Predicting the level of use of underground routes in a multi-level urban environment

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A Thesis
in
The Department
of
Geography, Planning and Environment

Presented in Partial Fulfillment of the Requirements for the Degree of
Master of Science (Geography, Urban and Environmental Studies) at
Concordia University
Montreal, Quebec, Canada

May 2010

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Your file Votre référence
ISBN: 978-0-494-67165-8
Our file Notre référence
ISBN: 978-0-494-67165-8

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Abstract

Predicting the level of use of underground routes in a multi-level urban environment
Wenyuan Zhang

Movement in dedicated pedestrian networks in urban environments is an important area for study in the field of urban planning. Researchers have investigated various related factors in path choice with regard to these settings. However, the preference of pedestrians for underground and surface routes in a multi-level urban system is still relatively unknown, making it difficult to model pedestrian dynamics in such complex spatial systems.

The purpose of this thesis project is firstly to investigate the factors affecting pedestrian path choice in a multi-level urban environment and secondly, to propose an assignment model for pedestrian circulation in a multi-level system, with parameters from the first study.

The results obtained from three operating tunnels in downtown Montreal show that seasonal change has an effect on pedestrian preference for path choices, suggesting that weather conditions are a major factor related to the use of underground routes. Although there is no statistically significant relationship between personal or systematic factors and preference for routes, the influence of systematic factors can be observed in the three cases. The assignment model is applied in a case study of Concordia tunnel system under construction. This study contributes to the investigation of factors affecting path choices, surface or underground routes, and proposes a new model to project pedestrian flow.

Acknowledgements

This thesis could not have been written without the encouragement and ideas of many people. First, I particularly appreciate the support from my thesis supervisor, Dr. John Zacharias, whose insightful suggestions and hard work during the past two years are greatly appreciated. Also, I would like to thank Dr. Tianxin Zhang who guided its early phases and contributed to its development. I am indebted to Dr. Ciprian Alecsandru for his thorough reading and valuable feedback.

In addition, I am grateful for the help from Dr. Pascale Biron and Mae Anne Burridge who made the process smoothly. Sincere thanks are also due to the many undergraduate students in Concordia University who collected data in the field.

My final thanks go to my wife, Shiqi Bao, for her dedication to everything.

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1 Part I—Investigating the factors contributing to pedestrian path choices

1.1 Introduction

Multilevel pedestrian movement systems in city centres are complex and have been a challenge to study, but are increasingly a fact of urban development. In some cases, there may develop parallel pathways serving the same destinations, but where they are at different levels. This is often the case with urban corridors underground that offer a different way to go than on the surface. But the high cost of development of such systems necessitates an economic and social benefit evaluation, which is often estimated by expected pedestrian flow. In the past, failure to accurately estimate the expected flow in the underground facilities led to corridors that were overcrowded or large spaces without people. So it is important to be able to predict, to some degree, the number of people expected to use a facility that is being planned underground. For the planner, it is aggregate behaviour patterns that are first in importance, to support the economic objective and system support. In the local environment of an urban underground tunnel, the choice to use the tunnel could be affected by various design factors, such as the location of major generators and attractors and their interactions, degree of vertical separation, energy required, spatial depth, and aesthetics (Chang & Penn, 1998; Foltête & Piombini, 2007; Zacharias, 2001). While most of these factors have been studied to some extent and in limited case studies, there is much more to do in this area. In particular, little attention has been paid to the issue of the preference of pedestrians for alternative underground and surface routes, together with the related factors. While many assumptions are made about the utility of such protected alternate routes through the city, there are few empirical studies of such cases. Some claim the importance of the detailed layout of the underground facility. In this group, are those who believe the number of turns is an important factor (Hillier, Penn, Hanson, Grajewski & Xu, 1993). Others hold that cognitive factors are important–legibility of the pathway, for example (Dalton, 2003). The traditional utility models suggest big resistance to climbing stairs but not escalators. Also relative distance of the two choices is thought important as means to save time and energy. Others pay more attention to the value of the facility itself. The comfort from walking on clean, well paved surfaces indoors is thought to influence the path choice. Outdoor conditions, including the weather, are thought to have a big effect on the choices.

In other words, there are many competing theories about why people, considered in aggregate, would choose one pathway on the surface over another underground. In addition to these physical factors, there are socio-demographic ones. The purpose of the trip might influence the choice–how rushed, how dressed, what purposes. There may be differences in the choices of different age groups, although such differences are hard to find so far in the literature on pedestrian behaviour.

The multilevel environments pose special problems and challenges for study. The space syntax models for predicting relative pedestrian volume (Hillier & Hanson, 1984) have produced little for three-dimensional networks although the three-dimensional aspect has been studied (Chang and Penn, 1998). The two-dimensional problem was relatively easier since there was only one kind of spatial choice to make, but the multilevel system has different kind of choices, more complex direction change and possible energy expenditure.

Some understanding about this kind of choice we make on a daily basis helps in understanding the effects of environment on our walking. Many theories exist about what influences our walking. How these influences work in such a case of a tunnel and a surface route helps us understand some part of behaviour and how we react to local conditions while walking.

Recent studies have considered how people navigate through space (Dalton, 2003; Haq & Zimring, 2003; Mittelstaedt & Glasauer, 1991). What people see has some influence over what they do in these cases. The environment of walking means seeing the environment continuously, where the organization of the paths, and some specific aspects have influence over path choice. This has applied to the number of turns in the walking system, as well as the perceived distance. Choices are observed in aggregate behaviour and so tend to be significant.

Therefore, the aim of this project is to investigate the factors contributing to pedestrian path choices on two alternate routes, one on the ground surface and the other immediately underneath. This is done by observing available cases that have observable conditions and certain comparable factors, with these factors taken into account in the observations. Two studies are conducted on these three cases: equivalent counts of surface and underground movement (n = 48) and a questionnaire applied to individuals at each of the three sites and when faced with their decision to use one or other path (n = 90).

The thesis is organized in two parts. First, the question of local choice when faced with a surface or underground route is examined. The results of the field work on those case studies are reported, relating ambient conditions and design to choice behaviours. The second part of the thesis proposes a model for estimating the flow through a tunnel under construction, by examining where people are coming from and applying what is known about their path choices to the case of the tunnel and surface ways being constructed.

The first part of thesis starts with a literature review on pedestrian behaviour. It is followed by a chapter on methodology, which elaborates the procedures for different data collection methods. Next, the analysis and results chapter presents the results of the field study on pedestrian path choice on underground and surface routes. The chapter of discussion and conclusion sums up the results, indicates the contribution of the thesis project, and makes recommendations for improvements to the study design.

1.2 Literature Review

Pedestrian behaviour can be explained as the phenomenon resulting from the interactions of external and internal factors faced by individuals, as seen in Figure 1.2-1. The external factors can be also viewed as the attributes of the pedestrian network while internal factors are more related to individuals. The following sections will discuss each factor in detail. This presentation is an evaluation of the contributing effect of the factor to overall pedestrian dynamics.

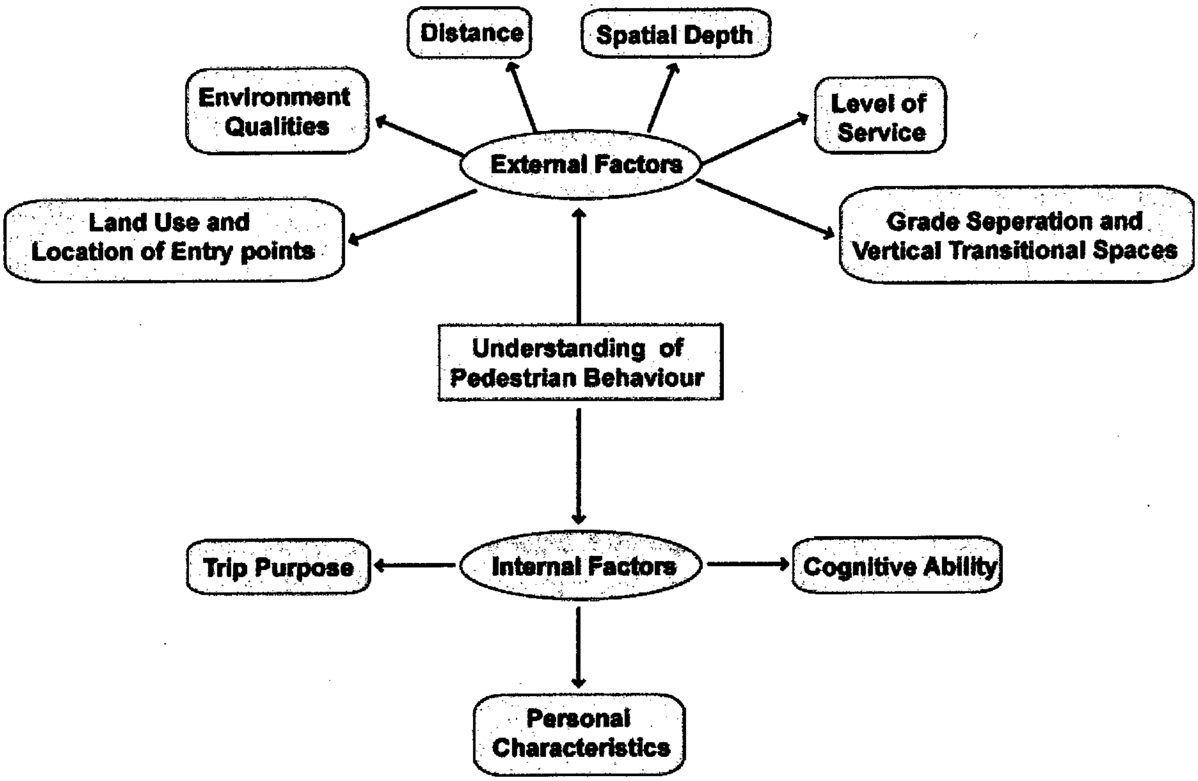

Figure 1.2-1: Literature map of pedestrian behaviors

1.2.1 External factors

1.2.1.1 Distance

In the process of making route choices, distance between origin and destination is considered a major factor, because of utility. Gärling and Gärling (1988) found that pedestrians tend to minimize distance and maximize utility of their trips. In other words, people are apt to minimize time and effort during their trips. Furthermore, two types of distance minimization–minimizing distance locally between destinations versus minimizing overall distance–were investigated with the conclusion that total distance rather than local distance was minimized in conjoint choices of route (Gärling & Gärling, 1988). Distance was a major factor to determine pedestrians route choices within centre establishments; moreover, people also prefer to shop at the establishments near to their homes (Borgers & Timmermans, 1986a). In downtown Calgary, nearly three quarters of the studied pedestrians choose the shortest routes according to an origin-destination survey (Seneviratne & Morrall, 1985). A similar result was found by Bovy & Stern (1990) who carried out observations in Jerusalem and discovered that about two-thirds of the participants chose the shortest distance route. Therefore, metric and perceived distance are believed to be important in path decisions.

