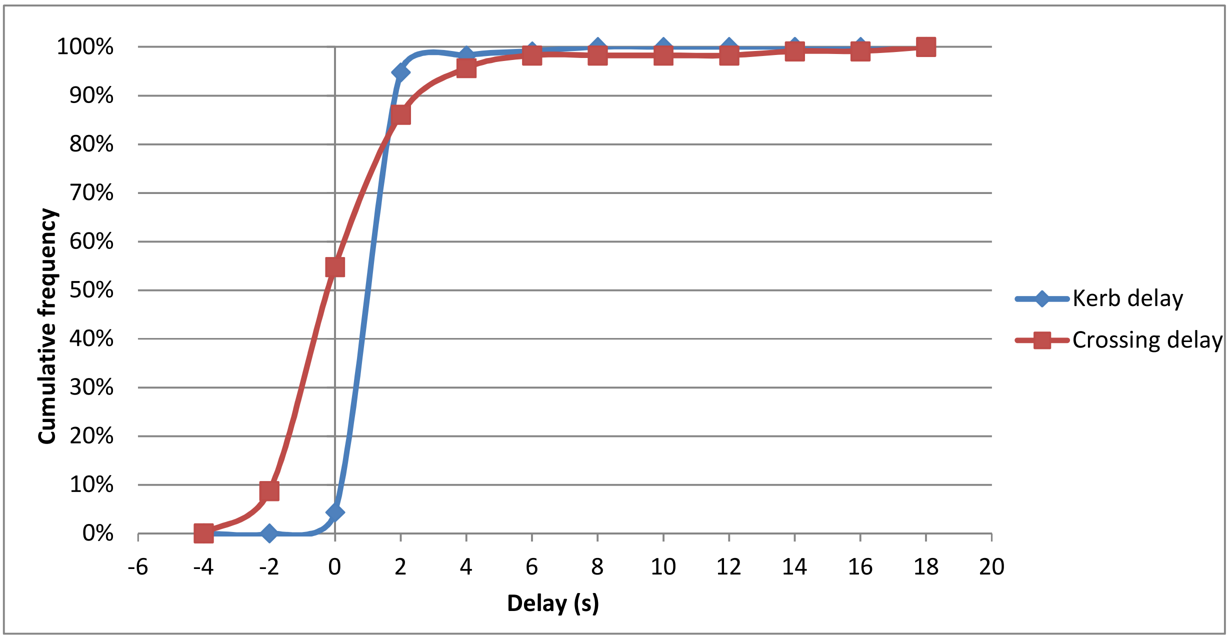

Figure 5-60: Cumulative distribution of kerb delay and crossing delay at unsignalised crossings on two-way and four-way-stop intersections

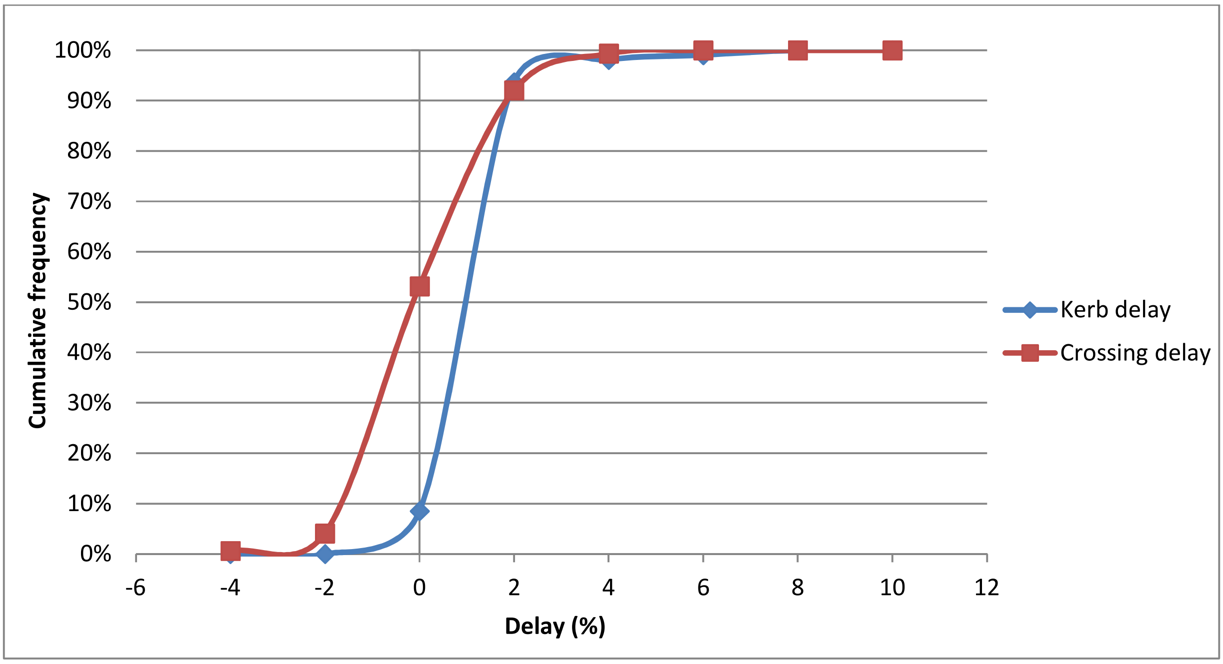

Figure 5-61: Cumulative distribution of kerb delay and crossing delay at unsignalised mid-block crossings on two-lane roads

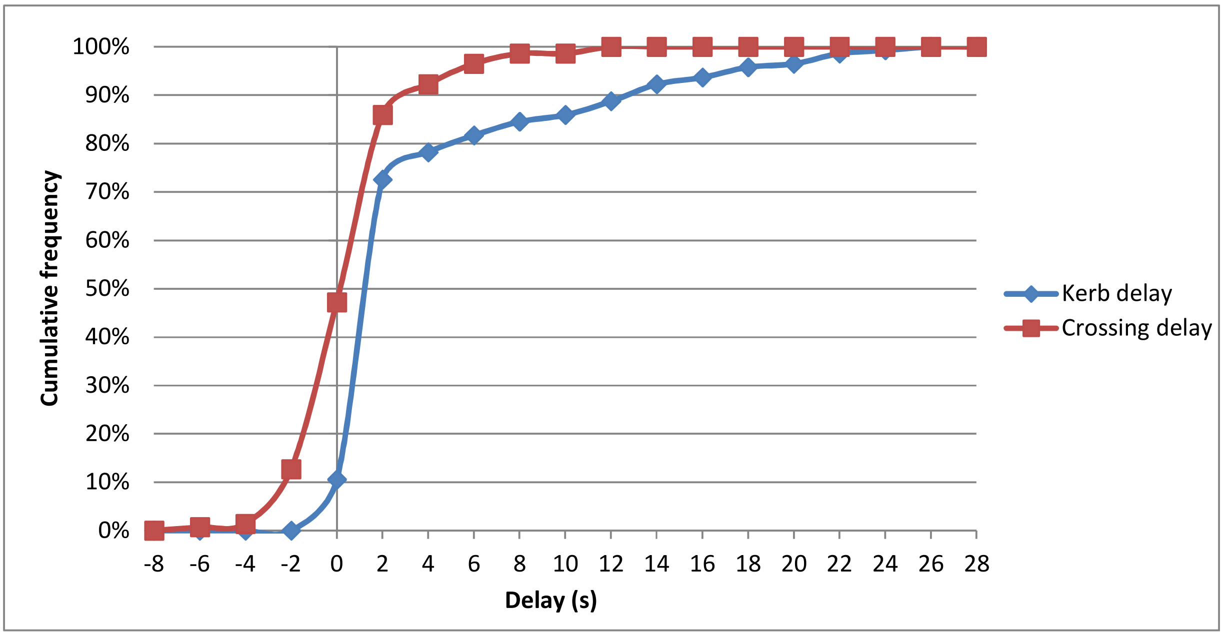

Figure 5-62: Cumulative distribution of kerb delay and crossing delay at unsignalised mid-block crossings on four-lane undivided roads

5.3.2. Effect of gender on pedestrian delay

Table 5-10 presents values of total delay by gender. Values of average delay and mean delay at all pedestrian crossing facilities revealed that females experienced longer delays than males, except in the case of signal-actuated crossings on four-lane undivided roads.

Table 5-10: Pedestrian total delay by gender

Category No	Gender	Number of pedestrians	%	Pedestrian total delay (s)		
				Mean delay	Average delay	Standard deviation
Category No 1	Male	168	168	3.65	6.91	11.63
	Female	68	68	5.70	12.39	14.40
Category No 2	Male	92	59	7.22	12.79	15.19
	Female	65	41	9.72	14.00	15.18
Category No 3	Male	72	52	0.84	0.61	2.31
	Female	66	48	2.00	3.13	3.08
Category No 4	Male	68	59	0.23	0.69	1.79
	Female	47	41	2.00	2.55	3.65
Category No 5	Male	163	52	0.89	1.18	1.62
	Female	153	48	1.20	1.78	1.68
Category No 6	Male	74	52	1.94	3.68	6.59
	Female	68	48	2.00	5.67	7.45

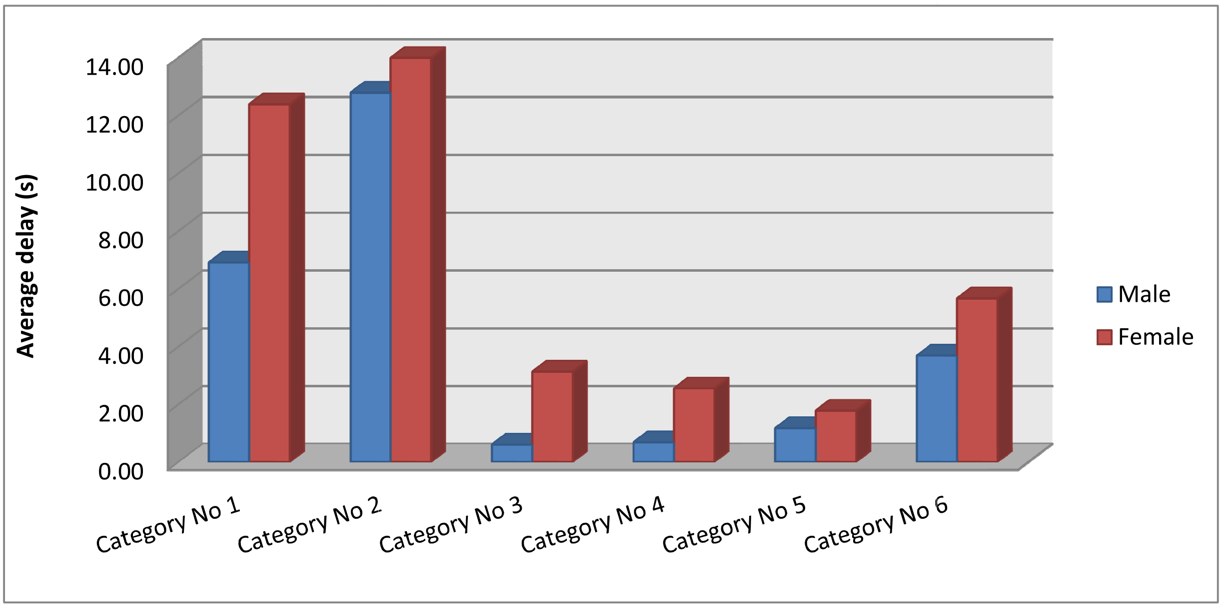

Figure 5-63: Average total delay per gender

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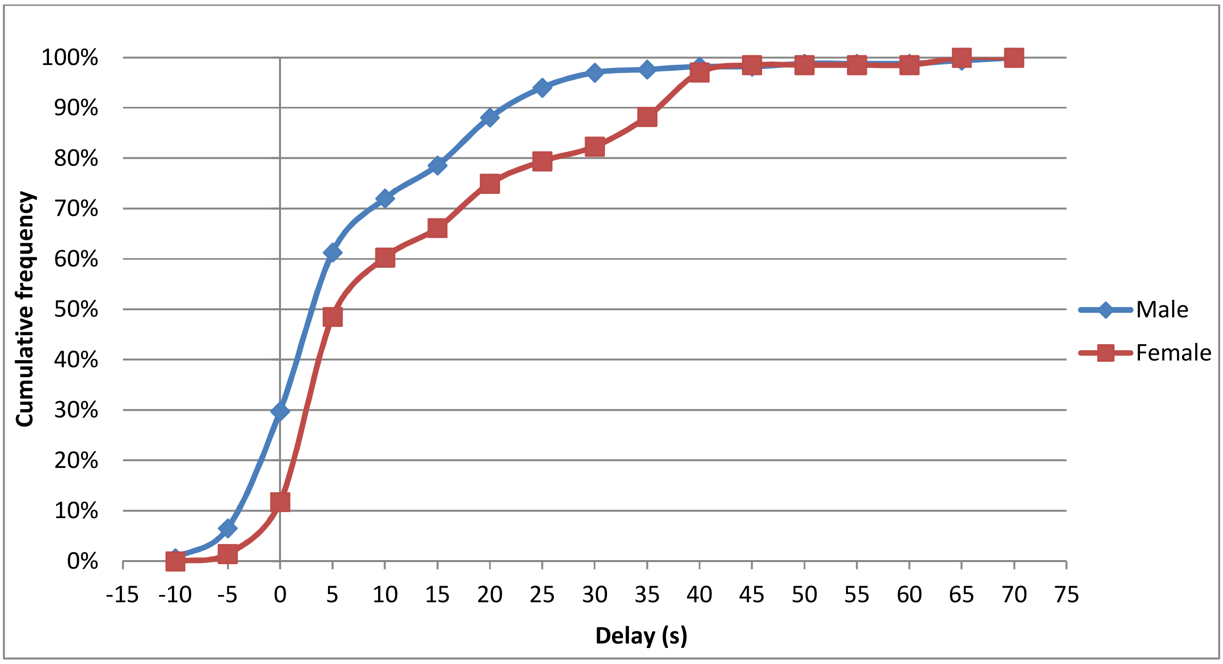

Figure 5-64: Cumulative distribution of the average total delay by gender at signal-actuated crossings on four-lane divided roads

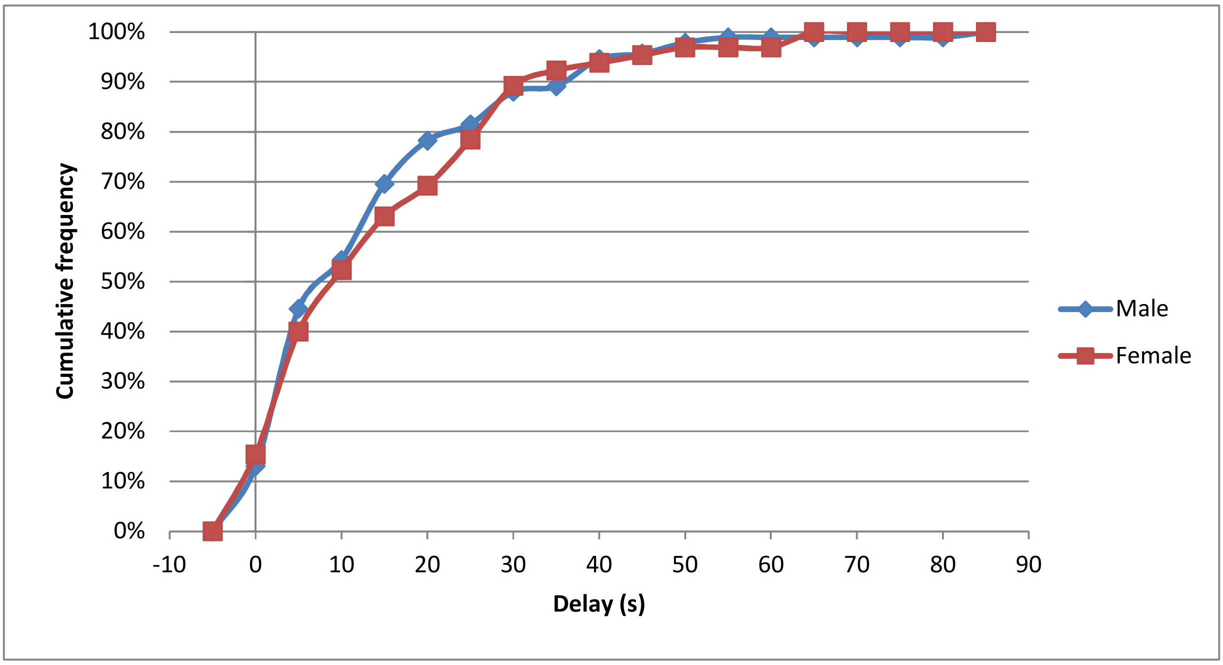

Figure 5-65: Cumulative distribution of the average total delay by gender at signal-actuated crossings on four-lane undivided roads

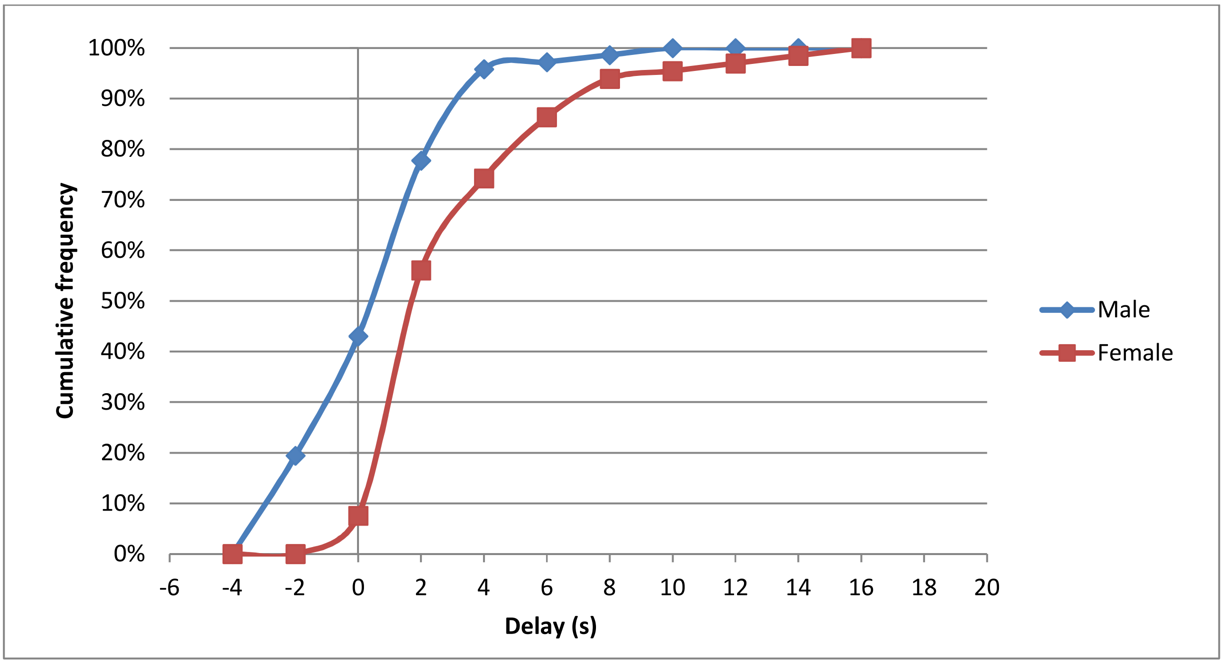

Figure 5-66: Cumulative distribution of the average total delay by gender at unsignalised crossings on T-junctions

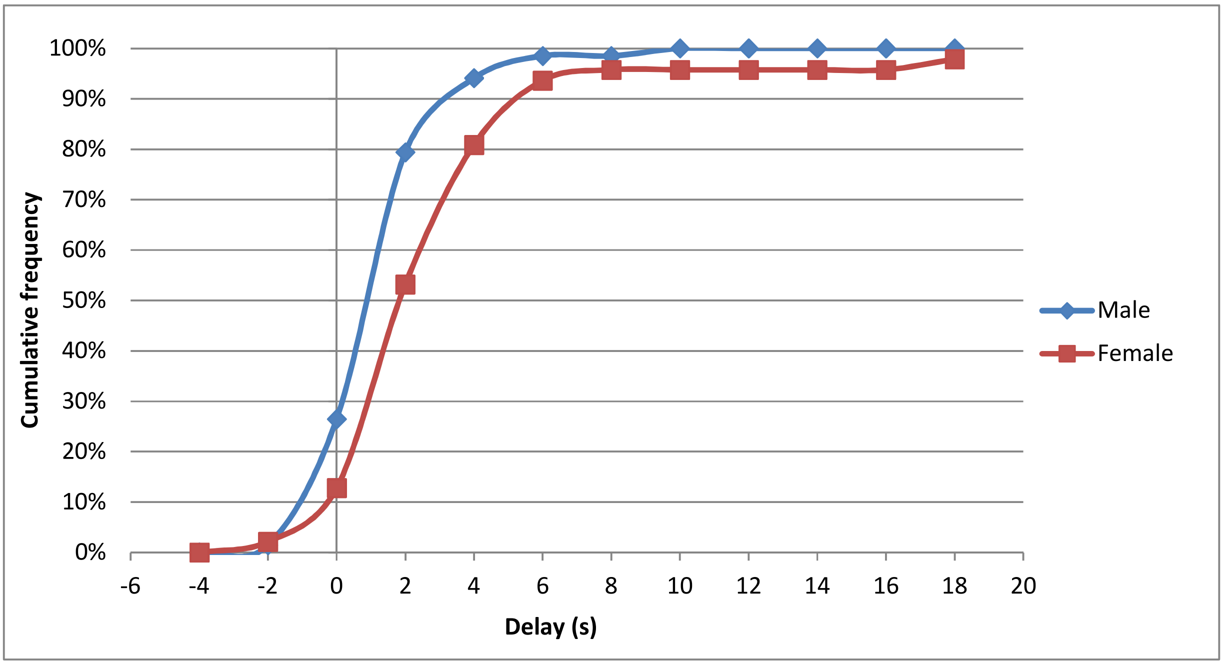

Figure 5-67: Cumulative distribution of the average total delay by gender at unsignalised crossings on two-way and four-way-stop intersections

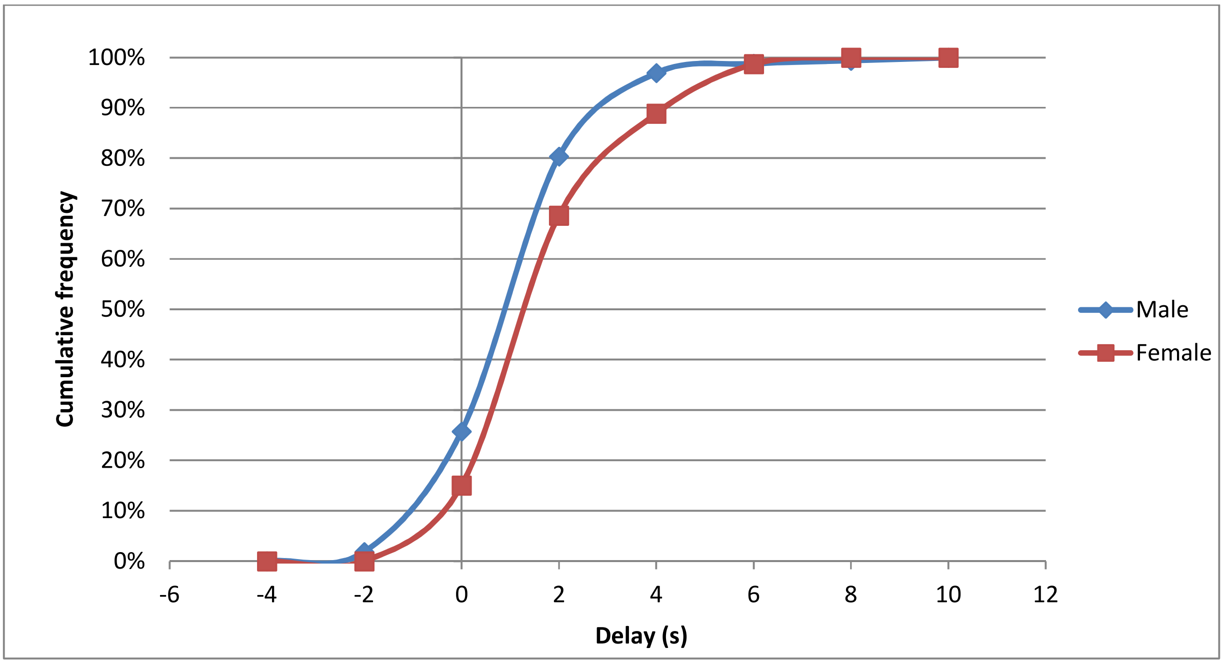

Figure 5-68: Cumulative distribution of the average total delay by gender at unsignalised mid-block crossings on two-lane roads

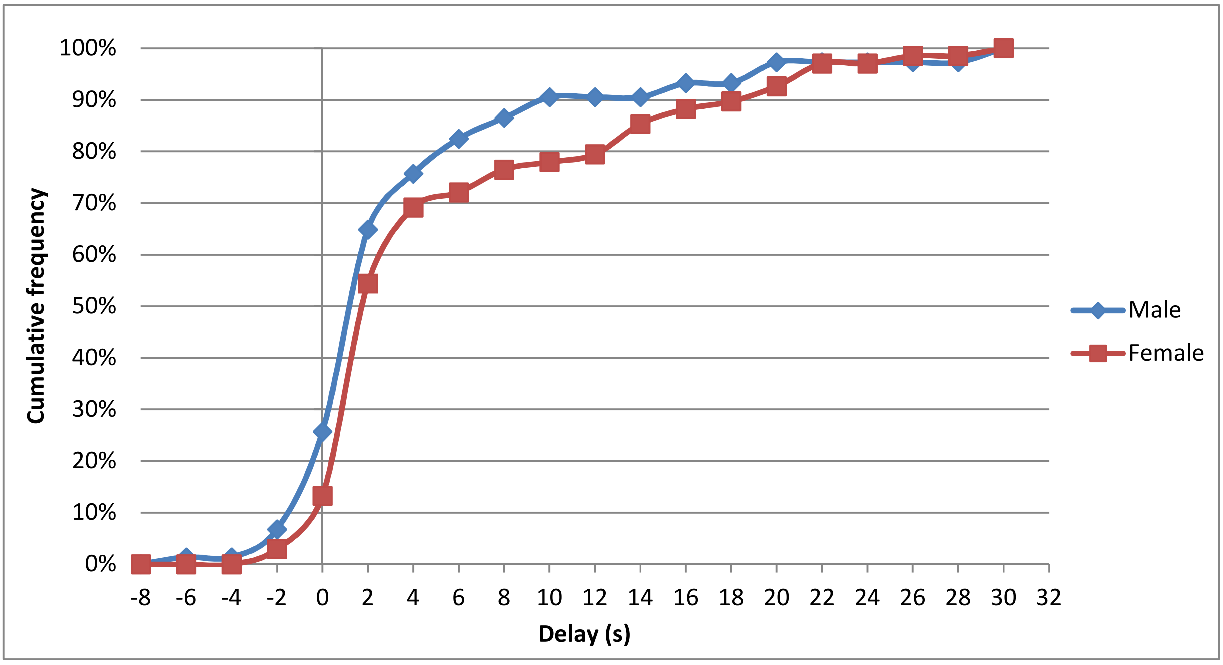

Figure 5-69: Cumulative distribution of the average total delay by gender at unsignalised mid-block crossings on four-lane undivided roads

5.3.3. Effect of age on pedestrian delay

Values of pedestrian delays are illustrated in Table 5-11 and the effect of gender on total pedestrian delay is highlighted in Figure 5-70. Older pedestrians were found to experience longer delays in Category No 2 (signal-actuated crossings on four-lane undivided roads), Category No 1 (signal-actuated crossings on four-lane divided roads) and Category No 6 (unsignalised mid-block crossings on four-lane undivided roads).