1.2.1.2 Spatial depth

Spatial depth is defined as the depth of one space from another that can be described by the number of the intervening spaces between these two spaces (Bafna, 2003). Spaces are defined in various ways–by intersection or by axial line, for example. The measure is topological, not metric. According to the research done by Chang (2002), spatial depth is seen as the main factor affecting pedestrians' path choices in multi-level spatial structures. The depth of space can be measured by the number of direction changes from other spaces; more specifically, a shallow space means more accessible with lower number of direction changes while a deep space means more difficult to access since it requires frequent direction changes from all other spaces (Chang, 2002). Rather than minimizing metric distance, pedestrians prefer to minimize spatial depth in such environments; more specifically, people are apt to select a series of the shallowest routes between main generators, even when the routes are crowded, threatened by heavy vehicular traffic, or not the shortest (Marchand, 1974). The preference can be explained by the fact that people tend to conserve linearity throughout their journey (Dalton, 2003). Multilevel networks are much more difficult environments to understand cognitively. The third dimension raises the complexity greatly. Also, people have difficulty incorporating two different cognitive maps, one at surface level and another at underground level (Passini, 1992). These studies suggest that cognitive factors, as much or more than metric factors, can account for path decisions. In this project, the factor of spatial depth is investigated by counting the number of direction changes over 45 degree along the studied routes.

1.2.1.3 Grade separation and vertical transitional spaces

Level changes act more strongly on flow than distance. Escalators and stairs act to reduce the flow between vertically separated places. For example, a study of the multi-level London walkway system showed that pedestrian volumes decreased with levels of grade separation from the surrounding streets (Chang & Penn, 1998). In shopping environments, it is difficult to make several levels work equally well because of resistance to go up and down. At Alexis-Nihon shopping centre in Montreal, it was found that 37% of visitors did not change floors and only 46% visited two floors in the Alexis-Nihon Plaza with three shopping levels (Zacharias, 2000b). Vertical transitional spaces including stairs, ramps, escalators, and lifts also play an important role in controlling accessibility of the system. The configuration of transitional space in terms of type of vista, degree of enclosure, transition type, and the connection with main streets can affect movement patterns; for example, a more visible transitional space is more attractive to pedestrians, and escalators and lifts are preferred over stairs and ramps (Chang & Penn, 1998). So it appears an important friction on flow that there are level changes.

1.2.1.4 Level of service

Level of service for the pedestrian may affect the level of flow when there is an alternative. If the corridor is crowded and slow, the pedestrian may decide on less busy alternative. The concept of level-of-service was formulated by Fruin (1971), measured as volume of pedestrians per unit width of the pedestrian space. Many developments of this measure have come from this first one. Based on the work by Fruin (1971), Helbing et al. (2001) found that pedestrian motion was affected by interactions with others, so self-organization would occur at a certain density. More specifically, pedestrian flow tended to separate in opposing directions when pathways became more congested since there was less need for pedestrians to stop or use the techniques of avoidance (Helbing, Molnar, Farkas, & Bolay, 2001). Moreover, crowding can lead to a state of "overload" which causes the increase in purposefulness and walking speed (Stokols, 1972). Thornton et al. (1987) pointed out that crowding could reduce the time that pedestrians have to notice the surroundings in which they move. In terms of route preference, Muraleetharan & Hagiwara (2002) revealed that pedestrians chose the routes with higher level-of-service rather than shorter distance on longer travel paths. One explanation of this kind of decision was that pedestrians aimed to minimize the difficulty of walking or maximize the continuity of the facility (Muraleetharan & Hagiwara, 2002). Overall, they suggested that the factors of overall level-of-service, lengths of sidewalks and cross walks should be considered to determine path preference (Muraleetharan & Hagiwara, 2002). Where the conditions can seem to be congested and present difficulties for walking, it seems this may be an important factor in the choice.

1.2.1.5 Land use and location of entry points

Land use is another factor affecting pedestrian dynamics and decision behaviour (Borgers & Timmermans, 1986b; Zacharias, 2000a). It was found that pedestrian dynamics and choices of routes were mainly affected by the land uses and activities along their trips (Zacharias, 2000a). For instance, there was a correlation between redistribution of pedestrians in the central area and expansion of the Chicago Loop office district (Ashish Sen and Associates, Inc., 1989). Another example was found in the Cincinnati skywalk system where concentration of pedestrians was related to the amount of commercial floor space (Bhalla & Pant, 1985). The location of entry points or generators in the pedestrian network, such as transportation terminal, parking facility, or office buildings, also plays a significant role in the distribution of movement; for instance, the introduction of a metro system led to changes in shopping patterns in one city (Davies & Bennison, 1977). The factor of land uses and location of entry points are considered in the study to determine the contribution of commercial establishments and university facilities to pedestrian flow and estimate the volume of pedestrians generated from a new building.

1.2.1.6 Environmental qualities

Microclimatic conditions such as sunlight, temperature, humidity, and wind have a definite impact on pedestrian behaviours and decision-making (Zacharias, Stathopoulos, & Wu, 2001). For example, it was found that presence in public places had a positive relationship with air temperature ranging from -3°C to 25°C. Another study found that individuals tend to walk faster in conditions of warm air temperatures (Rotton, Mark, & Robert, 1990). Delicately deployed artificial lighting can lead to the increase of pedestrians on streets after dark (Painter, 1996). It was also found that visual content of the environment had a significant impact on pedestrian decision behaviour (Zacharias, 2001). For instance, people show high levels of preference for open urban spaces with large amounts of vegetation (Thelen, 1996). Moreover, ambient sound plays an important role in human perception and behavior; more specifically, high-traffic noise can make pedestrians walk faster and notice less around them (Korte & Grant, 1980). People form opinions about the environment and some behaviours are linked to perceptions of the environment. It is then possible that perceptions of qualitative aspects of the pathways will have influence over the path decisions.

1.2.2 Internal Factors

1.2.2.1 Trip purpose

Exploratory behaviour can be distinguished from goal-directed behavior in pedestrian environment. A goal-oriented trip tends to be minimized in time and distance (Lorch & Smith, 1993; Seneviratne & Fraser, 1991). People who use a street as a through route will generally walk faster than those who are shopping (Thornton, McCullagh, & Bradshaw, 1987). Although the majority of trips are characterized by minimizing time and distance, there are other trips involving complex motivations such as leisure and entertainment components which fail to be explained by utility theory (Zacharias, 2000a). For instance, the order of purchasing products can determine pedestrian route choices in the commercial area (Borgers & Timmermans, 1986a). The perception of crowding will be affected by immediate tasks; for example, the crowding can be attractive in a recreational context while it has a negative effect for pedestrians with purposeful shopping or under time pressure (Eroglu & Machleit, 1990; Zacharias, 1997). Thus it is important to know the purpose of the trip as a possible effect on the path choice.

1.2.2.2 Cognitive ability

The cognitive ability of pedestrians to find their way based on their spatial knowledge of landmarks, routes, and objects was investigated in previous research (Cornell, Sorenson, & Mio, 2003; Raubal, Egenhofer, Pfoser, & Tryfona, 1997). The difficulty of integrating vertically separated spaces can lead to the feeling of being trapped in multilevel underground complexes (Passini, 1992). Cognitive maps representing the pedestrian system can lead to different perceptions of environment and decision-making on path choices due to the fact that they are subject to individual differences. Chang (2002) also found that those who were familiar with the environment tended to choose the most direct and simplest routes in the system since they had developed more precise recognition of spatial structure. Familiarity with the location and the details of the choices available may have influence over the choice.

1.2.2.3 Personal characteristics

Age and mobility have an important effect on pedestrian movement behaviour. The accessibility of the pedestrian network can become an important issue for older people and those with mobility impairments in terms of the efforts involved to deal with barriers which affect their frequent and extensive use of public space (Lavery, Davey, Woodside, & Ewart, 1996). For vulnerable groups, the perception of safety of the environment will affect their path choices and behaviours (Painter, 1996). Age and gender should be included as independent variables as a consequence.

1.3 Hypothesis

The above discussion suggests that choice is conditioned by several factors. The decision model could be quite complex. Nevertheless, because of the importance accorded to immediate conditions and especially to the ground conditions and precipitation, those conditions associated with the weather or seasonal variations in conditions are hypothesized to be most important in the cases of tunnel and surface routes in the downtown area of Montreal. The hypothesis statement is as follows:

Seasonal effects and weather have a significant impact on the level of use of underground routes in a multi-level urban environment, with significantly lower level expected in the summer season.

It is also expected that systematic factors are important in the level of use of underground routes and explain a large part of the choice.

It follows that purpose and demographic characteristics have relatively less impact.

1.4 Methodology

There are two parts to this methodology section. The first one aims to find out how weather effects due to change in season affects the level of use of underground routes when seen as an alternative to a surface route. The second part is concerned with the degree to which eight factors contributed to pedestrian preference for underground routes. Those factors, following the discussion above are: distance, changes in direction, changes in level, crowding, shops and services, path condition, air temperature, safety from traffic.

1.4.1 Studying the effect of seasonal change

A survey of available sites for study in downtown Montreal revealed three tunnels with the following characteristics: a single visible path was needed between the decision point at the entrance and the exit point so that individuals could be observed by one person when they travelled from end to end. The tunnel should offer an alternate surface route that is close to the alignment of the tunnel. There were three tunnels having this description. Eight counts of 5 minutes duration were taken on separate occasions at each of the tunnel-surface route combinations in February and again in May at about the same time of day on weekday.

1.4.1.1 Three operating tunnels

The first tunnel (tunnel #1) was located under Rue De la Gauchetière and linked Place Bonaventure and the CN office building, as seen from Figure 1.4-1 to Figure 1.4-5. A variety of shops are distributed along the tunnel that connected with the ground floor of two buildings by two-way of escalators and stairs. Rue De la Gauchetière in this section was a two-way road with two lanes for car traffic and another two lanes for on-street parking.