Table 5-11: Pedestrian total delay by age group

Category No	Age category	Number of pedestrians	%	Pedestrian total delay (s)		
				Mean delay	Average delay	Standard deviation
Category No 1	Younger	78	33	3.20	7.36	13.14
	Older	158	67	4.41	9.05	12.49
Category No 2	Younger	83	53	4.72	10.41	12.00
	Older	74	47	9.86	16.52	17.57
Category No 3	Younger	87	63	1.84	1.39	2.43
	Older	51	37	1.84	2.54	3.64
Category No 4	Younger	82	71	1.00	0.75	2.29
	Older	33	29	3.07	3.18	3.37
Category No 5	Younger	206	65	1.00	1.22	1.46
	Older	110	35	1.89	1.94	1.93
Category No 6	Younger	94	66	1.94	2.06	4.16
	Older	48	34	7.94	9.67	8.72

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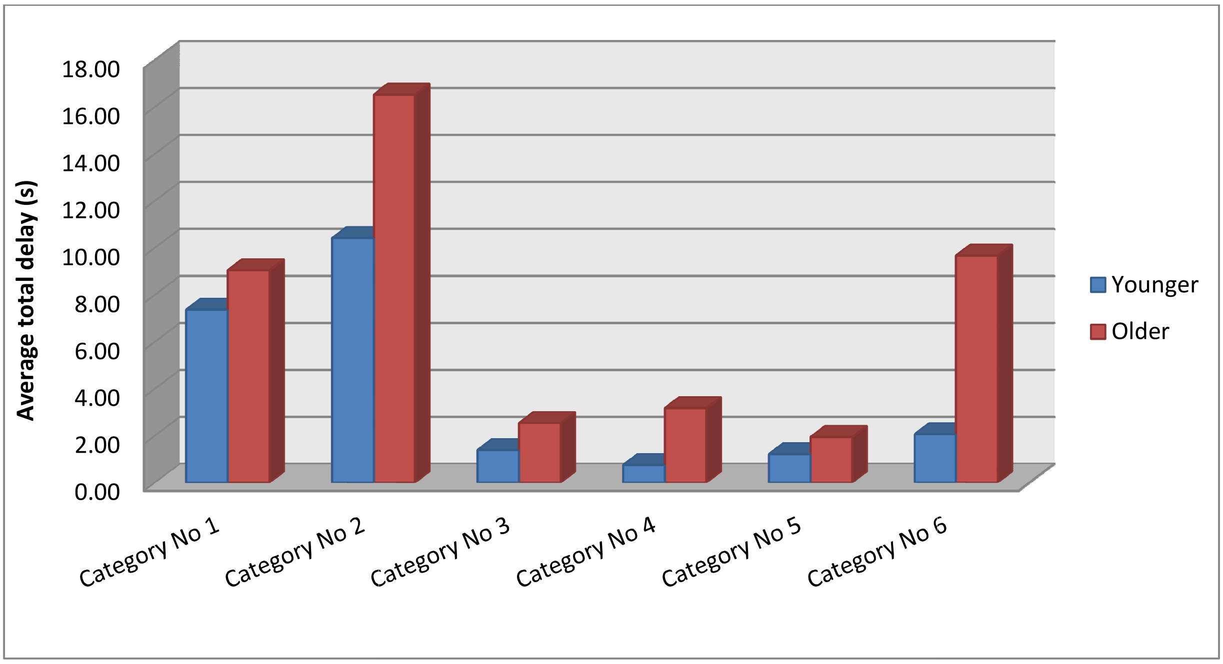

Figure 5-70: Average total delay by age group

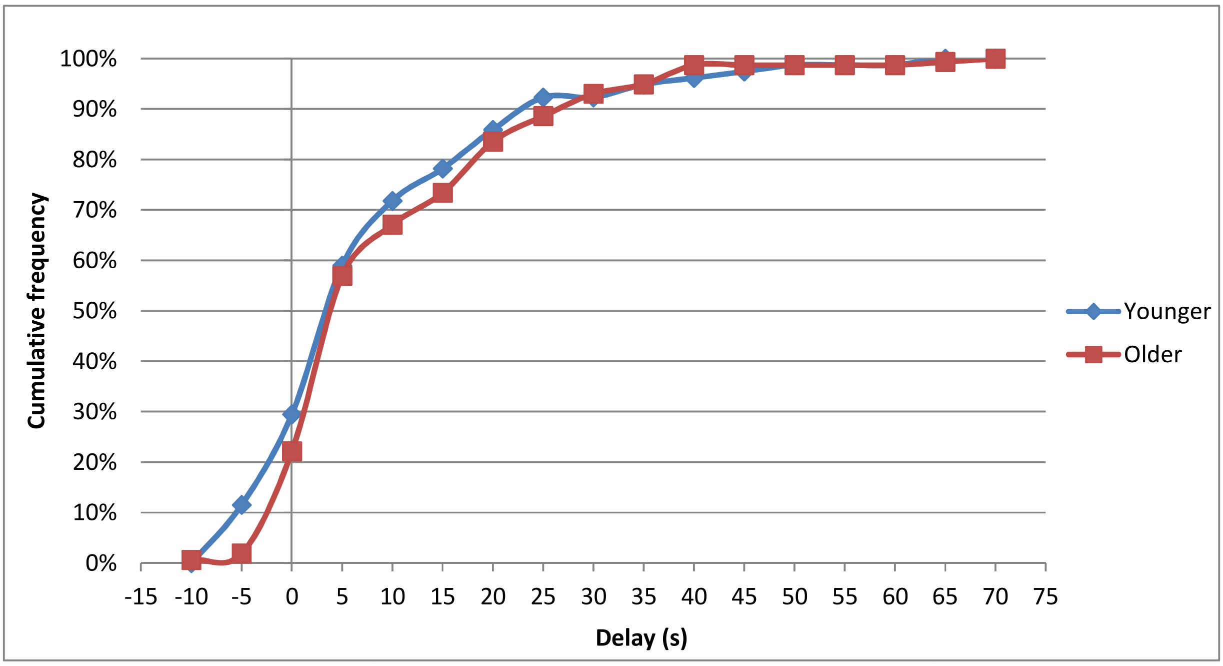

Figure 5-71: Cumulative distribution of the average total delay by age group at signal-actuated crossings on four-lane divided roads

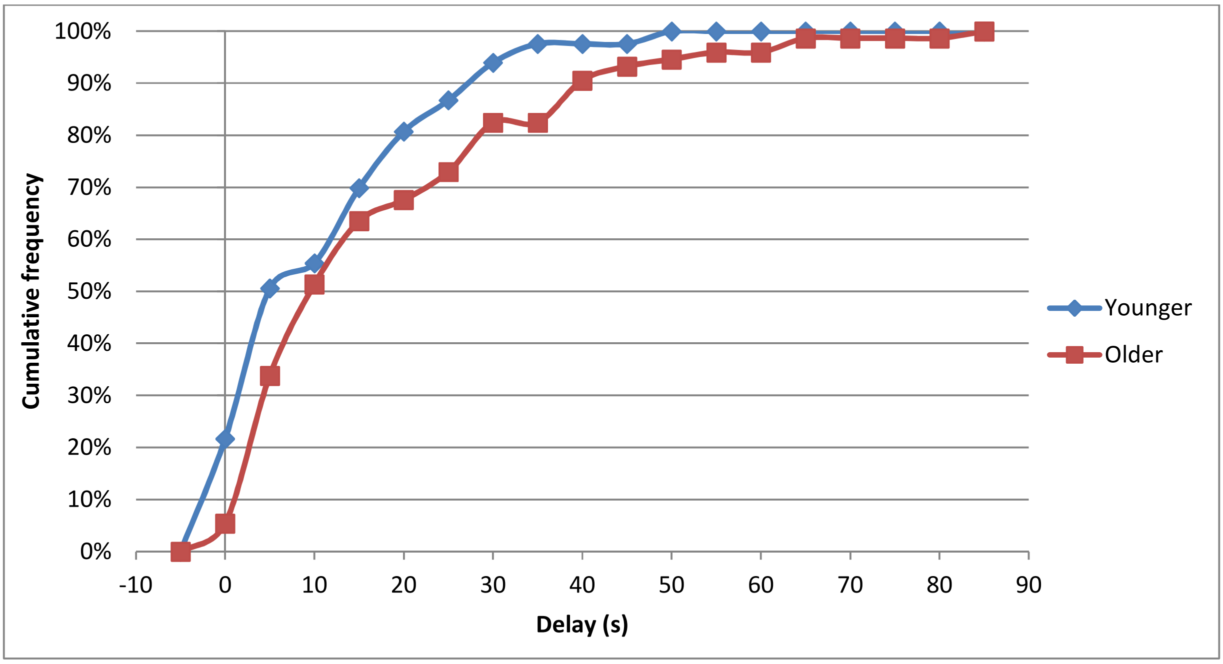

Figure 5-72: Cumulative distribution of the average total delay by age group at signal-actuated crossings on four-lane undivided roads

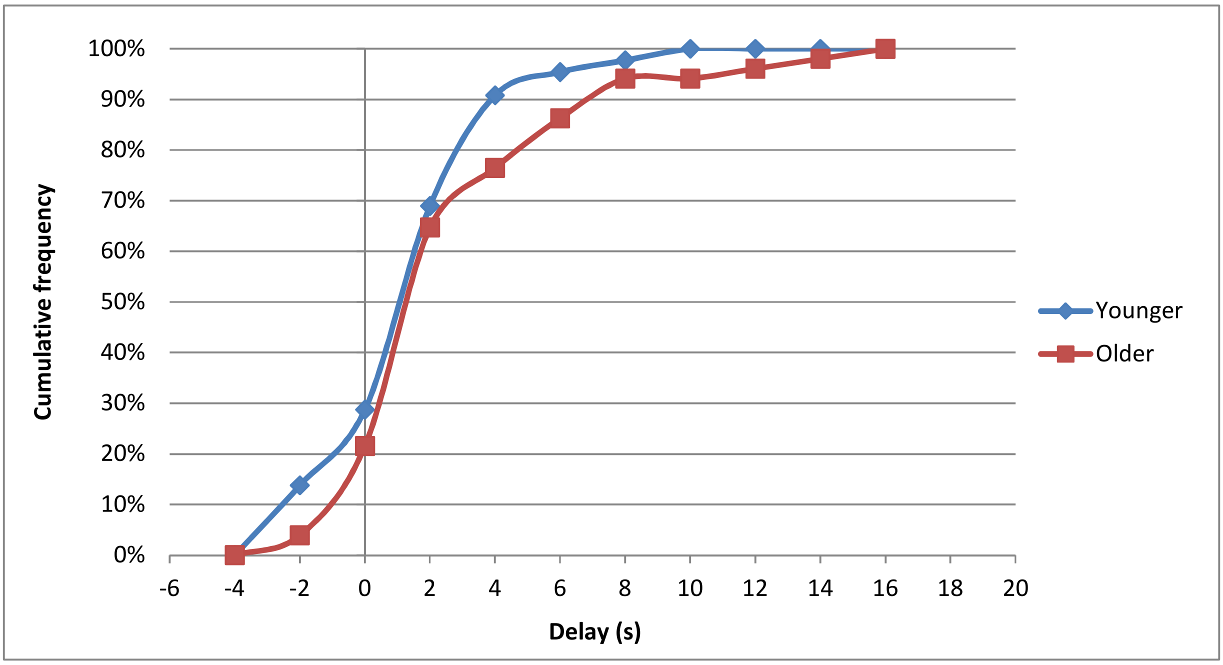

Figure 5-73: Cumulative distribution of the average total delay by age group at unsignalised crossings on T-junctions

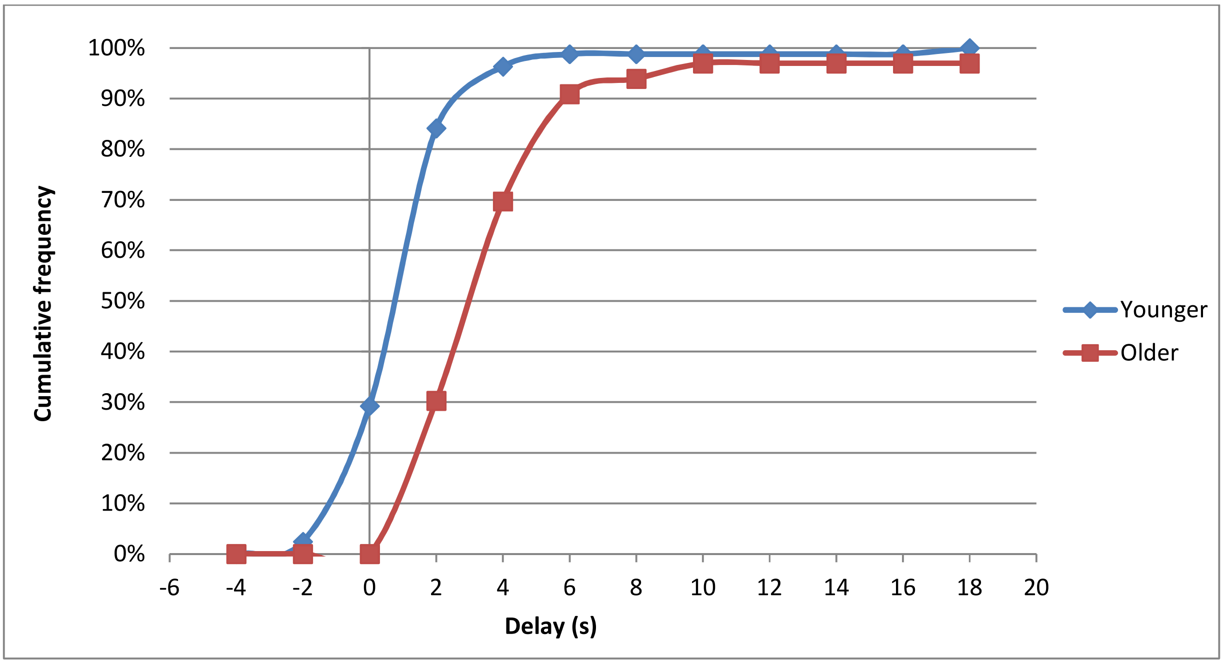

Figure 5-74: Cumulative distribution of the average total delay by age group at unsignalised crossings on two-way and four-way-stop intersections

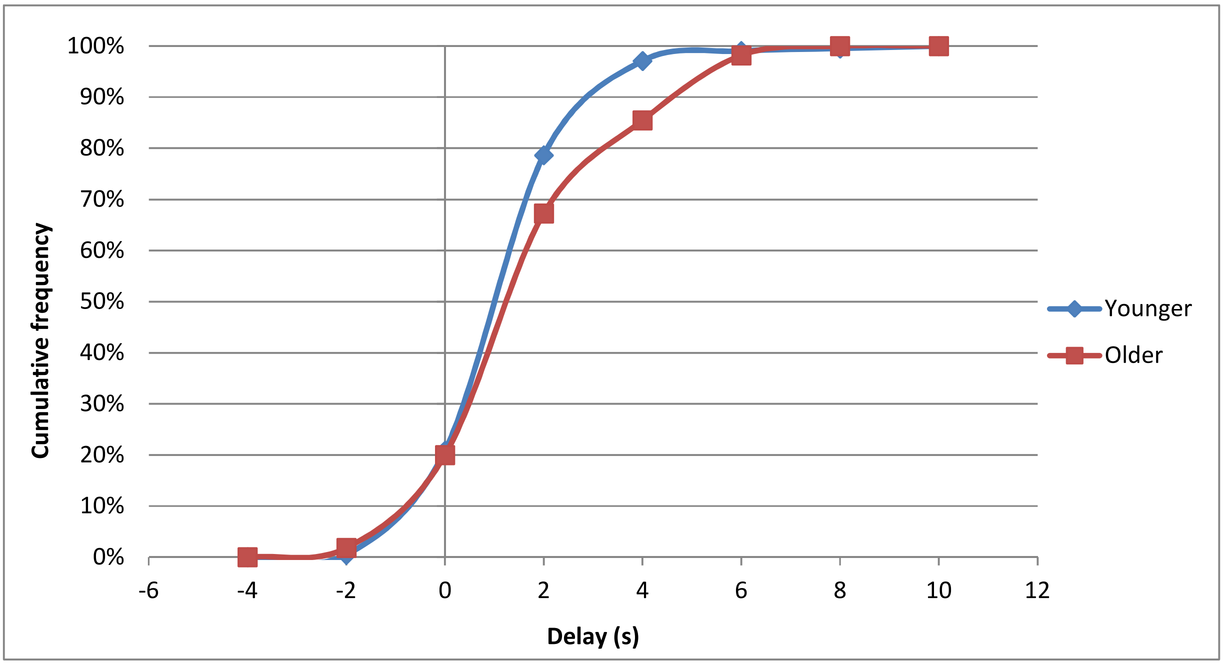

Figure 5-75: Cumulative distribution of the average total delay by age group at unsignalised mid-block crossings on two-lane roads

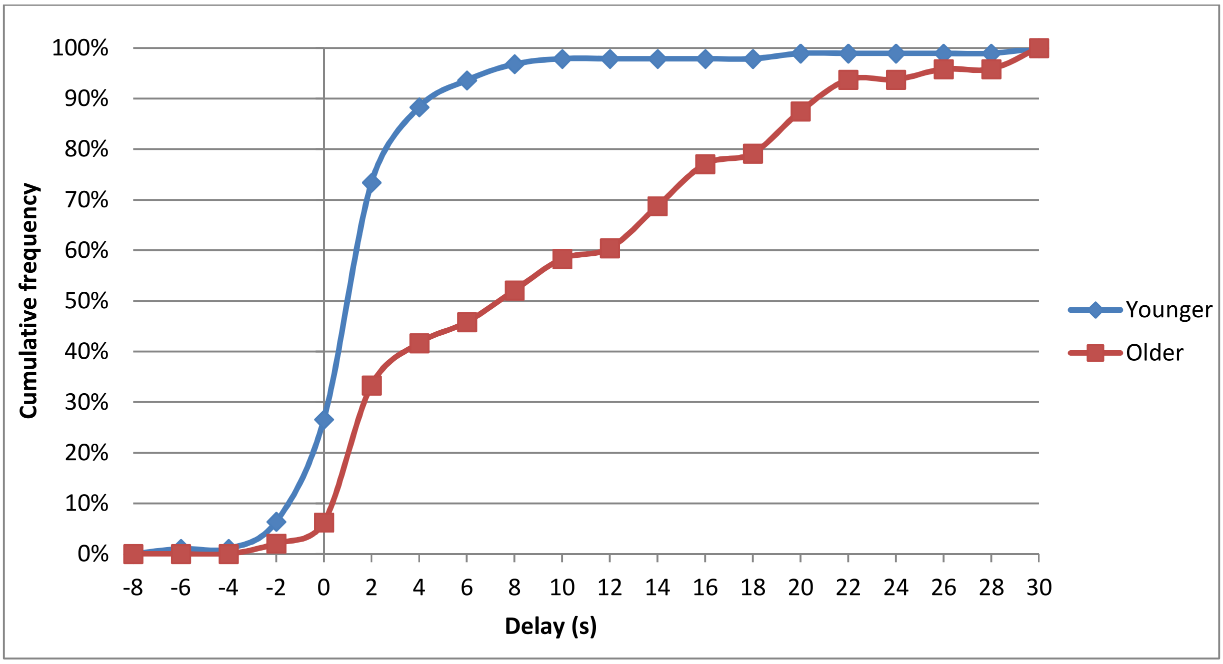

Figure 5-76: Cumulative distribution of the average total delay by age group at unsignalised mid-block crossings on four-lane undivided roads

5.3.4. The effect of traffic signal on pedestrian delay

Total delay was examined in Table 5-12 on the basis what traffic signal was displayed when the pedestrian arrived at the kerb. Pedestrians were found more likely to arrive at the kerb during the red man signal (see Figure 5-77) and it was during the same signal they became more delayed. Similarly, while the influence of the vehicle signal on the pedestrian delay was studied, a different situation was found: arrival in green vehicle signal was associated with higher delay as illustrated by Figure 5-78. Compliant pedestrians who crossed during the green man signal experienced shorter delays compared to those who violated the red man signal, except in Category No 1 (signal-actuated crossings on four-lane divided roads). The signal calling time and the start-up times for the two crossing groups are presented in Table 5-15.

Table 5-12: Average total delay per pedestrian arrival signal

Category No	Arrival signal	Number of pedestrians	%	Delay (s)	
				Average delay	Standard deviation
Category No 1	Steady red man	211	89	9.22	13.21
	Flashing red man	21	9	2.68	3.07
	Green man	4	2	0.35	1.77
Category No 2	Steady red man	150	96	13.89	15.23
	Flashing red man	4	3	1.72	2.00
	Green man	3	2	-1.00	1.73

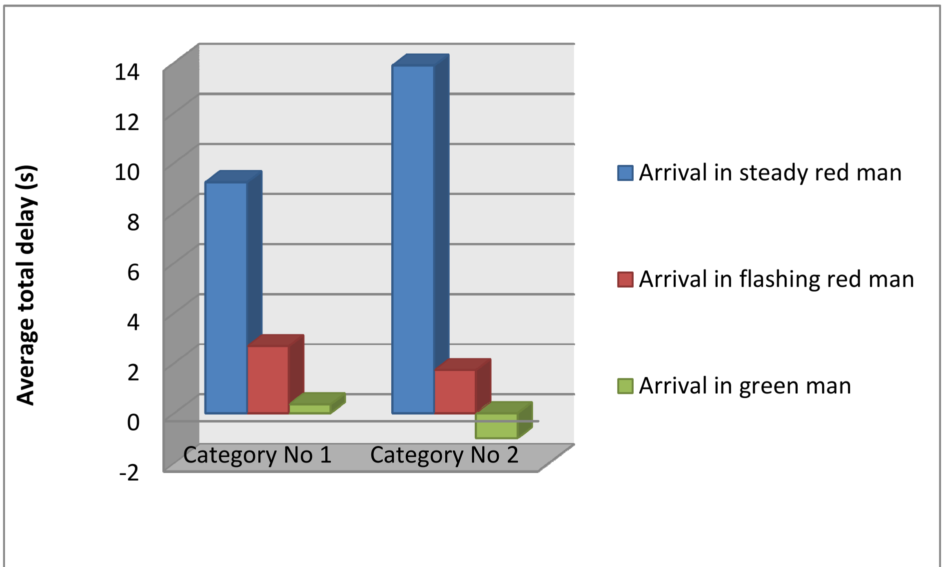

Figure 5-77: Average total delay per pedestrian arrival signal

Table 5-13: Average total delay per arrival vehicle signal

Category No	Arrival signal	Number of pedestrians	%	Delay (s)	
				Average delay	Standard deviation
Category No 1	Vehicle green signal	110	47	13.49	12.55
	Vehicle red signal	126	53	4.13	11.17
Category No 2	Vehicle green signal	94	60	17.86	15.47
	Vehicle red signal	63	40	6.48	11.81

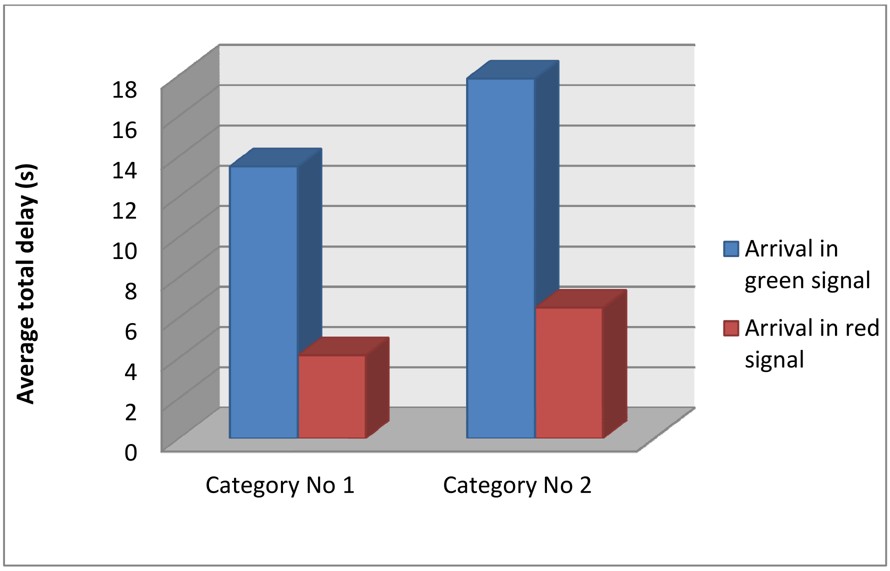

Figure 5-78: Average total delay per arrival vehicle signal

Table 5-14: Average total delay per crossing pedestrian signal

Group No	Crossing signal	Number of pedestrians	%	Total delay (s)	
				Average delay	Standard deviation
Category No 1	Steady red man	205	87	8.77	12.93
	Flashing red man	21	9	2.68	3.07
	Green man	10	4	15.07	16.56
Category No 2	Steady red man	129	82	11.84	13.85
	Flashing red man	5	3	18.12	36.71
	Green man	23	15	20.36	13.99

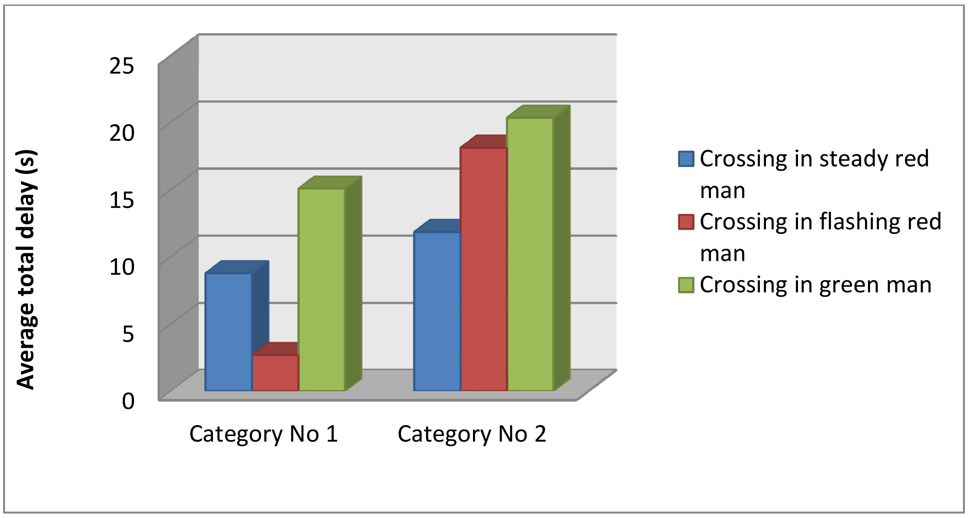

Figure 5-79: Average total delay per crossing pedestrian signal

Table 5-15: Signal calling time and start-up time

Category No	Average calling time (s)	Standard deviation(s)	Start-up time (s)	Standard deviation (s)
Category No 1	43.25	26.97	2.78	1.30
Category No 2	31.53	20.48	3.05	6.28

5.3.5. Discussion-Pedestrian delay

Kerb delay peaked at three crossing facility categories, namely Category No 2 (signal-actuated crossings on four-lane undivided roads), Category No 1 (signal-actuated crossings on four-lane divided roads) and a small peak emerged in Category No 6 (unsignalised mid-block crossings on four-lane undivided roads). The common characteristic of these crossing facilities are wide road (four-lane roads) with high traffic volume. In the same category of unsignalised pedestrian crossings, crossings located on four-lane road were the ones which exhibited higher values of kerb delay and total delay. This emphasizes a significant influence of crossing distance on pedestrian delay. Category No 1 and Category No 6 were both characterized by fast-moving vehicles. This may suggest a relationship between the kerb delay, crossing distance and vehicle speed. Negative values of crossing delay explains directly the higher walking speed at the crossing facility whereas higher values of crossing delay are associated with conflict situations such as stopping or slowing down while crossing as shown by Figure 5-83. The highest proportions of the kerb delay and the total delay were found at the signalised intersections (i.e. Category No 1 and Category No 2). This suggests that the traffic signals significantly increased the total and the kerb delays.

It was revealed in this study that females had longer delays than males at all crossing facility categories. This finding indicates that females are more patient than males in traffic situations. Risk taking behaviour in traffic situations predominantly found among males may explain this finding. Similarly, older pedestrians were delayed more than younger pedestrians. The same reason may explain also the revealed age differences in pedestrian delay. Younger pedestrians are likely to be impulsive in traffic situations than older pedestrians. The effect of age on pedestrian delay was found significant at wider mid-block crossings as shown by Figure 5-70 and Figure 5-76. The delay distribution for both age and gender presented the similar peaks. This again supports the strong effect of the type of pedestrian crossing on total delay experienced by pedestrians.

As violating the red man signal was the common crossing behaviour at the two signalised intersections (Category No 1 and Category No 2), the majority of delays experienced may be associated with finding a gap in the traffic stream rather than waiting for the green man signal. The effect of traffic volume in this context may be indirectly implicated. The traffic signals during which the pedestrian arrived and crossed the road significantly influenced pedestrian delay. Pedestrians who arrived during the vehicle green phase were more delayed than those who arrived during the red phase. Given that the rate of traffic signal compliance was significantly low (see Figure 5-79) pedestrians who arrived during the vehicle green phase were not delayed as a result of waiting for the pedestrian green signal. They were waiting, rather, to find an acceptable gap in the traffic stream.

Arriving during the red vehicle signal was found to be associated with reduced delays. In this context, pedestrians who arrived when vehicles were stopped tended to cross immediately regardless the state of the pedestrian signals. Shorter delays observed in Category No 1 (signal-actuated crossings on four-lane divided roads) may be related to the higher walking speeds (running behaviour) frequently observed at this type of crossing facility. Those who violated the red man signal were the ones who gained more time because they were probably aware of the risk associated with their unsafe behaviour and adjusted their crossing speeds accordingly. The values of signal calling time reflect the amount of time a compliant pedestrian would wait for the green man signal to be displayed. Those values were found to be significantly higher than the average total delay experienced at the same crossing facility (see Table 5-15). This suggests that crossing against the red man signal is associated with saving in time. As an example, in Category No 1 (signal-actuated crossings on four-lane divided roads), pedestrians who crossed against the red man signal gained 35 seconds that they would have spent if they had crossed during the green man signal. The corresponding value in Category No 2 (signal-actuated crossings on four-lane undivided roads) was found to be 19 seconds.

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The average value of start-up times revealed in this study was similar to the value of 3 seconds recommended in The Highway Capacity Manual (HCM). That is, pedestrians who crossed at signalised crossings during the green man signal had an average delay of about 3 seconds between the time the green man signal was displayed and the time they started crossing the road.

5.4. Pedestrian gaze behaviour

5.4.1. Number of head movements

The average number of head movements in each direction is presented in Table 5-16. The average number of head movement peaked in Category No 2 (signal-actuated crossings on four-lane undivided roads), followed by Category No 1 (signal-actuated crossings on four-lane divided roads). Another small peak was found in Category No 6 (unsignalised mid-block crossings on four-lane undivided roads). In Category No 6 (unsignalised mid-block crossings on four-lane undivided roads), pedestrian gaze targets were found in three directions only. When the total number of head movements were plotted at every crossing facility category, more observations were found to be performed when pedestrians were crossing than when they were waiting at the kerb (see Figure 5-82). Few head movements at the kerb were found at the crossings located at T-junctions (Category No 3).