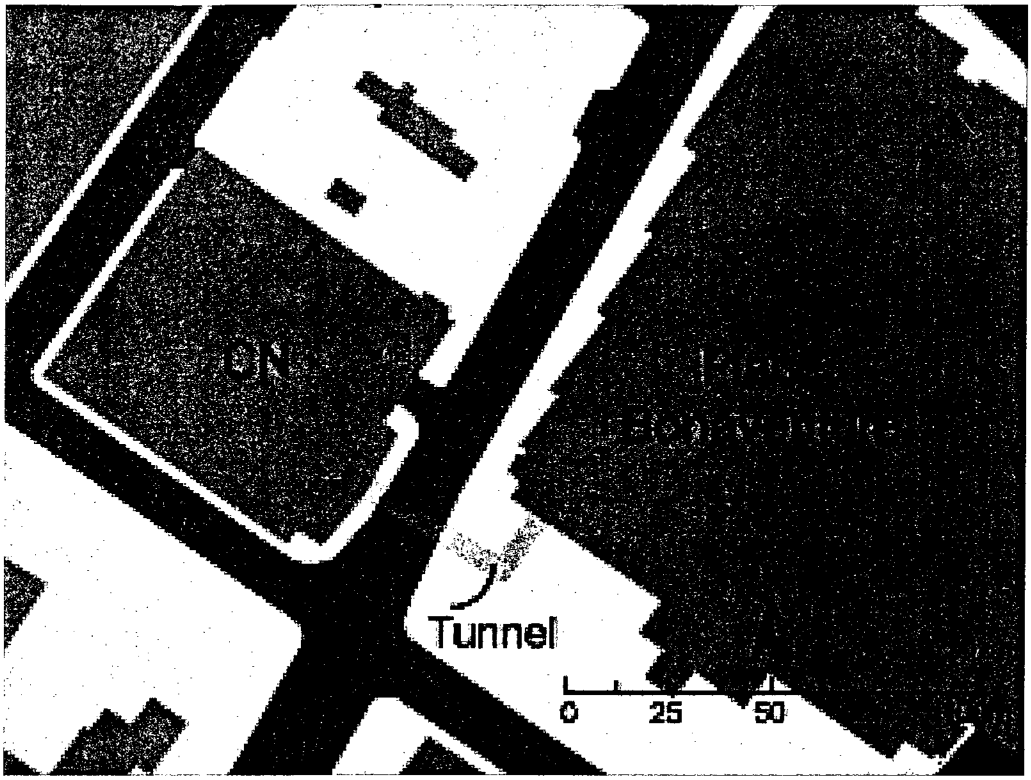

Figure 1.4-1: Map of tunnel #1 connecting CN and Place Bonaventure

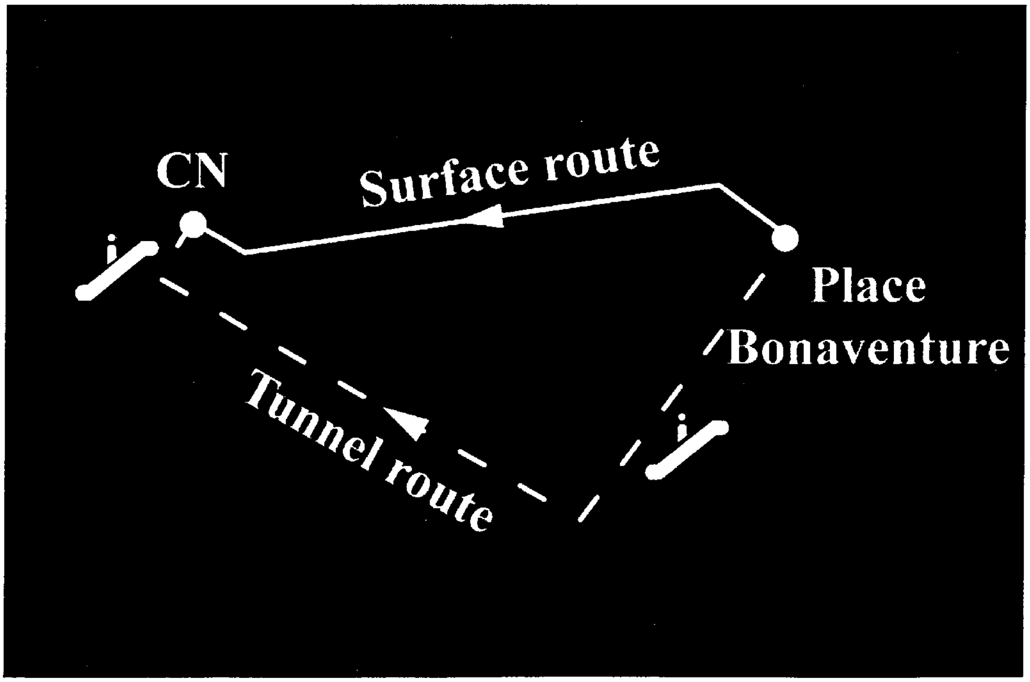

Figure 1.4-2: Illustration of two alternative routes (tunnel #1)

Figure 1.4-3: CN office building

Figure 1.4-4: Place Bonaventure building

Figure 1.4-5: Interior view of tunnel #1

The second tunnel (tunnel #2) is located under Rue Sainte-Catherine and connected Place des Arts and Complexe Desjardins, as seen from Figure 1.4-6 to Figure 1.4-10. Stores and booths lined the way of the underpass which ended with two-way escalators and stairs to the first floor of Place des Arts. In Complexe Desjardins, the tunnel became an immense public plaza where two vertical transitional spaces were identified as major pathways leading to the first floor, one with a staircase and the other including both stairways and two-way escalator. Rue Sainte-Catherine is a one-way road with two lanes for traffic and another two lanes for parking.

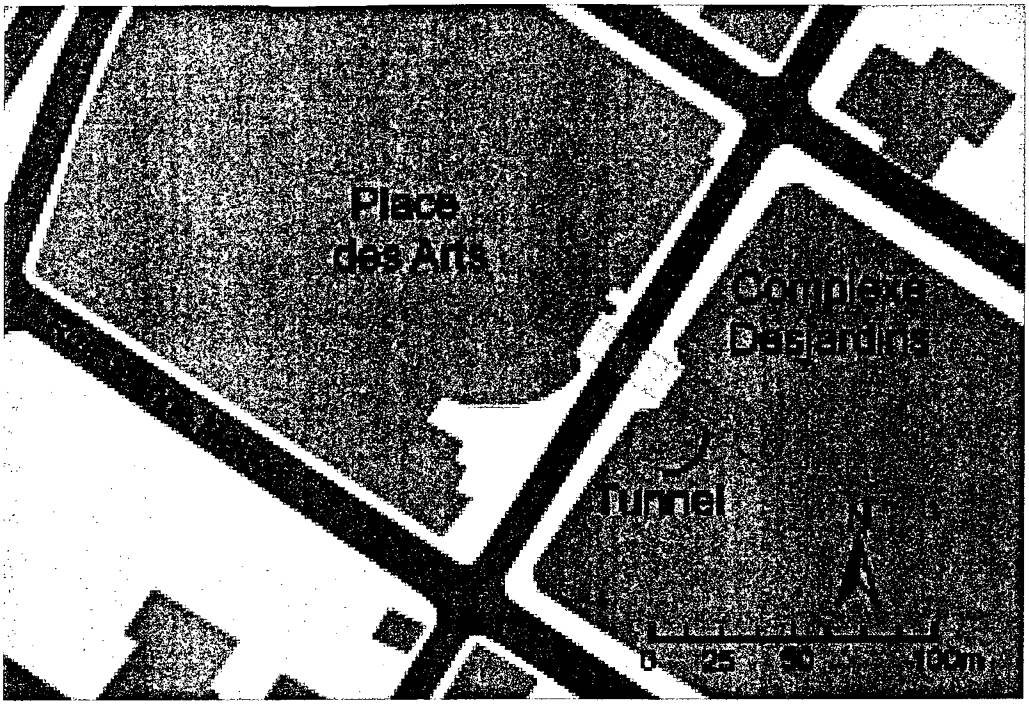

Figure 1.4-6: Map of tunnel #2 connecting Place des Arts and Complexe Desjardins

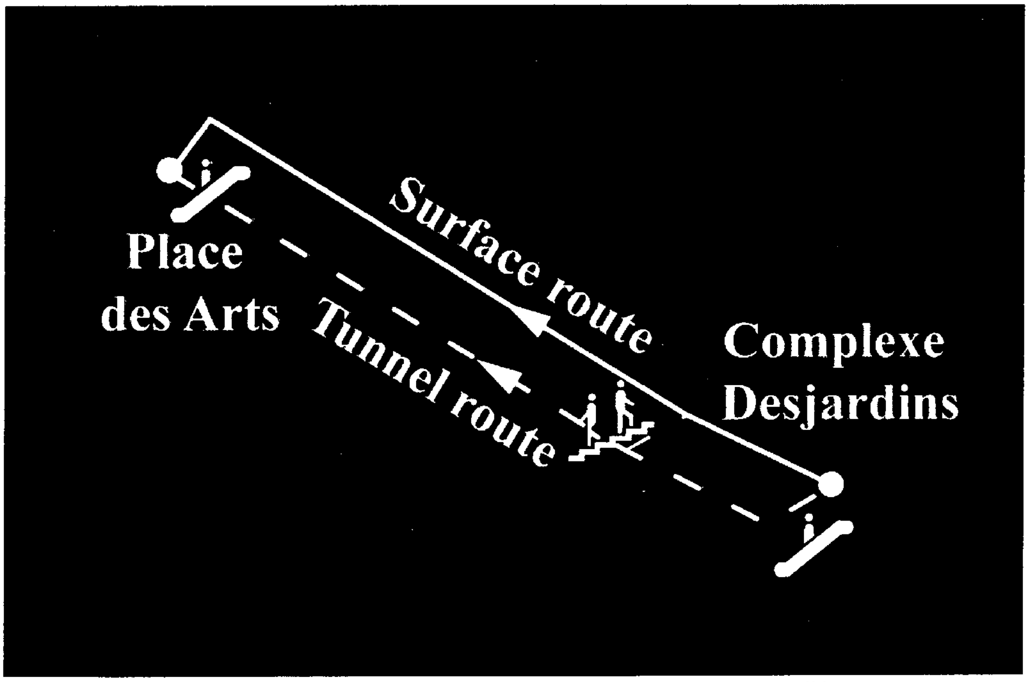

Figure 1.4-7: Illustration of two alternative routes (tunnel #2)

Figure 1.4-8: Place des Arts building

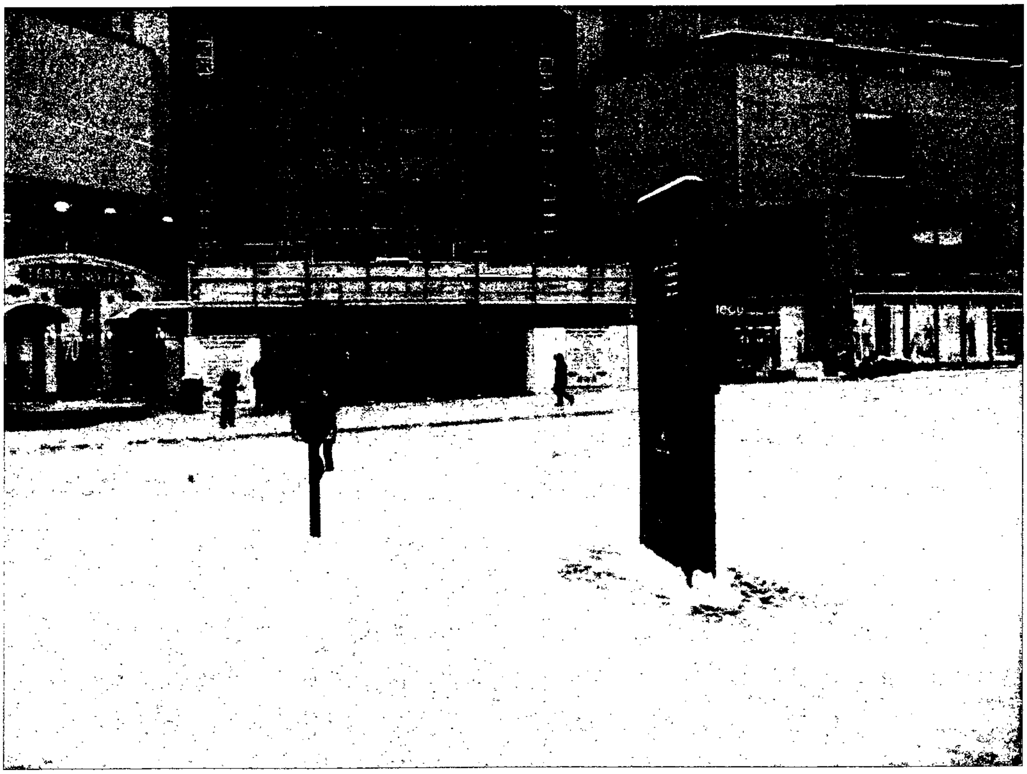

Figure 1.4-9: Complexe Desjardins building

Figure 1.4-10: Interior view of tunnel #2

The third tunnel is also located under the Rue De la Gauchetière and linked Complexe Guy-Favreau and Palais des Congrès, as seen from Figure 1.4-11 to Figure 1.4-15. No commercial activity was witnessed in the tunnel which included a segment of ramp on the way. Two-way escalators along with a staircase lead from the underpass to the ground floor of Complexe Guy-Favreau while only a stairway acts as a vertical transitional space at the other end. Rue De la Gauchetière becomes a one-way service road with one lane for car movement and another lane for parking in the area.