Table 5-16: Average number of head movements at the kerb

Category No	Head movements at the kerb				
	Right	Left	Back	Ahead	Total
Category No 1	2	2	1	1	4
Category No 2	2	2	1	2	5
Category No 3	1	1	1	1	2
Category No 4	1	1	1	1	2
Category No 5	1	1	1	1	3
Category No 6	1	2	1	1	3

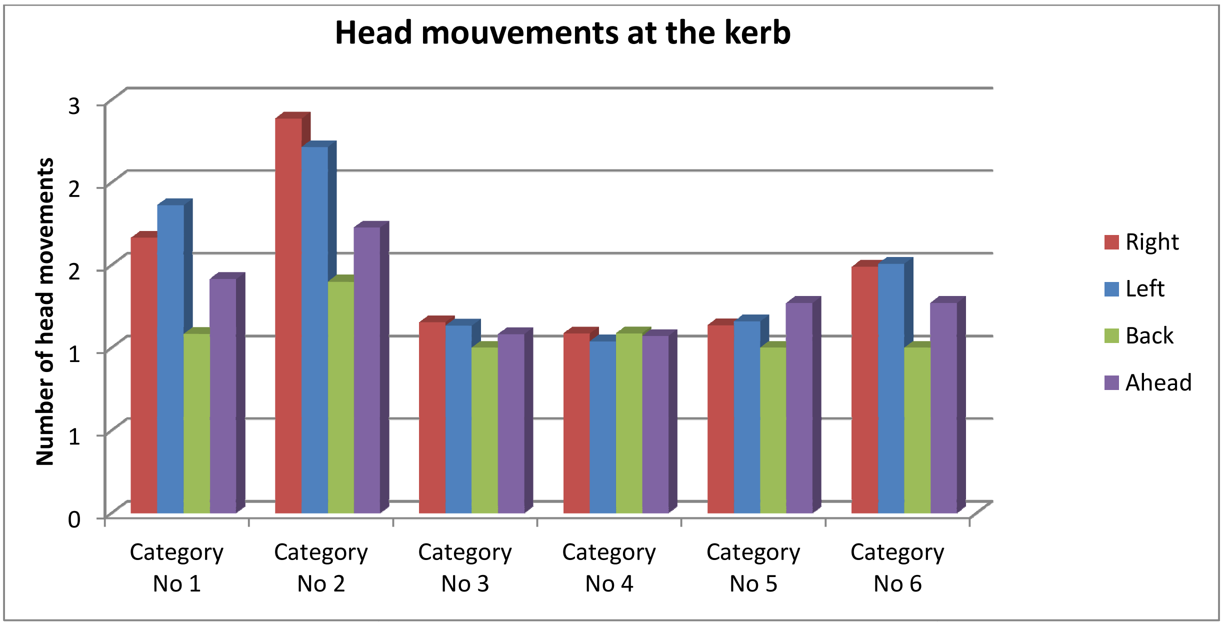

Figure 5- 80: Average number of head movements at kerb

Table 5-17: Average number of head movements while crossing

Category No	Head movements while crossing				
	Right	Left	Back	Ahead	Total
Category No 1	1	2	1	2	3
Category No 2	2	2	1	3	6
Category No 3	1	1	1	2	4
Category No 4	1	1	1	2	4
Category No 5	1	1	1	2	3
Category No 6	1	2	0	3	6

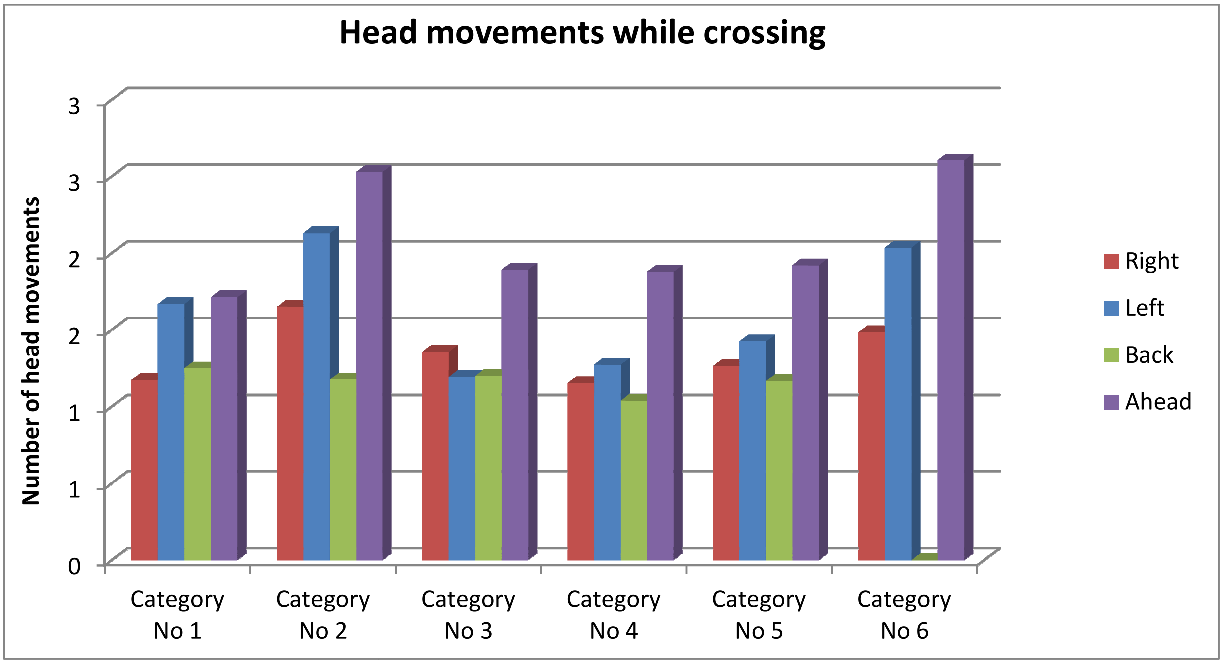

Figure 5- 81: Average number of head movements while crossing

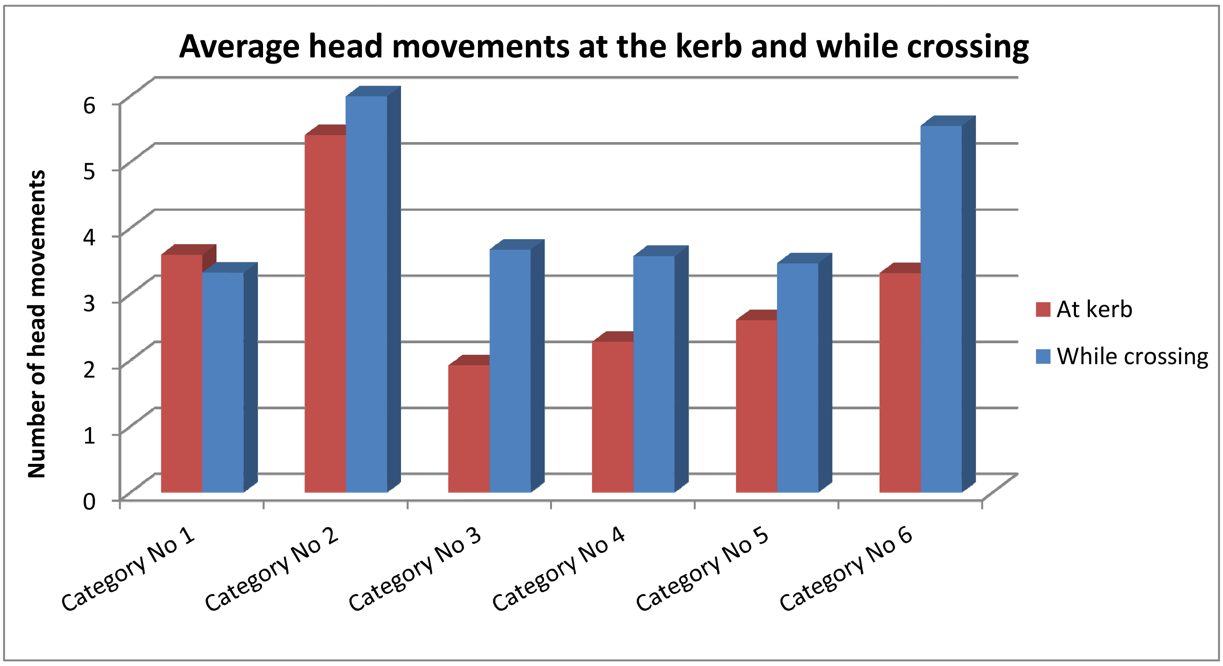

Figure 5-82: Comparison of average head movements at kerb and while crossing

5.4.2. Discussion-Gaze behaviour

The analysis of head movements revealed that pedestrians tend to look predominantly in the direction of a possible threat. While standing at the kerb, pedestrians directed more attention to near-side traffic (right hand) to check approaching vehicles. This is the reason of higher number of pedestrian looking directed to the right hand. A minimum of 4 head movements is recommended in The Highway Code; look to the right side, look to the left side, to look to the right side again and to the ahead position (Schoon, 2010). Following this crossing rule, we can say that the total number of head movements less than 4 is insufficient for a safe crossing decision. This may lead to the conclusion that proper gaze behaviour was performed only at in Category No 1 (signal-actuated crossings on four-lane divided roads) and Category No 2 (signal-actuated crossings on four-lane undivided roads). Given that the number of head movement was found higher at crossings located on four-lane roads (see Figure 5-82), a close relationship between the number of head movements and crossing distance may exist. However, the time focused on any direction may be important while studying pedestrian gaze behaviour. It was observed that some pedestrians focused for longer periods on a single direction and others performed many looks in short time. Not too much is known about the amount of information processed in those two different situations.

5.5. Conflict study

5.5.1. Result presentation

Table 5-18 presents the percentages of observed conflicts at the pedestrian crossings. Running was the most frequent evasive action adopted by pedestrians in conflict situations, followed by midway stopping. Asking priority by using a hand sign was another conflict measure adopted in this study and was observed mainly at unsignalised pedestrian crossings (see Figure 5-83).

Table 5-18: Percentages of observed conflicts at pedestrian crossings

Category No	Step back to kerb (abortion of crossing)	Midway stopping	Running	Slowing down while crossing	Asking for priority by using hand sign
Category No 1	3	6	35	4	1
Category No 2	1	27	17	17	1
Category No 3	0	9	2	0	0
Category No 4	0	3	1	1	1
Category No 5	1	1	5	3	6
Category No 6	3	7	13	9	8

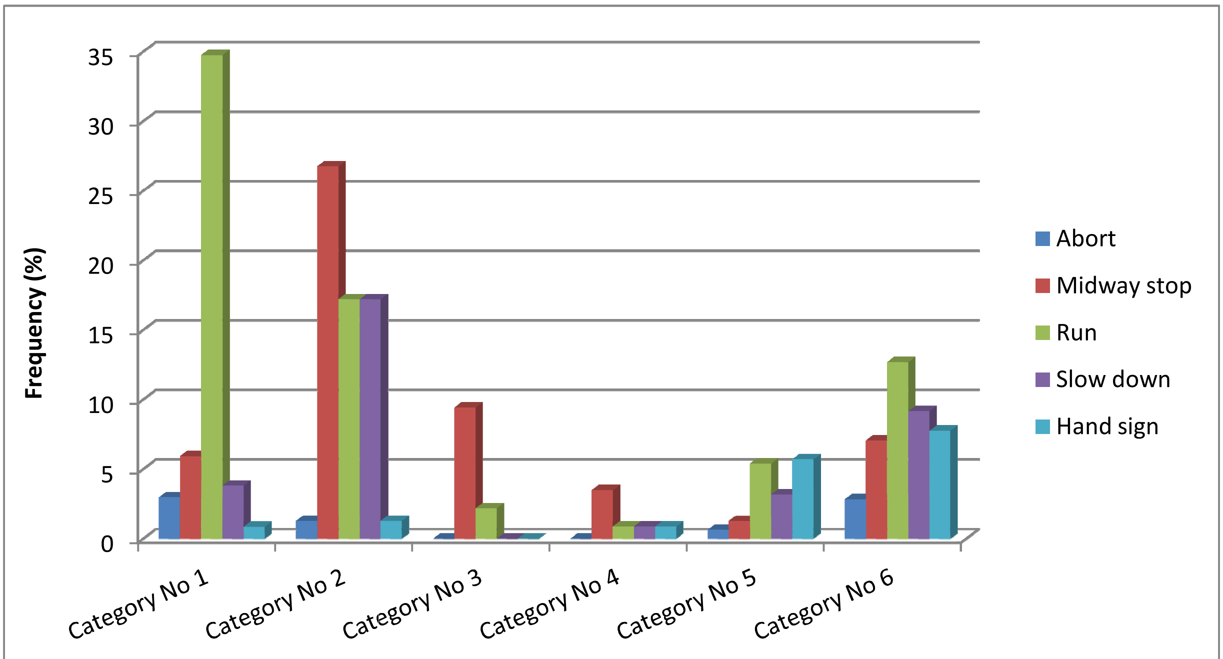

Figure 5-83: Distribution of observed conflicts at pedestrian crossings

5.5.2. Discussion-Conflicts

The analysis of conflicts data revealed a relationship between the number of conflicts and geometric and operational characteristics of the pedestrian crossings. Using a hand sign to request priority was more frequently observed at wider unsignalised mid-block crossings. The use of hand sign was found in two different contexts. Firstly, it was a pedestrian crossing at an unsignalised mid-block or at an intersection who realized that a driver was not willing to stop. In this context, a hand sign was used to impose the right-of-way to the motorist. Secondly, a hand sign was used when a pedestrian had performed an unsafe crossing behaviour such as violating the red man signal or crossing outside the pedestrian crossing. In this context, the hand sign was given as a way to beg tolerance from the motorist who has the right-of-way over the pedestrian. In some instances, motorists also used a hand sign to grant the right-of-way to pedestrians who were hesitant to cross the road.

5.6. Compliance behaviour

5.6.1. Observational study

Table 5-19 illustrates the proportions of pedestrians who stopped at the kerb to check the traffic before crossing the road and the proportions of those who continued without stopping. The failure to stop at the kerb before crossing was found to be the most unsafe crossing behaviour (see Figure 5-84). Stopping at the kerb has emerged in higher proportions in the crossing groups located at wider roads (Category No 2, Category No 1 and Category No 6). A high rate of red light violation is evident in Table 5-19 and Figure 5-86. The rate of red light violation in the two groups varied from 82 percent to 87 percent.

Table 5-19: Percentages of crossing tactics at pedestrian crossings

Category No	Stopped at the kerb	Continued without stopping	Starting the crossing in the marked area	Ending the crossing in the marked area
Category No 1	49	51	70	61
Category No 2	67	31	89	72
Category No 3	16	84		
Category No 4	20	81		
Category No 5	26	75	92	77
Category No 6	35	65	96	95

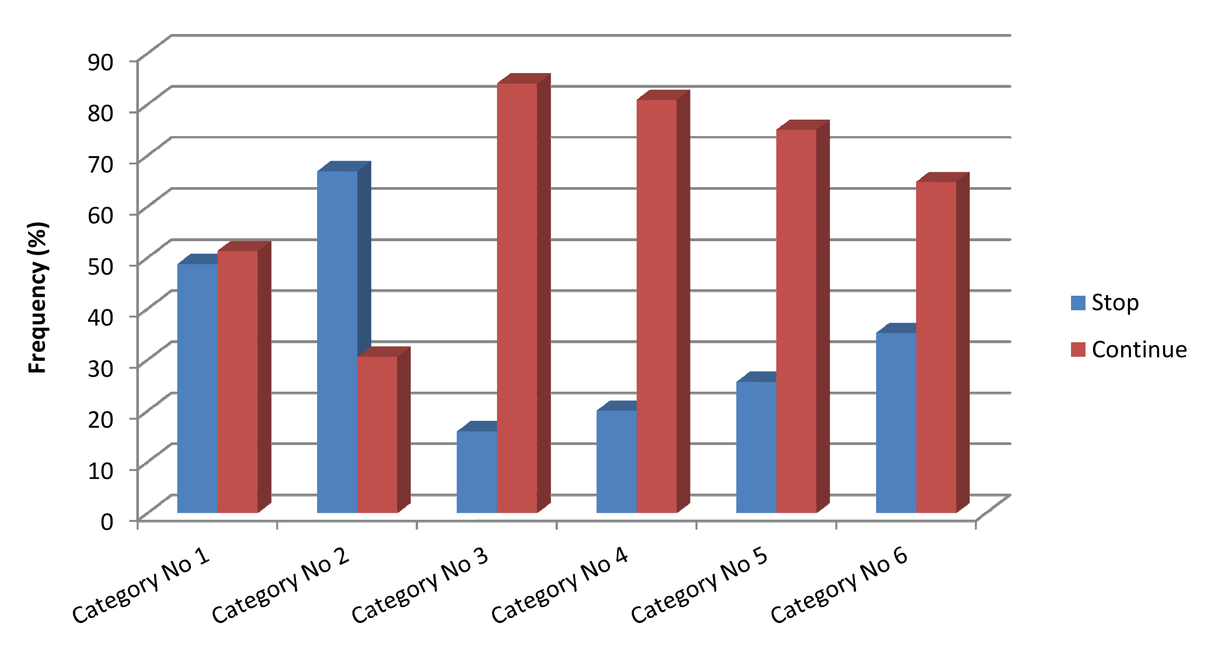

Figure 5-84: Distribution of crossing tactics at pedestrian crossings

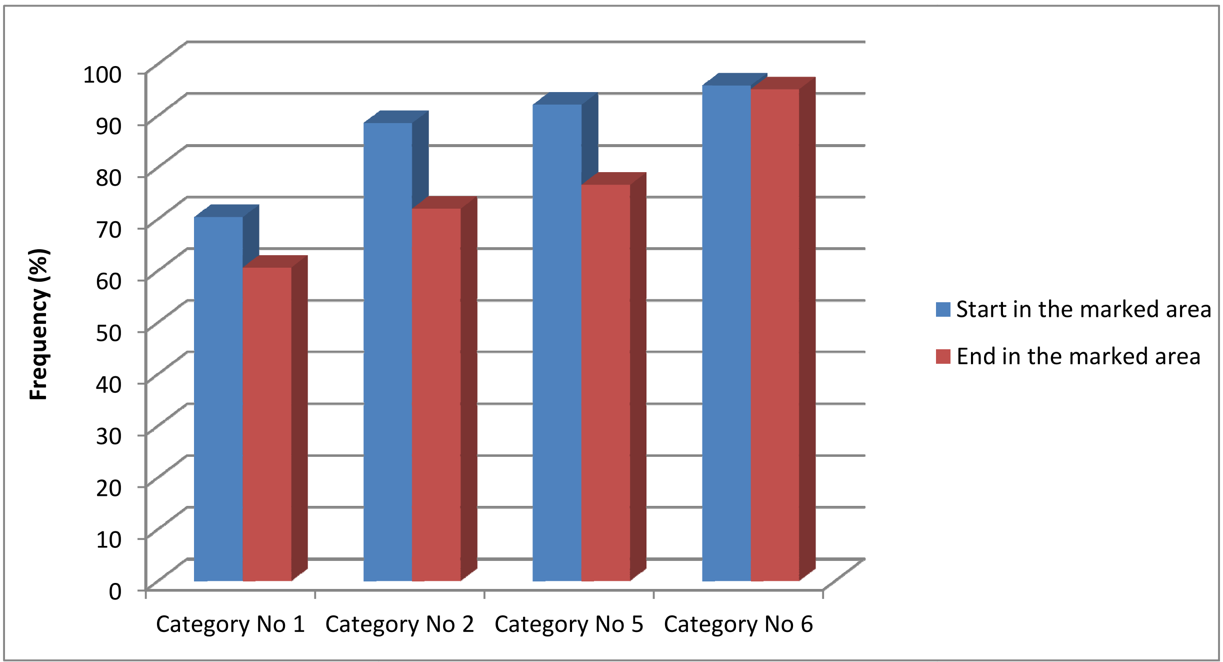

Figure 5-85: Distribution of crossing tactics at pedestrian crossings

Table 5-20: Percentages of signal compliance behaviour

Category No	Crossing signal		
	Steady red man	Flashing red man	Green man
Category No 1	87	9	4
Category No 2	82	3	15

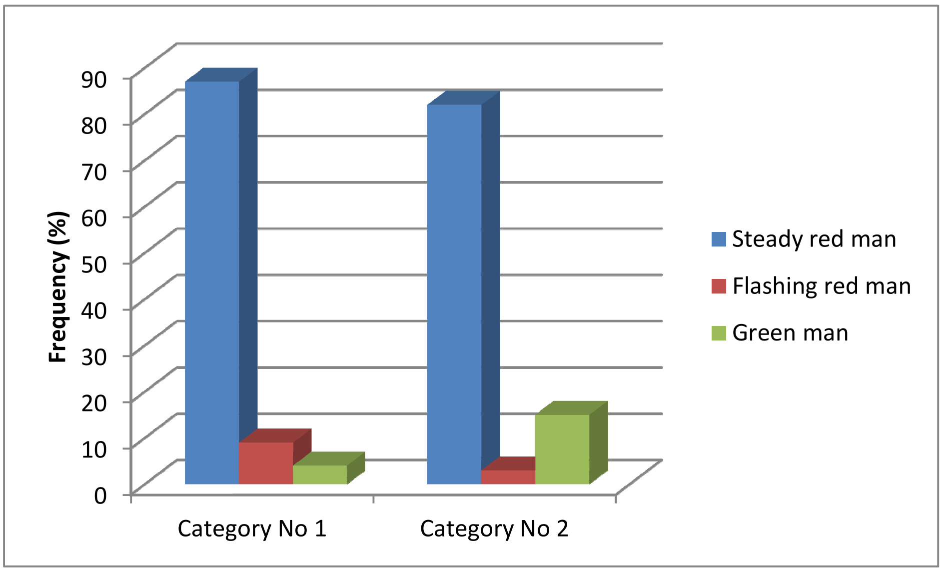

Figure 5-86: Distribution of signal compliance behaviour.

5.6.2. Discussion-Compliance behaviour

It is required that pedestrians have to first stop at the kerb to check whether the traffic has stopped before they start crossing. While crossing, pedestrians have to walk between the markings or over the studs. At signalised crossings, pedestrian have to start crossing only when the green signal is displayed and they are not supposed to be in the crossing when the signal turns to steady red man. Following these basic crossing rules, it was revealed in this study that the majority of observed pedestrians at every crossing facility failed to stop before they started crossing. The lowest percentages of pedestrians who continued without crossing were found at in Category No 2 (signal-actuated crossings on four-lane undivided roads) and in Category No 1 (signal-actuated crossings on four-lane divided roads). However, it seems that high traffic volumes caused this observed behaviour more significantly than simple disobedience. On the other hand, stopping was predominantly observed at the two-lane roads as shown by Figure 5-84. These two findings lead to conclude that kerb stopping behaviour is associated with crossing distance. It was generally observed from the video observations that the majority of pedestrians start checking the oncoming traffic at a certain distance from the kerb and reached the kerb after processing the necessary information. At this point, their crossing decision has already been made. The crossing Category No 3 and Category No 4 are unmarked and the use of marked area by pedestrians who were crossing was not investigated. The distribution of crossing behaviour exhibited in Figure 5-85 indicates that some pedestrians started crossing in the marked area but they did not end the crossing in the marked area. It was only in Category No 6 (unsignalised mid-block crossings on four-lane undivided roads) where those who started crossing in the marked area finished their crossing in the marked area.

5.6.3. Survey

While the observational research allowed a description of the crossing behaviours of pedestrians to be developed, it did not allow for explanations into motives for the behaviour of individuals. As such it was decided to incorporate a series of interviews with pedestrians to add such information.

A total number of 231 pedestrians participated in the on-street interviews conducted at 5 signalised intersections and one informal mid-block crossing. Of them, 148 pedestrians were males and 83 were females, comprising 64 percent and 36 percent, respectively. About half of respondents (51 percent) were middle-aged pedestrians. Young pedestrians and elderly pedestrians accounted for 37 percent and 12 percent, respectively. Respondents who have a driving licence accounted for 17 percent and those who drive a car accounted for 24 percent. The knowledge of influential factors of spatial and temporal non-compliance behaviour was the main focus of the interviews.

Table 5-21: Characteristics of interview respondents

Behaviour investigated	Gender				Age						Driver status							
	Male		Female		Young		Middle age		Old		With a driving		No driving licence		Driving a car		Not driving a car	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Spatial non compliance	57	62	35	38	30	33	47	51	15	16	17	18	75	82	21	23	71	77
Temporal non compliance	91	65	48	35	56	40	70	50	13	9	22	16	117	84	34	24	105	76
Total number	148	64	83	36	86	37	117	51	28	12	39	17	192	83	55	24	176	76

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Table 5-22: Reported reasons of spatial non-compliance

Reasons of spatial non-compliance	Number	Percentage
To save time	36	33
It is difficult to cross at signalised intersection	19	18
It is safer to jaywalk	14	13
No traffic was present	10	10
I did not know there is a pedestrian crossing	6	6
I did not see the pedestrian crossing	5	5
I am familiar with jaywalking	4	4
Motorists do not stop for pedestrians	3	3
Pushbuttons are not working	1	1
Red man signal takes too long to change to green	1	1
Other reasons	7	7

Table 5-23: Reported reasons of temporal non-compliance

Reasons of temporal non-compliance behaviour	Number	Percentage
No traffic was present	46	30
Vehicles were stopped	37	24
To save time	29	21
I did not see that the light was red	8	5
Motorists do not stop during the green man signal	8	5
I do not trust pedestrian light, I look at oncoming vehicles	4	3
Red man signal takes too long to change to green	4	3
I am familiar with crossing during the red man signal	3	2
I am good enough to take a chance and cross during red man signal	3	2
Pushbuttons are not working	3	2
Other reasons	7	5

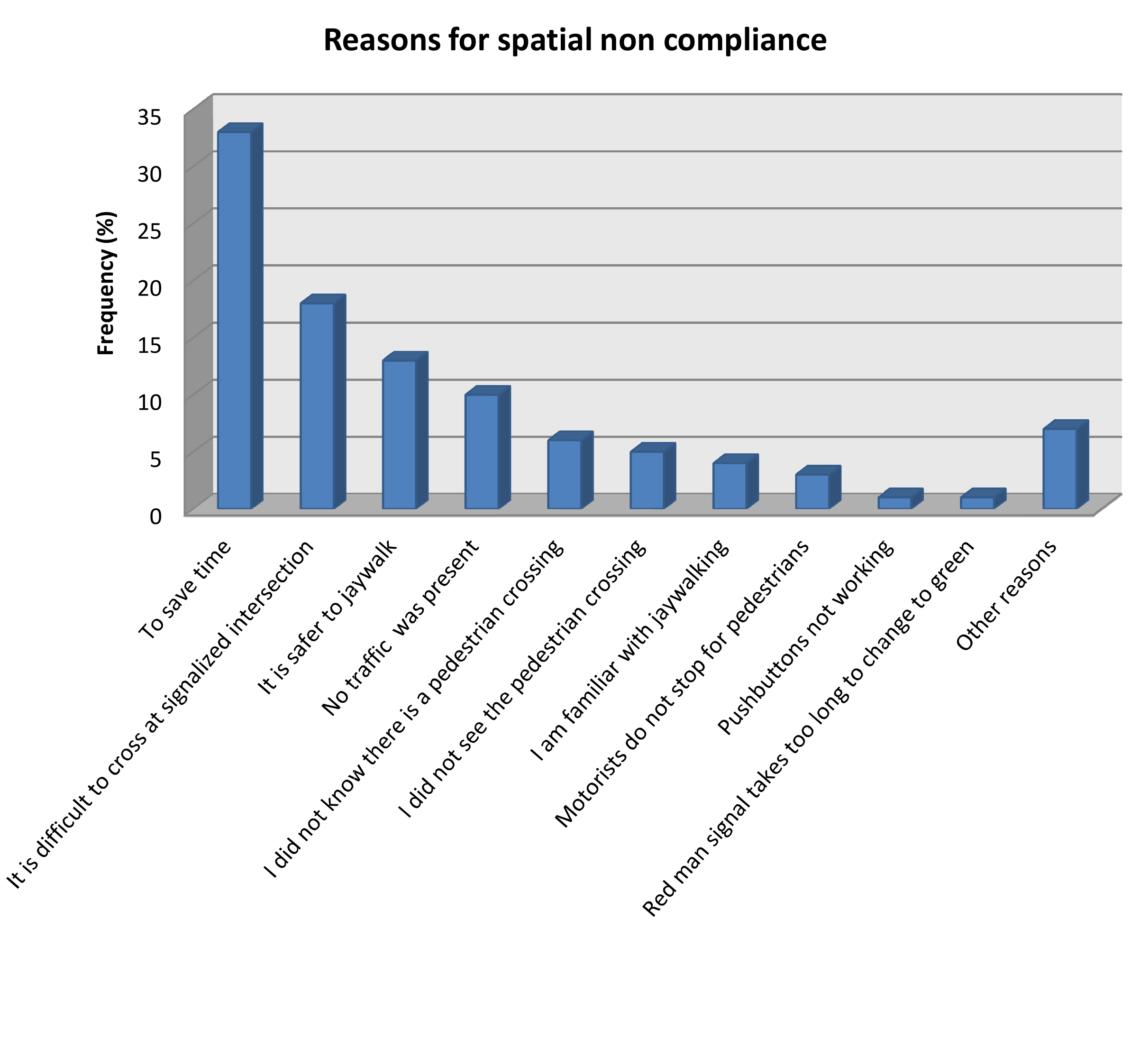

Figure 5-86: Frequency distributions of reported reasons of spatial non-compliance