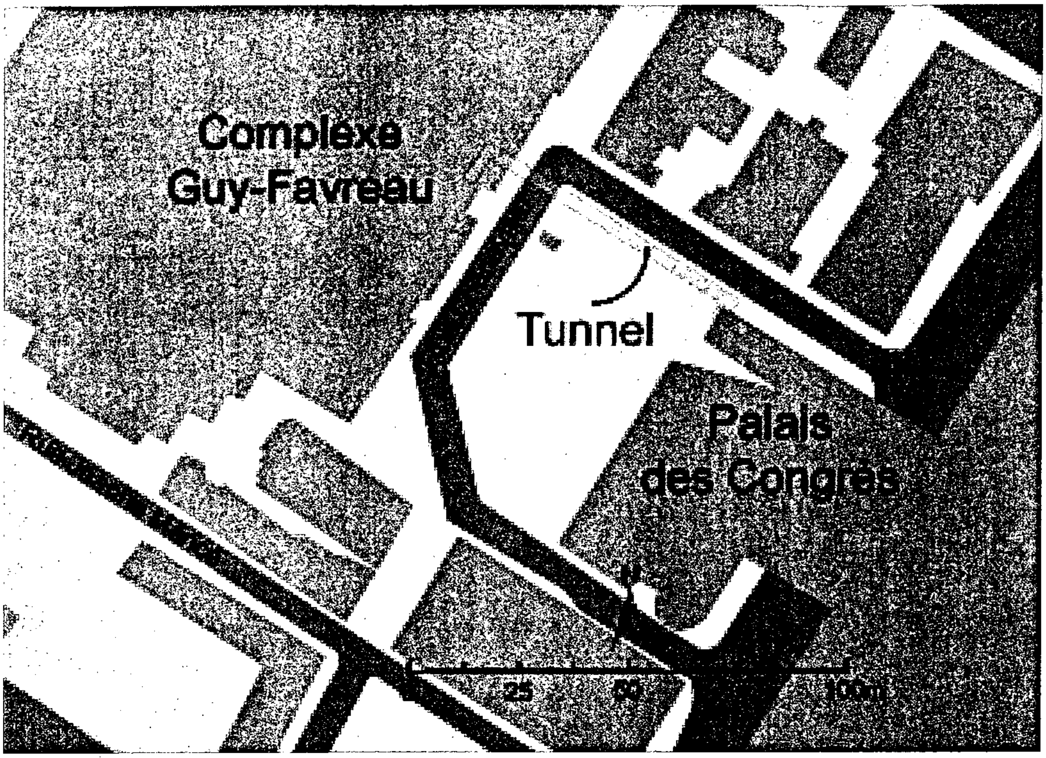

Figure 1.4-11: Map of tunnel #3 connecting Complexe Guy-Favreau and Palais des Congrès

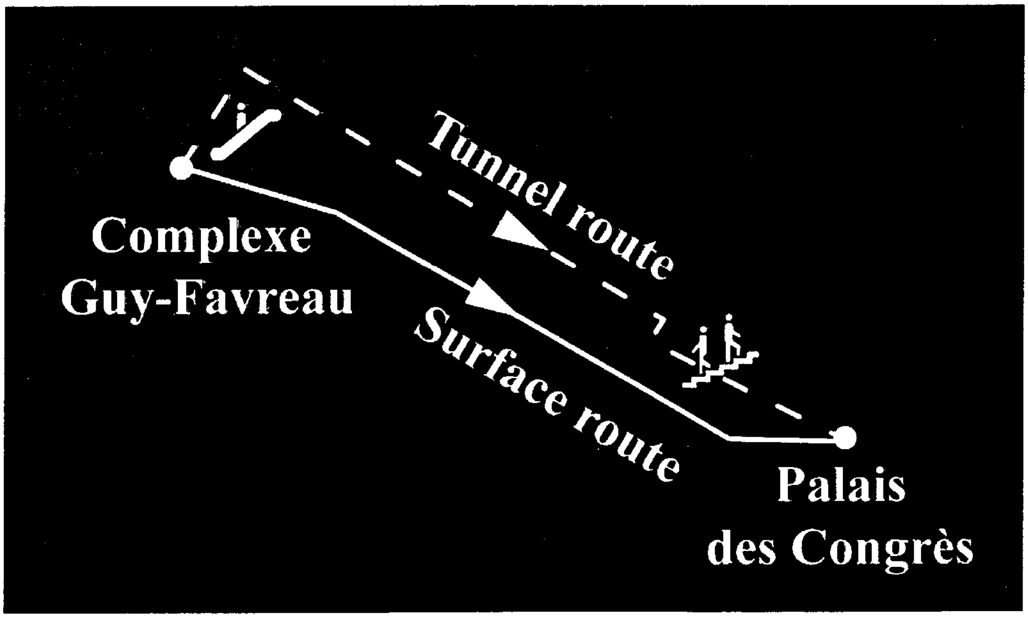

Figure 1.4-12: Illustration of two alternative routes (tunnel #3)

Figure 1.4-13: Complexe Guy-Favreau building

Figure 1.4-14: Palais des Congrès building

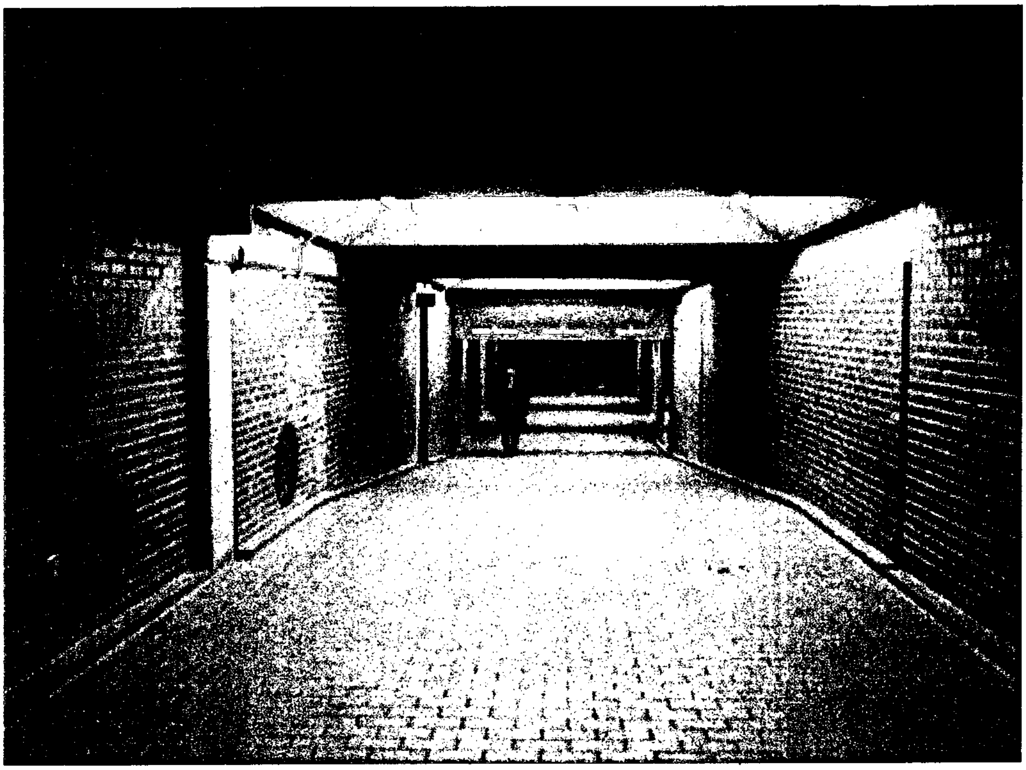

Figure 1.4-15: Interior view of tunnel #3

1.4.1.2 Procedure for collecting observation data

The counts were conducted from a single vantage point allowing view of both pathways to ensure that the path being executed began at the choice point and resulted in an exit at the opposite check point (Refer to Figure 1.4-2, Figure 1.4-7, and Figure 1.4-12). More specifically, only the pedestrians who had the same origin and destination (O-D) pair and route choice were counted on each route for the purpose of analyzing the preference on underground routes. The time period between 4pm and 6pm on a weekday was chosen to conduct cordon count in order to get statistically satisfying data since there would be more people moving between two opposite buildings during afternoon rush hours. The observation data were collected in February of 2009 and May of 2009.

1.4.2 Studying the contribution of personal and systematic factors

1.4.2.1 Questionnaire

The pedestrian survey was carried out along with a questionnaire in the three tunnels mentioned above (See Appendix A for survey questionnaire). Participants were asked to answer a questionnaire including demographic characteristics, trip purpose, familiarity, route choice and related factors affecting their choice of alternative above- and below-ground routes. The questionnaire served to ask the respondents to rank several important network and individual factors discussed above so as to understand the needs of pedestrians and refine the designs of pedestrian facilities. The variables investigated could be divided into two categories. The first category was about characteristics of trip makers (gender, age, familiarity, trip purpose). The second category was about characteristics of locations and weather conditions. Question (1) was used for identifying the familiarity of the respondents. Question (2) served to classify the trip types. Respondents were asked to indicate their route choice in question (3). Question (4) and (5) were open questions that served to get the information of path choices based on the respondents' own knowledge without any hints from interviewers. Question (6) included the external factors such as distance (F1), spatial depth (F2), grade separation and vertical transitional spaces (F3), level of service (F4), land use (F5), environmental qualities (F6, F7, F8). It is important to note that the surface routes on the sites of the first two tunnels involve jaywalking on the streets, which leads to the investigation of the factor of the safety without crossing the streets (F8). Question (7) served to identify other factors influencing pedestrian path choice.

1.4.2.2 Survey procedure

The survey was conducted on site at the three tunnels during May and June in 2009. Thirty respondents were approached individually using a random protocol on each tunnel (90 respondents at three tunnels overall). When they agreed to participate in the study, they were asked to fill in the questionnaire. They were informed of the purpose of the study orally (by the researcher) and in writing (on the questionnaire). The selected individuals were approaching the choice point and were about to make a decision either to take the tunnel or the surface route. Their trip was then interrupted by the researcher who asked if they would mind asking questions about this location and their choice.

1.5 Analysis and Results

This section starts with the analysis of the effect of outdoor conditions associated with seasonal weather, followed by the data from the questionnaire concerning systematic and personal factors of route choice.

1.5.1 Effect of seasonal changes in weather

There were two groups of observation data in three existing tunnels (Table 5.2-1 & Table 5.2-2). The first group was collected between 16 February, 2009 and 26 February, 2009. There were eight counts in each location over two weeks excluding Friday and weekends. The range of air temperature was from 2° C to -9° C, with the average value of -4° C. The second group of data was collected between 4 May, 2009 and 14 May, 2009, with eight counts in each location from Monday to Thursday, over two weeks. The range of air temperature was from 11° C to 20° C, and the average value was 16.5° C. All individuals were counted travelling from either end of an origin-destination pair and making one or other of the two choices available.

Location	**Alternative routes**	**May**		**February**	
		N	Ratio	N	Ratio
Tunnel #1	Surface	87	64%	66	43%
	Underground	48	36%	88	57%
Tunnel #2	Surface	206	67%	233	44%
	Underground	103	33%	299	56%
Tunnel #3	Surface	394	94%	657	77%
	Underground	26	6%	194	23%

Table 1.5-1: Revealed preference of route choices in three operating tunnels

Table 1.5-1 shows the two months of observation data in three operating tunnels. Overall, there is much variation in the distribution between surface and underground choices in this case. There is also a marked shift to the underground route in the cold season over all cases of about 20% of the total flow. Although the initial distribution of travellers varies much across the cases, the increase in use of the underground route in February is more or less proportional across the cases. So weather is having a significant and consistent effect in this limited sample of cases.

As will be seen in the next section on personal and systematic factors in path choice, these observed choices have a correspondence with the stated preferences of travellers faced with the decision in the field. The stated shift to underground route in February across tunnels #1, #2, and #3 bears close relationship with the observed behaviours above, with increases of 21%, 23% and 17% respectively (Table 1.5-1). This result suggests that location itself had little effect on redistribution of movement in the cold or mild seasons, but the seasonal difference (~20° C., for example) accounts for an apparently consistent behavioural change.

1.5.2 Seasonal change and revealed preference on route choices

The result shows that the ratios of people choosing underground routes in winter were higher than in summer in all three operating tunnels. The next step was to test the hypothesis mentioned above or answer the questions if the relationship was statistically significant, and in the case of significance, how strong it was.

1.5.2.1 Bivariate analysis

Since seasonal change and route choices were categorical variables, contingency table and chi-square tests were applied to determine the significance level of these two variables. The tests were done by the software called SPSS 15.0 version (available on http://www.spss.com).

Alternative routes	**May**		**February**	
	N	Ratio	N	Ratio
Surface	687	79.5%	956	62.2%
Underground	177	20.5%	581	37.8%
Total	864	100%	1537	100%
Note: X^2=76.755, *p* < .0001, *Cramér's V*=.179.				

Table 1.5-2: Contingency table showing the relationship between seasonal change and route choices

As Table 1.5-2 shown, people prefer surface route on both May and February, but there is 17.3% of increase on choosing the underground route on February. Furthermore, the result of chi-square test indicates a highly significant relationship between seasonal change and route choices (chi-square = 76.755, p < .0001).

1.5.2.2 Power analysis and effect size

To know the strength of the relationship between seasonal change and route choices, the proportions of people choosing underground routes in summer and winter season were compared to produce the associated parameters of power and effect size. The method used was Cohen's *h* (1988), generated from the formula as $h = |\Phi_1 - \Phi_2|$ (non-directional), where Φ_1 is the transformation of the proportion of underground route users in winter, and Φ_2 is the transformation of proportion of underground route users in summer. Next, the effect size was differentiated in three levels of *h* as small, medium and large by Cohen (1988). A small effect size was defined as values between 0.20 - 0.49, a medium effect size was defined as values between 0.50 – 0.79, and a large effect size was defined as values larger than 0.79.

Season	**n**	**n'**	**P**	**Φ**	**h**	**Effect size**	**Power (a_2=0.05)**
May	864	1106	0.21	0.952	0.376	small	>.995
February	1537		0.38	1.328			

Table 1.5-3: Power analysis of seasonal change and proportions on underground route

Table 1.5-3 shows the result of power analysis of seasonal change and proportions of people choosing underground route for all three locations. Although the effect size of proportions difference between May and February is small, the power is greater than 99.5%, meaning that there is over 99.5% of probability that it would yield statistically significant results at 95% confidence. This is mostly due to the large sample size.

1.5.3 Investigation of personal and systematic factors

The results of the field questionnaire are reported in this section. The questionnaire included personal items including gender, age, familiarity with the location, and stated trip purpose.

A randomizing selection protocol was used. Not all those approached agreed to respond, but the response rate was about 40% overall. The resulting distribution across gender and age categories is quite even, which helps in the analysis. The samples may not be representative of all the population in each area, but at least the samples can be compared (see Appendix C).

1.5.3.1 Personal factors and stated preference on route choices

1.5.3.1.1 Gender and route choices

Route choice	gender				total	
	male		female			
	N	Ratio	N	Ratio	N	Ratio
Surface route	28	57.1%	22	53.7%	50	55.5%
Underground route	21	42.9%	19	46.3%	40	44.5%
total	49	100%	41	100%	90	100%

Table 1.5-4: Gender variation in route choices in all three tunnels

Table 1.5-4 shows gender variation in route choices in all three cases, in which males and females both preferred surface route. Although the proportion of females (53.7%) are a little less likely than males (57.1%) choosing underground route, there is no statistically significant relationship between gender and route choices (chi-square = .110, p = .74).

1.5.3.1.2 Age and route choices

Route choice	age				total	
	15-50		Over 50			
	N	Ratio	N	Ratio	N	Ratio
Surface route	37	54.4%	13	59.1%	50	55.5%
Underground route	31	45.6%	9	40.9%	40	44.5%
total	68	100%	22	100%	90	100%

Table 1.5-5: Age variation in route choices in all three tunnels

Table 1.5-5 shows age variation in route choices in all three cases, in which two age groups, 15-50 and over 50 both prefer the surface route. Although the proportion of respondents over 50 years old (59.1%) are a little more likely than younger people (54.4%) to choose the surface route, there is no statistically significant relationship between age and route choices (chi-square = .15, p = .70).

1.5.3.1.3 Familiarity and route choices

Route choice	familiarity				total	
	none to 1 time		2 times and over			
	N	Ratio	N	Ratio	N	Ratio
Surface route	34	54.0%	16	59.3%	50	55.5%
Underground route	29	46.0%	11	40.7%	40	44.5%
total	63	100%	27	100%	90	100%

Table 1.5-6: Familiarity variation in route choices in all three tunnels

Table 1.5-6 shows familiarity variation in route choices in all three cases, in which no matter how often respondents visit the places, they all prefer the surface route. Although the proportion of respondents visiting the places more often (59.3%) are a little more likely than other people (54.0%) to choose surface route, there is no statistically significant relationship between familiarity and route choices (chi-square = .21, p = .64).

1.5.3.1.4 Purpose and route choices

Route choice	purpose				total	
	work		non-work			
	N	Ratio	N	Ratio	N	Ratio
Surface route	20	58.8%	30	53.6%	50	55.5%
Underground route	14	41.2%	26	46.4%	40	44.5%
total	34	100%	56	100%	90	100%

Table 1.5-7: Purpose variation in route choices in all three tunnels

Table 1.5-7 shows trip purpose variation in route choices in all three cases, in which both groups prefer the surface route. Although the proportion of respondents with the purpose of work (58.8%) are a little more likely than other people (53.6%) to choose surface route, there is no statistically significant relationship between trip purpose and route choices (chi-square = .24, p = .63).

1.5.3.2 Systematic factors

1.5.3.2.1 Ranking the importance of systematic factors

Respondents were asked to rate certain factors by their importance in making their path choices in general. The idea of this question was to try to see in terms of relative importance in the minds of the respondents some factors in the environment. A 5-point ascending scale of importance was applied to metric distance, changes in direction, level change, crowding, shops and services, clear pathway, moderate temperature and traffic safety. There were significant differences in aggregate responses to each of these factors (Figure 1.5-1). A clear pathway at moderate temperature figure more highly than do directional and level changes or the presence of shops.

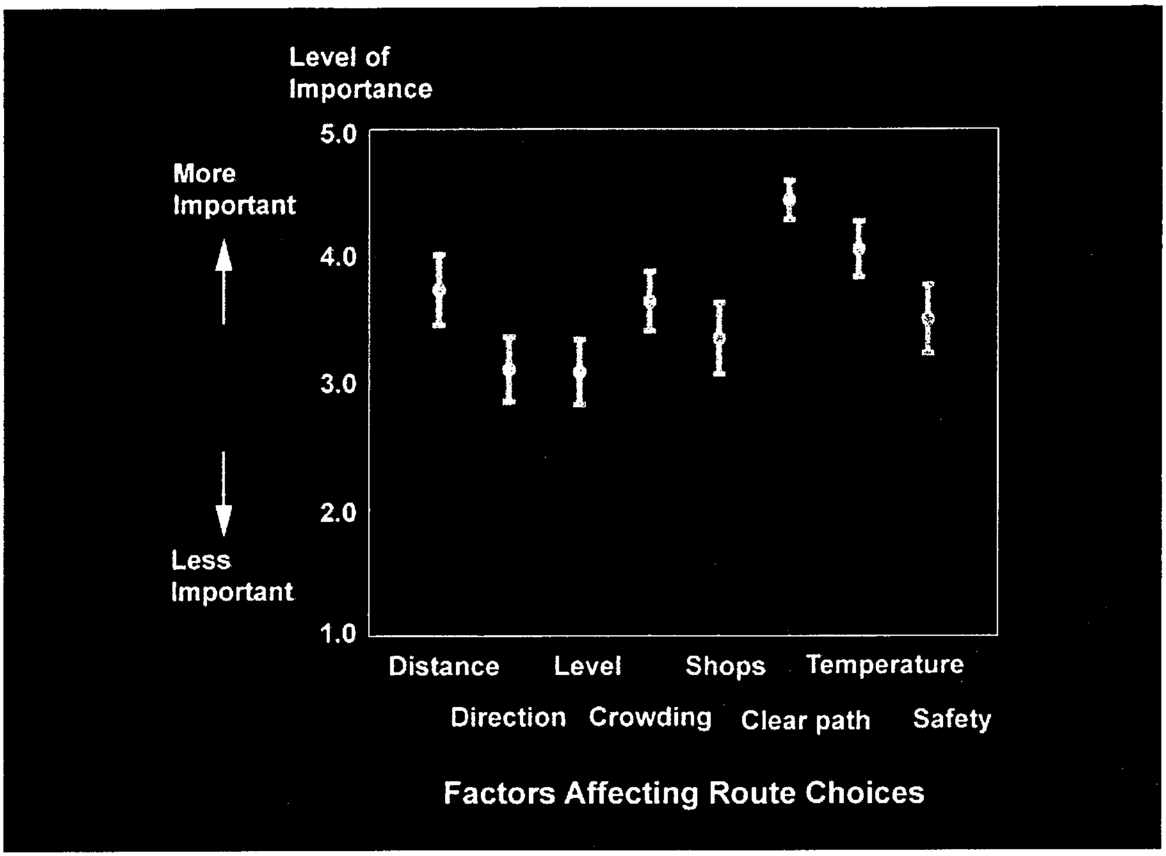

Figure 1.5-1: Related factors with 95% confidence interval of level of importance

1.5.3.2.2 Systematic factors and revealed preference of route choices

Next the physical characteristics of the three cases are examined against the route choices that were observed in the first field study. In this case the dependent variable is the ratio of pedestrian choosing underground route, while various system metrics are the independent variables.