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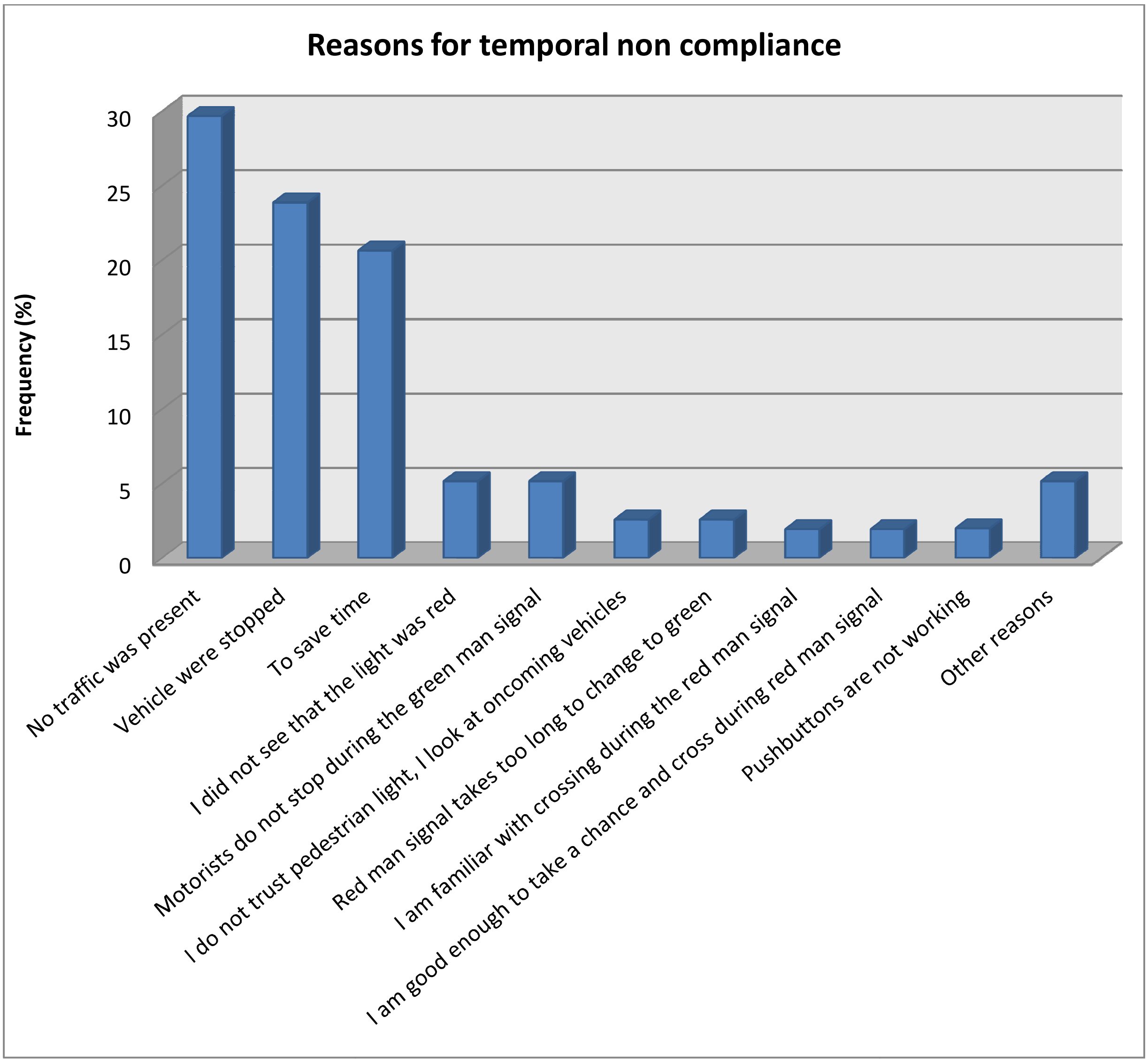

Figure 5-87: Frequency distributions of reported reasons of temporal non-compliance

5.6.4. Discussion

With regard to spatial non-compliant behaviour, responses collected from all surveyed sites were grouped into 11 response categories. Table 5-21 presents the frequency distributions of responses for spatial non-compliant behaviour. About half responses fell in two response categories; “to save time” with a score of 33 percent and “it is difficult to cross at signalised intersections” with 18 percent. The frequency distribution of other reasons can be seen from Table 5-21 and Figure 5-87. The response category “to save time” includes three types of responses: “I am in hurry”, “to save time”, “the pedestrian crossing is too far away” and “to get to my destination quickly”. The category “other reasons” includes responses such as “too many people crossing at the pedestrian crossings”, “robots favour drivers not pedestrians”, “I want to avoid cars standing on the pedestrian crossing” and “the green arrow was on, which means that if cars are turning it will be easy to move between cars rather than in front of cars”.

With regard to temporal non-compliant behaviour, three reasons comprising 75 percent emerged as the main influential factors as illustrated by Figure 5-88. These three responses were “no traffic was present”, “vehicle were stopped” and “to save time”. Other reasons can be seen from Table 5-22 and Figure 5-88. The response category “other reasons” includes responses such as “I do not feel like push the button”, “the green light does not stay on for long”, “I did not see the red light for pedestrians”, “when I feel it is safe enough to cross, then I cross”, “the traffic has to stop when I am crossing”, “pedestrian light is not working”, “the green arrow was showing”, and “the green arrow was showing, which means that I had an opportunity to cross”.

The dominant reported reasons of spatial non-compliant behaviour were to save time and the complexity of crossing at signalised intersections. It is cited frequently in international literature that pedestrians tend to shorten their walking distances in order to reach to their destinations quickly, regardless of the road-crossing rules. In line with the international literature (e.g. Sisiopiku and Akin, 2003; Behrens, 2010), the location of pedestrian crossings relative to the pedestrians’ movement desire lines was the main influential factor of jaywalking. A high rate of jaywalking was at the informal crossing on Merriman Street. Pedestrians avoided using the signal-actuated crossing (pedestrian crossing No 3 at the Merriman/Bird Street intersection) and opted for an informal mid-block crossing to reach the shopping malls. Jaywalking was mainly associated with traffic conditions at the other five signalised pedestrian crossings. Either vehicles were stopped in the crossing, forcing the pedestrians to cross behind vehicles or non-compliant pedestrians avoided crossing in front of stopped vehicles fearing that they would be caught when vehicles started moving. Other reasons reported by jaywalkers were related to difficulties associated with crossing at signalised pedestrian crossings. Although it was reported by only one participant, high pedestrian volume may have some influence on the decision to jaywalk.

With regards to temporal non-compliant behaviour, traffic conditions (e.g. low traffic volume), perceived benefits associated with crossing against the red man signal (e.g. savings in time, avoidance of conflicts with turning vehicles), pedestrians’ perceptions of signal timing (e.g. red man signal too long) and their operational state (e.g. pushbuttons

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not working) and personal social psychological characteristics (e.g. attitudes, familiarity and self-efficacy) were the reasons explaining the pedestrians' tendency to violate traffic signal rules. These outcomes were in line with the reviewed international literature. Nevertheless, the lack of knowledge about road traffic rules emerged as another significant component of the reported reasons of non-compliant behaviour. A wrong interpretation of traffic signals could be seen clearly from the reported reasons (e.g. reported meaning of green arrow). The ambiguity of right-of-way was another important finding of the survey. Some pedestrians reported that they have right-of-way at the pedestrian crossing regardless of the traffic signals. The motorists' responsibility reported in this survey may lead to doubt also their knowledge about the right-of-way at signalised pedestrian crossings.

As it was calculated in the observational study, red light runners gained between 19 seconds and 35 seconds in average. These savings in time are enough to encourage pedestrians to violate the red light but the associated risks are often undermined by most of the pedestrians. The observed amount of time spent between the green signal actuation and the signal display (signal calling time) varied between 4 seconds and 83 seconds. This wide range of calling time at the signal-actuated crossings may sometimes lead pedestrians to mistakenly accuse the signals of being dysfunctional. This situation was observed at some signal-actuated pedestrian crossings where pedestrians reported that the pushbuttons were not working whereas they were working properly but the signal calling times were simply unacceptably long. Nevertheless, in line with some reported responses, pushbuttons were found defective at 2 signal-actuated pedestrian crossings.

It was observed also that sometimes pedestrian looked at traffic signals for vehicles rather than those for pedestrians. Those pedestrians may be the ones who reported that "vehicles were stopped" and those who reported that "they did not see that the light was red for pedestrians". Those who reported that they don't trust the pedestrian signals could fall into this category too.

5.7. Gap-acceptance

The calculated values of critical lags and critical gaps showed that the size of lags and gaps were closely similar. However, bigger sizes of critical lags and critical gaps were found on wider roads such as four-lane roads. The critical lag on two-lane road was found to be 2.19 seconds (Figure 5-88) whereas the critical gap was 2.28 seconds Figure 5-89). On four-lane roads, the critical lag appeared to be 3.90 (Figure 5-90) seconds and the critical gap appeared to be 3.08 seconds (Figure 5-91).