System factors	Tunnel #1	Tunnel #2	Tunnel #3
Difference of distance	23m	7m	9m
Difference of directions	2	0	3
Number of shops	11	16	0
Street width	16.5m	12m	8m
Traffic directions	2	1	1

Table 1.5-8: System configuration of three operating tunnels

Table 1.5-8 provides some differences in the three tunnels. Analysis was done on individual observation samples (see Appendix B). If other factors than location-related factors were most important in the result, then relationships should not appear with regard to the systematic factors in this small sample of sites. Therefore, the following results should only be taken to indicate whether there is some evidence of relationship between those systematic factors and behaviour. With regard to distance, there is a positive relationship between the length of the tunnel and the proportion using it (r=.325, p=.024). Note that the longer tunnels also fall beneath wider roads. There is a negative relationship between direction change and the choice of the tunnel route (r=-.52, p=.000), suggesting that the more turns there are in the pathway, the fewer the users, entirely consistent with the findings of Chang and Penn (1998). The presence of shops also figures as positive influence on choosing the tunnel (r=.68, p=.000). The width of the street-level path choice has a major influence on the choice to use the underground route–the wider the street, the higher the proportion using the underground route (r=.635, p=.000). Finally, there is a greater preference for underground routes when the surface vehicle traffic is two-way, rather than one-way (r=.397, p=.005). This makes sense in that it is more complex to cross a street with two-way traffic than with one-way traffic.

These results show that systematic factors are also important in the actual behaviour of pedestrians observed in this particular path choice situation. While the results need to be taken with caution as to the correlation coefficients, it is still likely that the results would go in this direction for a larger sample of sites, if such number of sites could eventually be found.

1.6 Discussion and Conclusion

1.6.1 Results

Based on the analysis of observation data on three operating tunnels, seasonal change has an effect on preference for surface and underground routes in a multi-level urban environment. In winter season, there was about 20% increase in the proportion of pedestrians choosing underground routes averaged over the cases. The results of the questionnaire survey also point out that weather factors including air temperature and path surface conditions are considered as the most important element causing change in route choices.

Although the relationships between personal factors and preference on route choices are not statistically significant, differences in the ratios choosing the underground route between three operating tunnels suggest that several systematic factors including distance, direction change, commercial activities, street width and traffic also play an essential role in route choices.

1.6.2 The contribution of the thesis to the study of pedestrian behaviour

Various related factors have been studied to understand pedestrian behaviour in specific situations. Distance was considered to be a major determinant of path choices in urban environments (Gärling & Gärling, 1988). However, Chang (2002) pointed out that spatial depth is the main factor in making route choices under the context of complex spatial configuration. In this study, rather than distance and spatial depth, weather settings such as air temperature and path surface conditions were ranked as the most important factor in choosing routes in multi-level urban environment with two alternative routes, surface route and underground route. The study also found out that there was a statistically significant relationship between seasonal change and route choices. Moreover, other related factors were investigated to understand pedestrian dynamics in such settings.

1.6.3 Recommendation

Many improvements could be made to the study such as increasing sample size of cordon counts, controlling specific measurements of weather conditions, etc. As discussed above, small sample sizes increase the risk of errors in the final result of pedestrian flow prediction. In this study, route choices varied in different seasons from empirical evidence; however, the effect of individual weather conditions such as air temperature, path conditions, wind speed, rain or snow, could be tested under experimental conditions. More cases with similar spatial configurations can be added to investigate systematic factors by applying multi-regression model to study their effects on route choices.

1.6.4 Implications

The disparity of preference on underground routes in different seasons suggests that decision makers should be aware of variations in facility management. The related factors should be tested more carefully to help create desirable walking environment for pedestrians.

2 Part II—Modelling pedestrian flow in a planned tunnel

2.1 Introduction

For the planner of tunnels and surface environments, being able to have some good idea of the number of people likely to be on each of the alternate paths, surface versus underground, is important. Where to invest the resources and with what purpose? Especially in the case of private investors but also public institutions and government may think about whether the investment in such an underground facility is worth it.

There has been much development of pedestrian models in the past fifteen years. They are used in research and in the planning stage of the project. But so far, there has been no complete way of projecting the pedestrian flow for multilevel situations, except by making some assumptions about behaviour. Therefore, the second aim of the thesis is to develop a model in predicting the level of use of underground routes in a multi-level urban environment.

Based on the findings in the first part of thesis, it is interesting to consider how such information can be applied in real cases in the city. A tunnel was under development at Concordia University, built by the University and with the purpose to connect together the main buildings of the campus downtown Montreal. On the surface there is heavy density of pedestrian traffic on the days of the week. The tunnel will permit students to walk between four main buildings without going outside. Meantime, the surface is also being improved with new sidewalks, a public square and benches. The question being asked is at what level the tunnel will be used. In our case, we would be interested to see how it is possible to estimate the movement through this tunnel, when accounting for some of the variables for which we have information. So an estimation model is prepared that considers a single movement vector–from the intersection of Guy and de Maisonneuve streets to the Hall-LB corridor. For this estimation, the flow from the connected buildings, the street and the metro are considered.

The second part of thesis starts with a literature review on modelling pedestrian behaviour. It is followed by a chapter on the methods used to model pedestrian flows. Next, the analysis and results chapter presents the procedure of modelling and applies the assignment model to the Concordia case. The discussion chapter further explores the limitations of modelling techniques. The concluding chapter sums up the results, indicates the contribution of modelling pedestrian behaviour, and makes recommendations for improvements to the model.

2.2 Literature Review

The modelling of pedestrian behaviour can not only enable planners and decision-makers to have better understanding of how individuals interact with the specific environments but also aid in designing a safe and effective pedestrian network (Antonini, Bierlaire, & Weber, 2006). Basically, there are two different approaches to model the complexity of pedestrian behavior: top-down vs. bottom-up. The former approach is to consider pedestrians as an aggregate flow while the latter regards pedestrians as a set of individuals or agents (Antonini et al., 2006).

2.2.1 Top-down modelling

Zacharias (2001) suggested that pedestrian flow in terms of persons per hour on path segments can be used to describe the intensity and spatial extent of aggregate pedestrian spatial behaviour. Several distinct approaches can be identified in the first set of models which are based on aggregate data and topological description of the walking system.

The most pragmatic and comprehensive one is to link a series of different factors to volumes of movement by using simple statistical regression (Batty, 2001). In this way, the relative importance of factors can be identified. Chang and Penn (1998) provided a good illustration of this method in their 'integrated multilevel circulation model' (IMCM). The model was calibrated to describe factors such as grade separation, depth properties of primary routes, and visibility of transition spaces; moreover, it can be used to investigate the order of significance of the different factors by excluding one variable at a time from the model (Chang, 2002).

The second approach is using spatial interaction theory in which walking movements are simulated as discrete choices with different competing utilities (Batty, 2001). Borgers and Timmermans (1986b) conducted research in which street interviews were employed to get information about the entry point of pedestrians to the studied area, the sequential shopping places they visited, and the routes they selected. The study focused on a shopping district in the city of Maastricht, Netherlands, where people leaving the area were asked to fill-out questionnaires which included small maps for drawing itineraries (Borgers & Timmermans, 1986a). The analytical process is Monte Carlo simulation model which demonstrates that the order of shopping activities can determine pedestrian path choices. The model was proved to be able to predict changes of pedestrian behaviour resulting from the relocation of shops and entry points in commercial districts (Borgers & Timmermans, 1986a).

The third approach to modelling is the accessibility approach developed by Hillier et al. (1993) who defined the accessibility of a street by its integration value, the value of which is correlated with pedestrian volume. The approach is also called space syntax, which aims to deal with the relationship between humans and the topological construct of cities, landscapes, buildings, settlements, and pedestrian environments. There is a fundamental principle for the research of space syntax, in which social structure is seen as spatial system while pattern of settled space is considered as involving social logic (Bafna, 2003).

Lastly, the largest set of models is based on modelling the dynamics of pedestrians with respect to their local pathway geometry, and the corresponding method is called fluid-flow analysis in which pedestrians are similar to particles making up a fluid flowing within constrained spaces (Batty, 2001). In this way, the crowd can be treated as fluid-like things by employing partial differential equations to depict the variations of density and velocity (Antonini et al., 2006).

2.2.2 Bottom-up Modelling

Bottom-up modelling, also known agent-based modelling, simulates each walker in the network; furthermore, it takes into account limited capacity of pedestrian ways and places and is based on a structure in which the behaviour of any agent or object is always a function of other objects in the system (Batty, 2001). The new way of modelling is seen as a superior alternative to older top-down models because of its advantages in terms of object-orientation, new forms of data collection, powerful computing ability, and new ways of articulating social systems (Batty, 2001). For example, the agent-based framework, PEDFLOW, models each pedestrian in parallel processing and focuses on how the individual negotiates other objects and agents (Kerridge, Hine, & Wigan, 2001). However, agent-based models have limitations in terms of studying individual behaviour and micro-scale movement (Willis, Gjersoe, Havard, Kerridge, & Kukla, 2004).

2.3 Methodology

A model to predict the level of use of underground routes in a multi-level environment incorporated the methods of cordon counts, field survey, and apportionment or assignment system. Cordon counts and field survey have been widely used to get empirical data on pedestrian dynamics. The apportionment system was founded on an assumption that the assignment of turning flows from a link was decided by the flows on each of the other links connected via the junction, where a link was defined as a route without junctions or turning possibilities except the two at either end (Thornton et al., 1987). For example, in a junction with four links as shown in Figure 2.3-1, the equation to determine what proportion of people turning from link 'a' to link 'b' could be expressed as follows:

$$N_{ab}=N_b / (N_b+ N_c+ N_d)$$

Where N_{ab} is the value of proportion turning from link 'a' into link 'b', and N_b, N_c, N_d are the numbers of pedestrians exiting the junction via links 'b', 'c', and 'd' (Thornton et al., 1987).

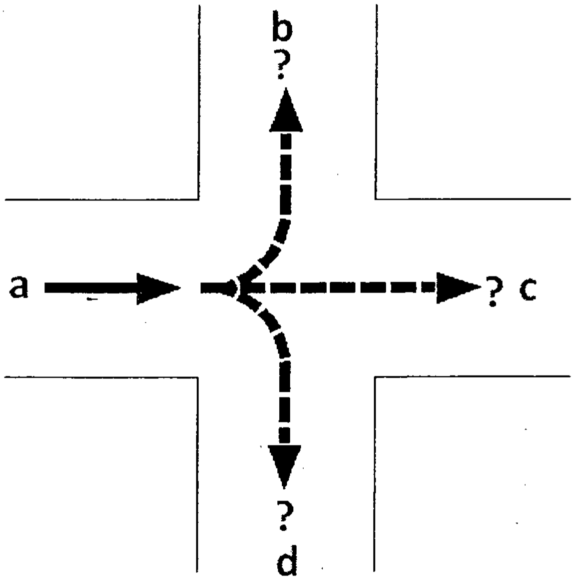

Figure 2.3-1: Flow apportionment system diagram

2.4 Analysis and results

2.4.1 Procedure of modelling pedestrian flow in a planned tunnel

As shown in Figure 2.4-1, the first step is to identify tunnel location, so that the generators and attractors of pedestrian flows can be located. The following step is to conduct O-D analysis which requires several techniques including cordon counts, apportionment system and field survey. The next step is to figure out the proportions of pedestrian flow choosing the tunnel route. The final step is to sum up the flows choosing the tunnel route and produce the result.

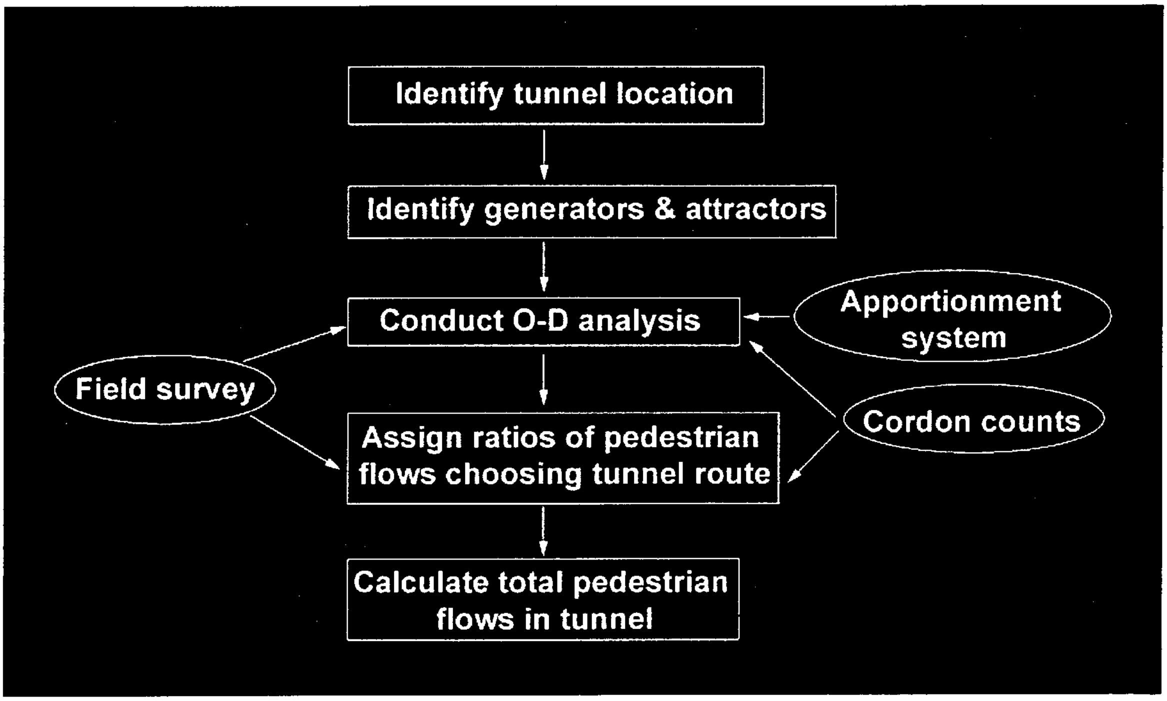

Figure 2.4-1: Procedure of modelling pedestrian flow in a planned tunnel

2.4.2 Application of the model

To illustrate the application of the model, a new tunnel under construction at Concordia University SGW campus was selected. Figure 2.4-2 shows the plan the multi-level spatial system of the area in 2008, while Figure 2.4-3 shows the system in 2009.