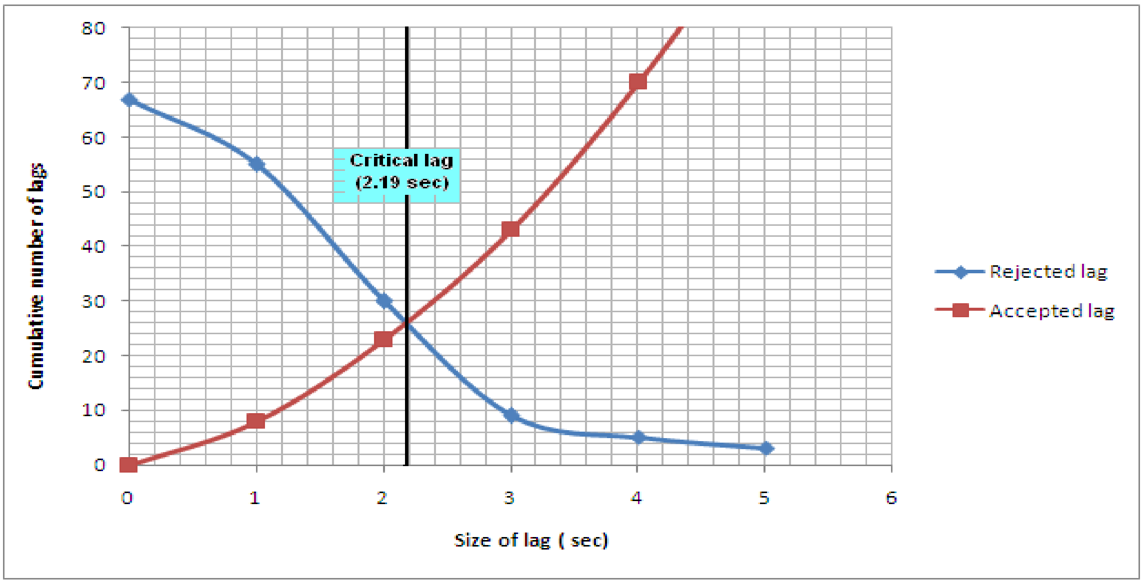

Figure 5-88: Critical lag on two-lane roads

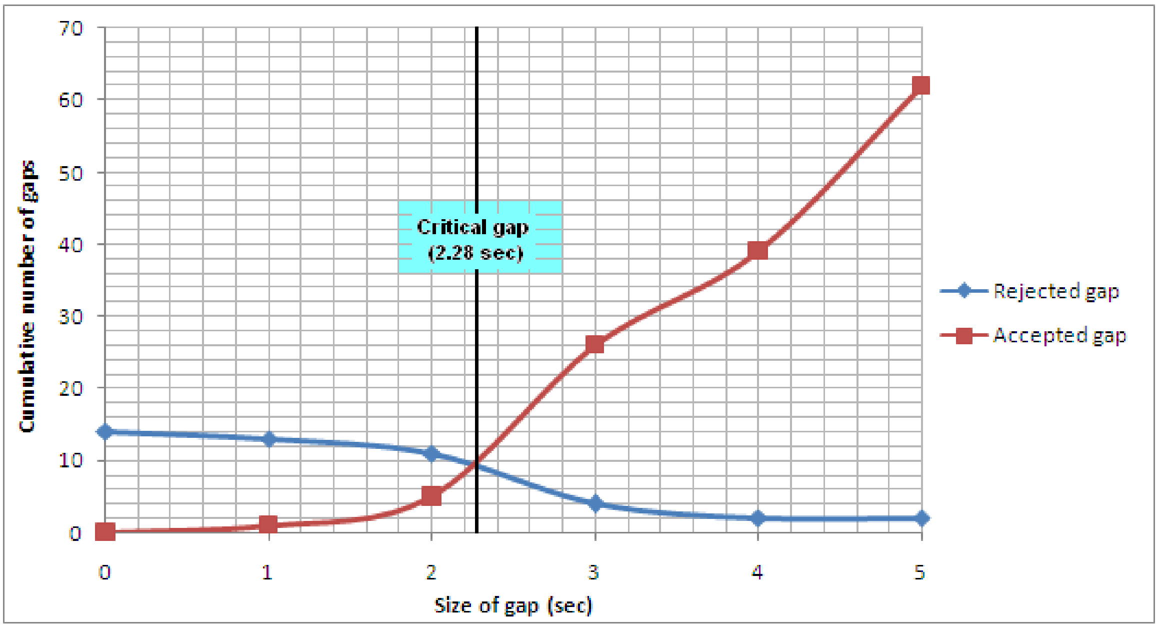

Figure 5-89: Critical gap on two-lane roads

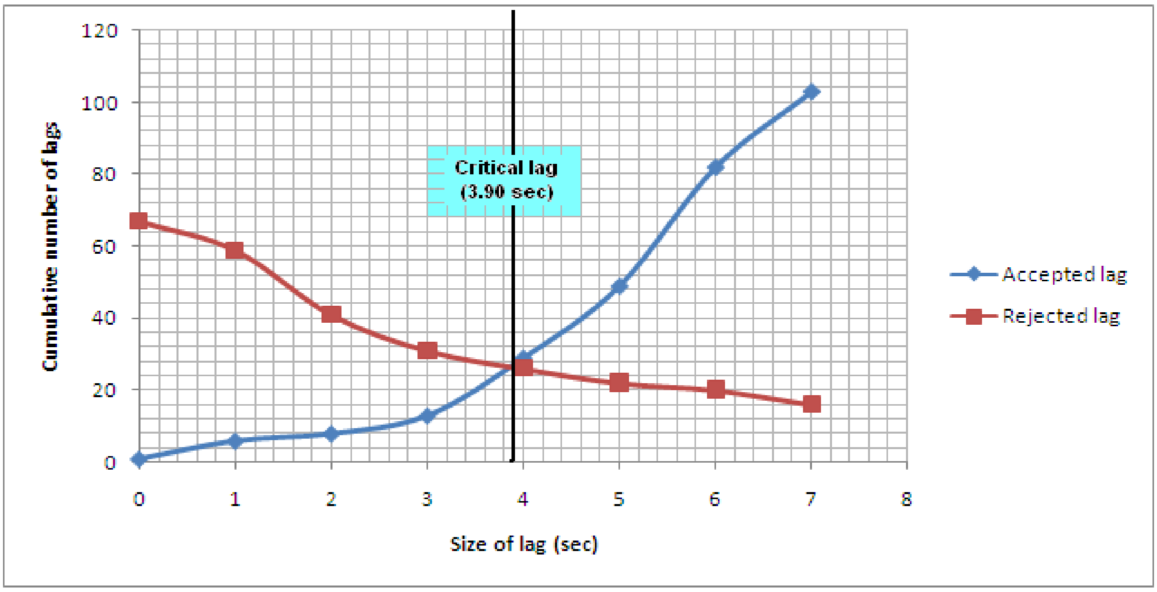

Figure 5-90: Critical lag on four-lane roads

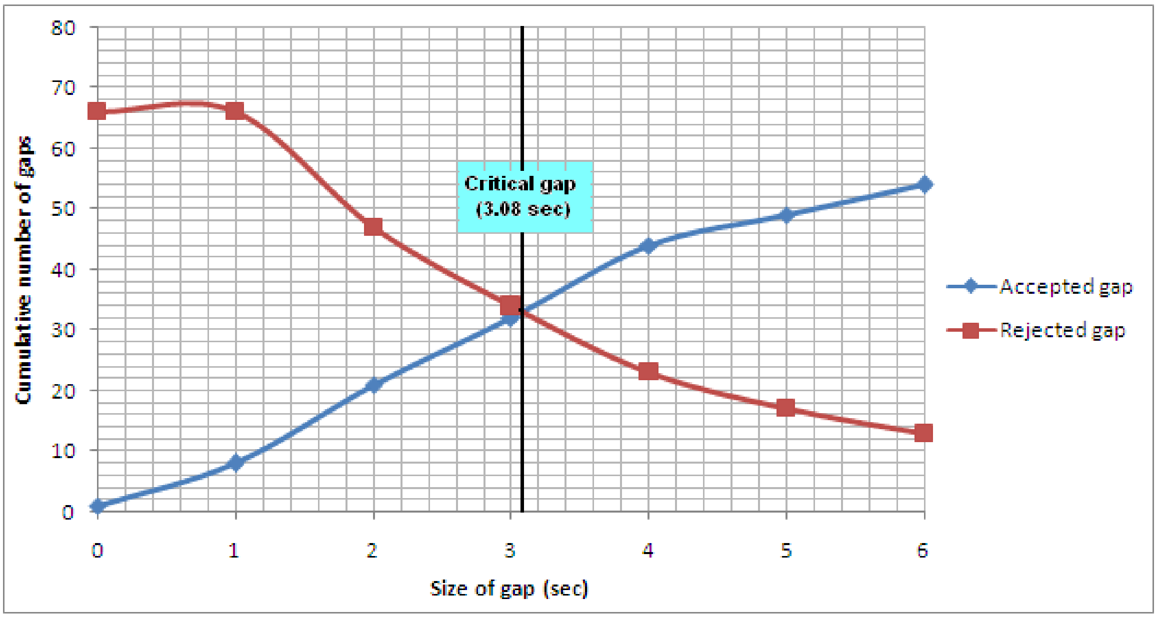

Figure 5-91: Critical on four-lane roads

Chapter 6. CONCLUSION AND RECOMMENDATIONS

6.1. Introduction

An in-depth understanding of pedestrian crossing behaviour was the main focus of this study. The patterns of crossing behaviour investigated throughout this study include pedestrian walking speed, pedestrian delay, pedestrian observational behaviour, pedestrian-vehicle conflicts, compliant behaviour with traffic rules and gap-acceptance. This study was conducted at 17 pedestrian crossings located in the city of Stellenbosch, in South Africa. The selected pedestrian crossings were in four main categories: pedestrian crossings located at signalised intersections, pedestrian crossings located at unsignalised intersections, signalised mid-block crossings and unsignalised mid-block crossings. Behavioural data were collected by means of three techniques: manual data collection, image videotaping and survey. This chapter presents the main conclusions from the analysis of the results presented in Chapter 5.

6.2. Conclusions

6.2.1. Pedestrian walking speed

The speed study conducted on a dataset of 1285 pedestrians indicated that the 15th percentile walking speed per pedestrian crossing category varied between 0.94m/s and 1.32 m/s at all pedestrian crossings investigated. The mean walking speed per pedestrian crossing category varied between 1.25 m/s and 1.56 m/s. Male pedestrians were found to walk more than female pedestrians and their respective proportions were 59 percent and 41 percent. A link between crossing distance and walking speed was identified in this study: pedestrians were found to walk faster at pedestrian crossings located on wide roads. It was revealed in this study that demographic variables affected the pedestrian walking speed. Male pedestrians walked at a mean speed varying between 1.28 m/s and 1.62 m/s whereas female pedestrians walked at a mean speed varying between 1.13 m/s and 1.46 m/s. It was concluded therefore that male pedestrians walk faster than female pedestrians. As regard age-related effect, being a young pedestrian was found to be associated with walking at higher speeds. The mean walking speed for younger pedestrians ranged between 1.25 m/s and 1.62 m/s whereas the mean walking speed for older pedestrians ranged from 1.25 m/s to 1.51 m/s. A noticeable relationship between walking speed and group size was highlighted in this study. It was revealed in this study that the higher the number of pedestrians in the group, the slower the walking speed. The majority of pedestrians observed in this study were found to be walking with a load. Walking with a load exhibited a small effect on the walking speed. Walking with a small load such as a bag, a handbag or backpack was predominantly observed in this study and failed to significantly influence the normal walking speed of pedestrians. Pedestrians who walked in groups were found more likely to be talking. This study also showed that distracted pedestrians walked slower than those who were not. Pedestrians who were observed in conflicts with motorists while crossing the road generally walked slower, except when the conflict involved running to take evasive action. The normal walking speed observed at sidewalks was found generally lower than the crossing speed. However, the high range of walking speeds

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recorded at sidewalks resulted from higher speeds exhibited by pedestrians walking on skateboards. The mean walking speed observed for the whole sample of this study was found to be greater than the design walking speed of 1.20 m/s recommended by most of the design manuals.

6.2.2. Pedestrian delay

A link between crossing delay and the type of conflict emerged in this study: running behaviour involved savings in time whereas stopping or slowing down involved delays during the actual crossing event. Pedestrian delays were found to be higher at wider roads with high traffic volume, highlighting thus a link between pedestrian delay, traffic volume and crossing distance. Demographic variables affected significantly the pedestrian delay: female pedestrians had longer delays than male pedestrians. An average total delay per pedestrian crossing category varied between 1.78 seconds and 12.39 seconds for females whereas for males the delay range was between 0.61 seconds to 12.79 seconds. A significant difference in delays experienced by the two age groups also emerged in this study: younger pedestrians were observed to be more impatient than older pedestrians. An average total delay varied from 0. 75 seconds to 10.41 seconds for younger pedestrians whereas it was in the range of 1.94 -16.52 seconds for older pedestrians. Traffic signals were another factor which affected pedestrian delay. Arrival in green phase for vehicles was associated with longer delays whereas arrival in pedestrian green phase was associated with shorter delays. A difference ranging from 19 seconds and 35 seconds was shown in this study between the expected delay and the actual delay at signal-actuated crossings. An average value of start-up time was found to be 3 seconds. In comparison with what is reported internationally, it can be concluded that pedestrians in our case study were significantly impatient.

6.2.3. Pedestrian gaze behaviour

The observed average total number of head movements performed at the kerb ranged between 2 and 5 whereas it ranged between 3 and 5 when pedestrians were crossing. More attention was focused to the right side when pedestrians were waiting at the kerb whereas it was in the ahead direction and the left side when pedestrians were crossing.

6.2.4. Conflict study

In pedestrian-vehicle conflict situations, five evasive actions were identified throughout this study. Running was found predominant at wider roads with high traffic volume and fast-moving vehicles. Using a hand sign to request the right-of-way was frequently observed at unsignalised pedestrian crossings.

6.2.5. Compliance behaviour

The majority of observed pedestrians failed to stop at the kerb to check the oncoming vehicles. It was shown also in this study that not all pedestrians who started crossing within the crossing markings ended crossing within the same markings. This study reported a high rate of red light violation ranging from 82 percent and 87 at 4 signalised intersections. The results from the on-street interviews revealed that perceived benefits like savings in time, together with the complexity of crossing at signalised intersections explained significantly the pedestrian spatial non-compliance. Factors such as traffic conditions (e.g. low traffic volume), perceived benefits associated with violating the pedestrian red light (savings in time), beliefs and attitudes towards traffic control devices emerged as important motives of pedestrian red right violation.

6.2.6. Gap-acceptance

It was shown in this study that pedestrians generally were willing to cross the road when lags greater than 2.19 seconds and gaps greater than 2.28 seconds were available on two-lane roads. For four-lane roads, they attempted to cross when lags greater than 3.90 seconds and gaps greater than 3.08 seconds were available on four-lane roads. It can be thus concluded that the pedestrian gap-acceptance is affected by crossing distance.

6.2.7. Limitations

Time constraints did not allow us to finish the study regarding pedestrian gap-acceptance. The dataset for this behaviour pattern comprised insufficient data required to come to reliable conclusions. The data coding is still in progress and findings relating to gap-acceptance behaviour will be published later.

6.3. Recommendations

A design walking speed of 1.2 m/s which corresponded with the 15th percentile walking speed of non-conflicting pedestrians is recommended for design purposes.

It was found in this study that generally pedestrians exhibited unsafe crossing behaviour and were impulsive in traffic conditions. In connection with these findings, multidisciplinary interventions involving four prominent disciplines, namely engineering, low enforcement, education and logistical support are needed to improve pedestrian crossing behaviour and to mitigate the pedestrian safety problem. Engineering interventions should start at the stage of planning. Pedestrian characteristics (e.g. demographic and socio-economic factors) and pedestrian needs should be taken into account in urban and transport planning. Effort is required in the design of the road environment to reduce the vehicular speed at pedestrian crossing and to segregate motorists from pedestrians in the transport system. Maintenance of pedestrian infrastructures necessitates more priority to avoid pedestrians' pretext of behaving unsafely owing to defective infrastructures. In connection with the findings of this study, pedestrian characteristics and needs should be accommodated in traffic management especially on wide and high speed roads.

Law enforcement should regularly control and regulate speed limits on road sections with substantial pedestrian activity (e.g. shops, schools, public transport facilities). Reckless and aggressive driving, especially at or near pedestrians crossings should be regularly surveyed by the law enforcement. Effort is needed from the law enforcement side to control substance and alcohol abuse among both pedestrians and motorists.

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Knowledge and skills about road traffic rules have to be transmitted through educational interventions. Behavioural change interventions have to be implemented via traffic safety campaigns and marketing. All this information should be targeted specifically at the most vulnerable groups of pedestrians (e.g. young pedestrians, socio-economically disadvantaged people). Adequate driver training also has to be a priority of traffic safety educators.

The logistical support has to coordinate all the traffic information to the authorities. Research activities need to be undertaken to provide new information about the problem. In connection with this, some engineering treatments are deemed necessary to reduce the number of pedestrians violating the red light. These treatments include the use of countdown timers (to avoid the uncertainty of the waiting time) and protecting the pedestrian green man signal at signalised intersections (to avoid conflicts with turning vehicles). We recommend thus future research on:

- Implications of implementing countdown timers at signal-actuated intersections.
- Implications of protecting the pedestrian green signal on the capacity of signal-actuated intersections.

We also recommend future research on motorists' beliefs and attitudes towards the pedestrian-driver interaction at pedestrian crossings.

It is also the responsibility of emergency services to manage accidents on roads. The role of administration also is of the great importance in addressing the pedestrian safety problem.

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APPENDICES

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APPENDIX A: FIRST VERSION OF THE QUESTIONNAIRE

A. PEDESTRIAN'S PERSONAL INFORMATION

i.Gender:	Male ☐		Female ☐	
ii. Age range:	Less than 15 years ☐		15-25 years ☐	
	25-55 years ☐		55 years and over ☐	
iii.Marital status	Married ☐	Divorced ☐	Widowed ☐	Single ☐
iv. Driver status:	a. Do you have a driving licence?	Yes ☐	No ☐	
	b. Do you drive a car?	Yes ☐	No ☐	

B. CHOOSE A RESPONSE TO THE FOLLOWING STATEMENTS WHICH IS BEST APPROPRIATE FOR YOU

1. When I have to cross the road at signalized crossing (Robot), I don't need to press the pushbutton and wait for the green man to appear because:

Statement	Rating				
	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree
1.1. The pushbottons are not working (disabled)					
1.2. I want to save my time					
1.3. The red man signal is too long for me					
1.4. I am good enough in taking a chance and cross easily by finding a gap through oncoming vehicles					
1.5.I am familiar with the pedestrian crossing that I use					
1.6.Turning vehicles don't stop during the green man signal					
1.7.The time for the green man signal is too short to finish my crossing safely					
1.8.I can cross when the signal turns red for vehicles					
1.9.Drivers must give me priority when I am crossing with the marked crossing					

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2. When I don't wait the green man signal, I prefer to cross behind or between stopped vehicles because:

	Rating				
2.1. I am afraid to be caught in the middle of the crossing when vehicles in the front of the queue start moving	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree
2.2.I feel safer when vehicles are stopped than when they are moving	Rating				
	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree

3.When I cross at signalized intersection (Robot):

	Rating				
3.1. I feel safe when there is a pedestrian refuge (island or median)	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree
3.2. I don't check the status of pedestrian signal (light),rather I look at oncoming vehicles	Rating				
	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree

4. I don't cross at a pedestrian crossing (=jaywalk) because:

	Rating				
4.1. I want to get to my destination very quickly	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree
4.2. Drivers do not stop for pedestrians at zebra crossings	Rating				
	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree
4.3. I don't want to irritate drivers	Rating				
	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree
5. I feel safer when I cross the road at a pedestrian crossing with other pedestrians than when I am alone	Rating				
	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree
6. I believe that I am a good pedestrian	Rating				
	Strongly agree	Agree	Neither agree or disagree	disagree	Strongly disagree

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APPENDIX B: FINAL VERSION OF THE QUESTIONNAIRE

SELF-REPORT QUESTIONNAIRE

Date:
Site Location:

PEDESTRIAN'S PERSONAL INFORMATION

Please place a cross in the appropriate block

i.Gender:	Male ☐		Female ☐	
ii. Age range:	Less than 15 years ☐		16-25 years ☐	
	26-55 years ☐		56 years and over ☐	
iv. Driver status:	a. Do you have a driving licence?	Yes ☐		No ☐
	b. Do you drive a car?	Yes ☐		No ☐

REASONS FOR UNSAFE CROSSING BEHAVIOUR

Please choose a response to the following statements which is the most appropriate for you by placing a cross in the appropriated block

What is the reason for the following unsafe crossing behaviour

A. Crossing the road out of the pedestrian crossing (jaywalking)

1. I want to reach to my destination quickly ☐
2. I want to save my time ☐
3. I am in a hurry ☐
4. Drivers do not stop for pedestrians at the pedestrian crossing ☐
5. Turning vecles do not stop when the light is green for pedestrians ☐
6. Pedestrian light is not working (disabled) ☐
7. It is complicated to cross at signalized intersection (Robot) ☐
8. Pushbuttons are not working (disabled) ☐
9. I am good enough in taking a chance and cross through oncoming vehicles ☐
10. Other pedestrians are crossing there ☐
11. There was no (or too much) traffic ☐
10. The red light takes too long to change in green ☐
12. Other reasons ☐

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B. Violating the pedestrian red light

1. I want to reach to my destination quickly
2. I want to save my time
3. I am in a hurry
4. Drivers do not stop for pedestrians at the pedestrian crossing
5. Turning vecles do not stop when the light is green for pedestrians
6. Pedestrian light is not working (disabled)
7. Pushbuttons are not working (disabled)
8. Pushbuttons are located far from my position
9. I don't trust pedestrian light, rather I look at oncoming vehicles
10. Other pedestrians were crossing in red light
11. Other pedestrian has pressed the button for me
12. I am good enough in taking a chance and cross through oncoming vehicles
13. The red light takes too long to change in green
14. Vehicles were stopped (it was red for vehicles)
15. There was no (or too much) traffic
16. Other reasons

C. Crossing behind or between stopped vehicles

1. I am afraid to be caught in the middle of the crossing when vehicles in the front of the queue start moving
2. Vehicles were stopped in the pedestrian crossing
3. I feel safer when vehicles are stopped than when they are moving
4. Other reasons

Thank you for your time and participation