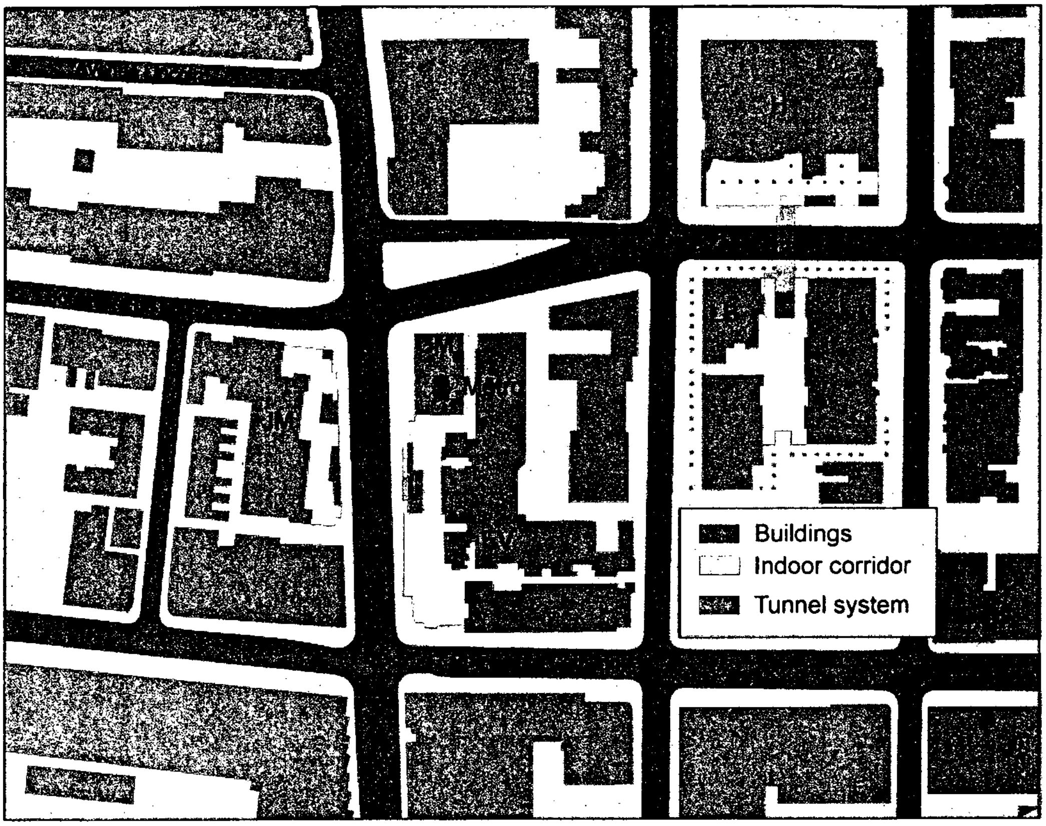

Figure 2.4-2: Plan of multi-level system of Concordia SGW campus in 2008

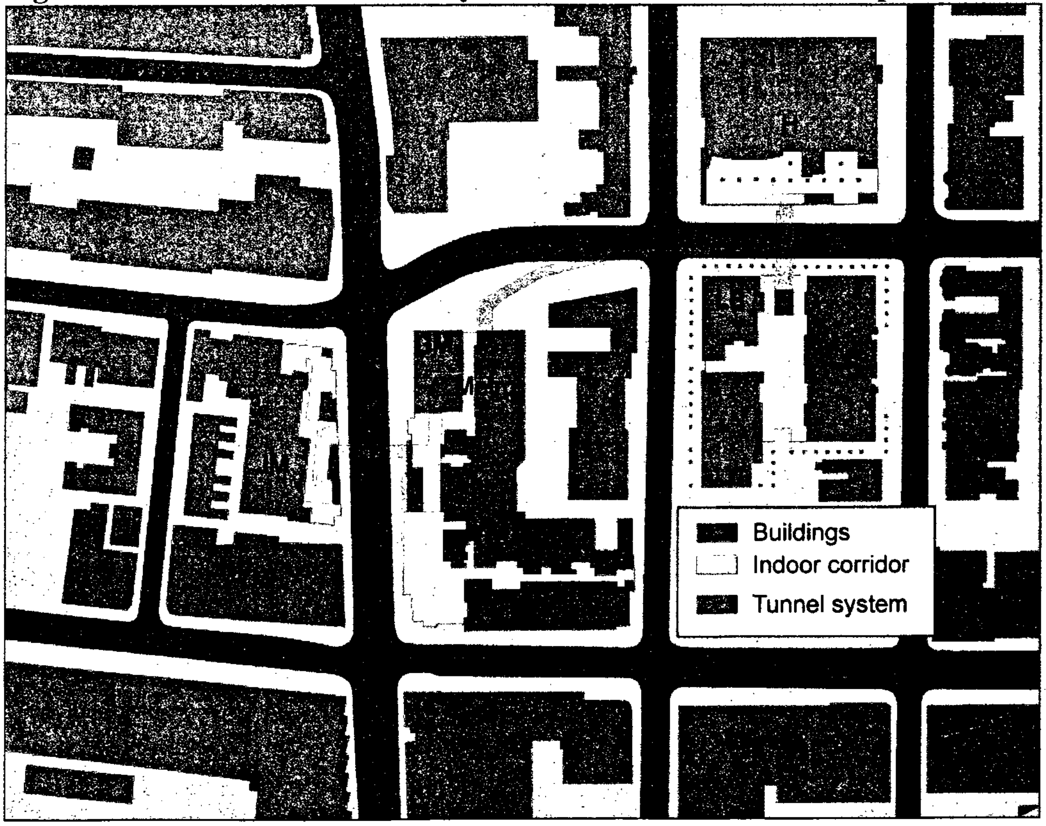

Figure 2.4-3: Plan of multi-level system of Concordia SGW campus in 2009

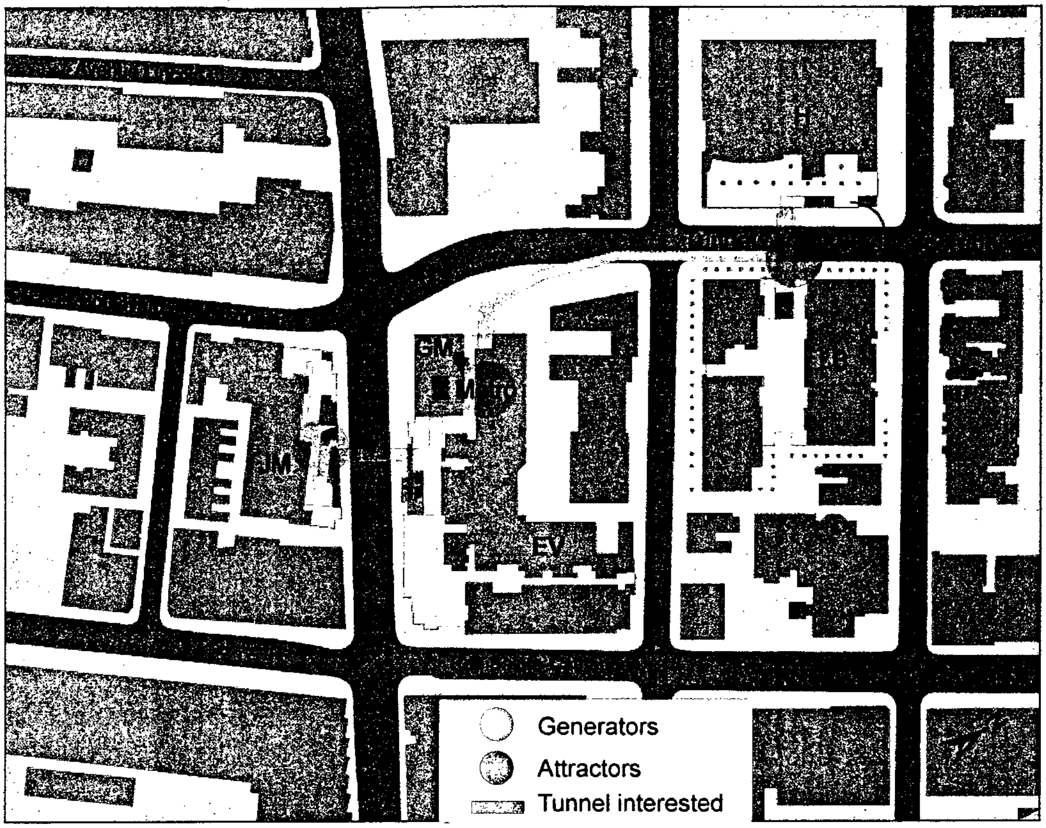

Figure 2.4-4: Identification of tunnel, generators, and attractors in SGW

Figure 2.4-5: A segment of the tunnel under construction

At the first step of modelling, the tunnel of interest connecting the metro station to the Hall and library buildings (H&LB) was identified, as shown in Figure 2.4-4. In this case, the expected result was to project the volume of pedestrian moving from west to east in the tunnel. Therefore, three generators were identified as the metro station, John Molson School of Business building (JM), and the street corner of Guy & Sainte Catherine, based on the field observation and the information about facility management at the university. H and LB buildings were seen as one attractor in this case since they shared the use of the tunnel of interest; as a result, three pairs of origin and destination (O-D) pedestrian flow can be determined to conduct O-D analysis: the metro station to H and LB, the street corner to H and LB, and JM to H and LB. Between these generators and attractor, there were two alternative routes, the surface route and the underground route, so acquiring the proportion to assign these flows into two sub-flows would involve the following step. The last step was to calculate the sub-flows choosing the underground route branched from three pairs of O-D pedestrian flows.

Before conducting O-D analysis, cordon counts were applied to collect the number of pedestrians passing through an imaginary line placed on each street segment in both directions within two minutes interval during three time slots of 8am to 10am, 11am to 1pm, and 4pm to 6pm on weekdays using a team of 6 surveyors in the fall of 2008 (see Appendix D). The three time slots were chosen to represent morning peak hours, lunch break, and afternoon peak hours for capturing the peak volume of pedestrian flow. The survey would produce the mean value of pedestrian flow on each street segment based on three counts in each time slot.

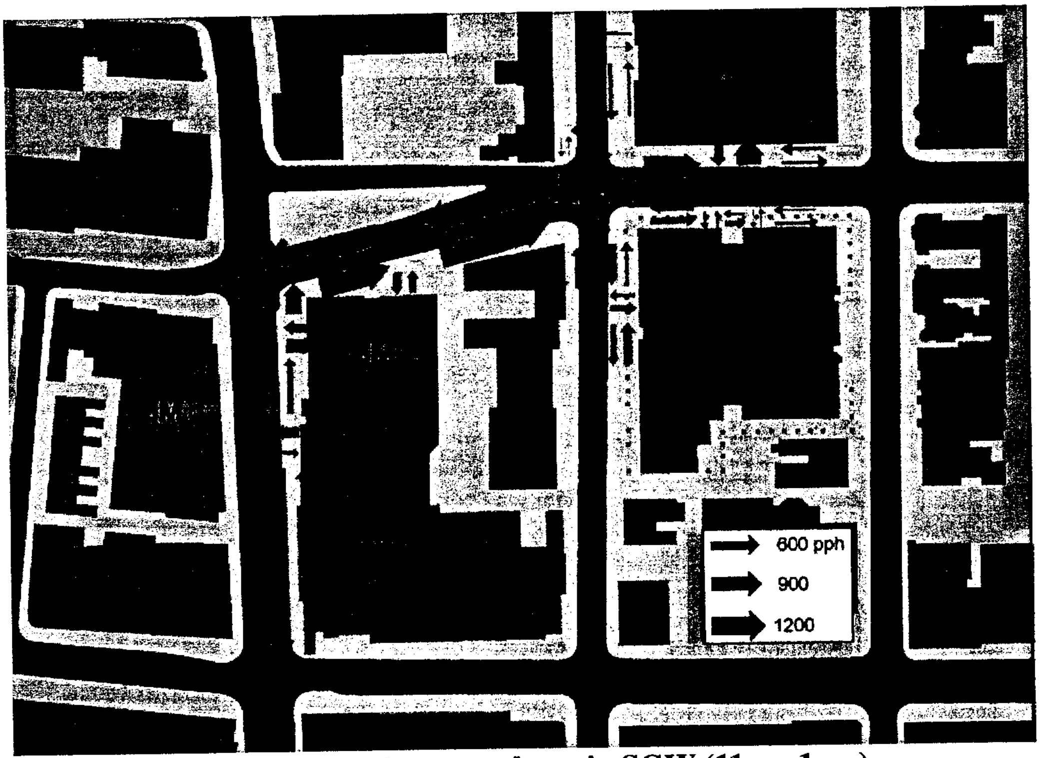

Figure 2.4-6: Pedestrian volume per hour in SGW (11am-1pm)

Using the time slot of 11am to 1pm as an example, pedestrian flow was counted on each street segment for 3 times to produce a mean value, which could be expressed as numbers of persons per hour, as shown in Figure 2.4-6 (for the other two time slot, see Appendix E).

The apportionment method developed by Thornton et al. (1987) was employed to conduct O-D analysis for three pairs of O-D pedestrian flow. The following sections would specify how to assign these flows into the surface route and the underground route, where the time slot of 11am to 1pm was chosen to illustrate this procedure (for the result of other two time slots, refer to Appendix H).

2.4.2.1 Pedestrian flow from the metro station to H & LB

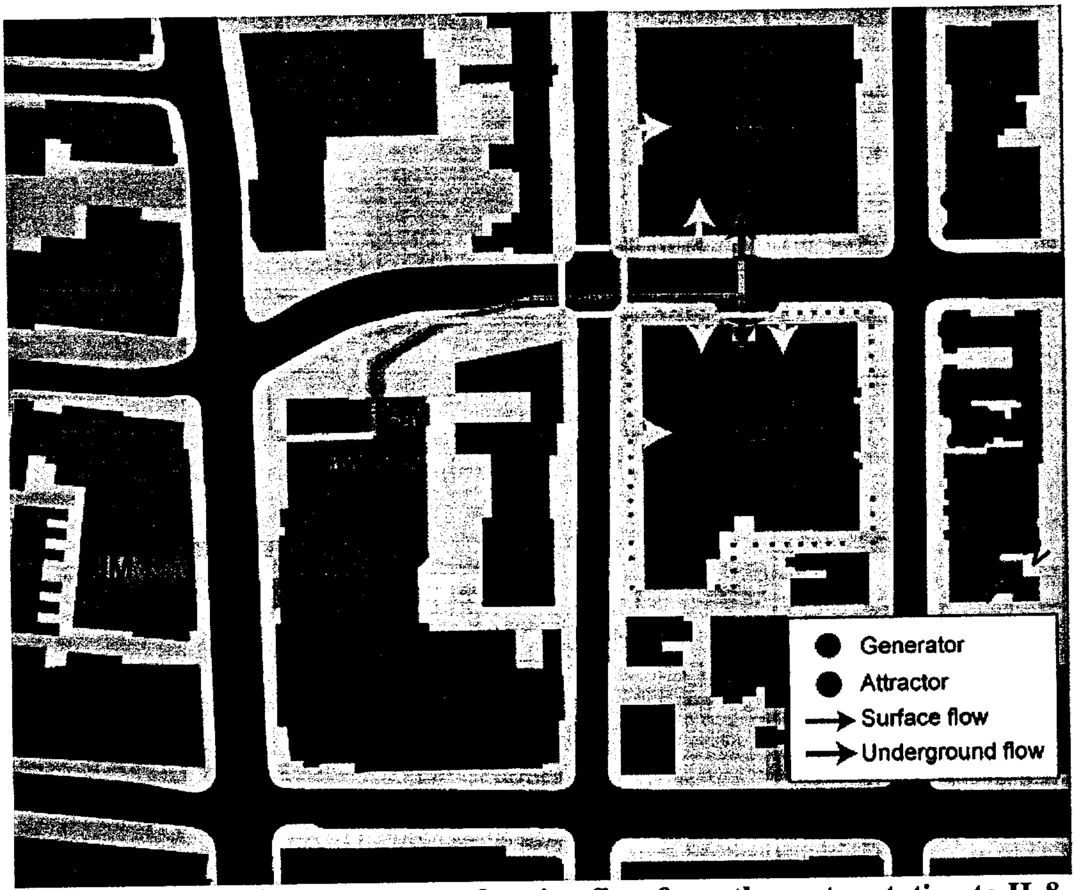

Figure 2.4-7: First pair of O-D pedestrian flow from the metro station to H & LB

Figure 2.4-7 shows the first pair of O-D pedestrian flow from the metro station to H & LB. It could be derived from the cordon counts of pedestrian flow using the tool of apportionment method, which was calculated at 71 persons per hour.

The ratio of people choosing the underground route from the metro station was estimated by a survey concerning the generation rate of commercial establishments and university facilities on the surface route. It was vital to state that the level of the station exit is located at the same level as the tunnel, meaning that people tend to choose the easier route, the underground route, to their destination without changing floor levels. However, the premise supporting the survey was that people choosing the surface route were attracted by the commercial establishments and university facilities on streets. The survey was conducted by a group of undergraduate students to produce the generation rate of the establishments, which was 0.25, meaning that 25% of pedestrians originating from metro station would choose surface route to visit these stores along their way to H & LB (see Appendix F). In other words, 75% of total volume of pedestrians from the station to H & LB would contribute to underground flow. As a result, in the first pair of O-D pedestrian flow, 53 persons per hour would choose the underground route, and 18 persons per hour choosing the surface route, as shown in Table 2.4-1.

Pedestrian Flow	Assigning ratio	N (persons per hour)
Total flow	100%	71
Underground flow	75%	53
Surface flow	25%	18

Table 2.4-1: Assignment of the first pair of O-D pedestrian flow (11am-1pm)

2.4.2.2 Pedestrian flow from the street corner to H & LB

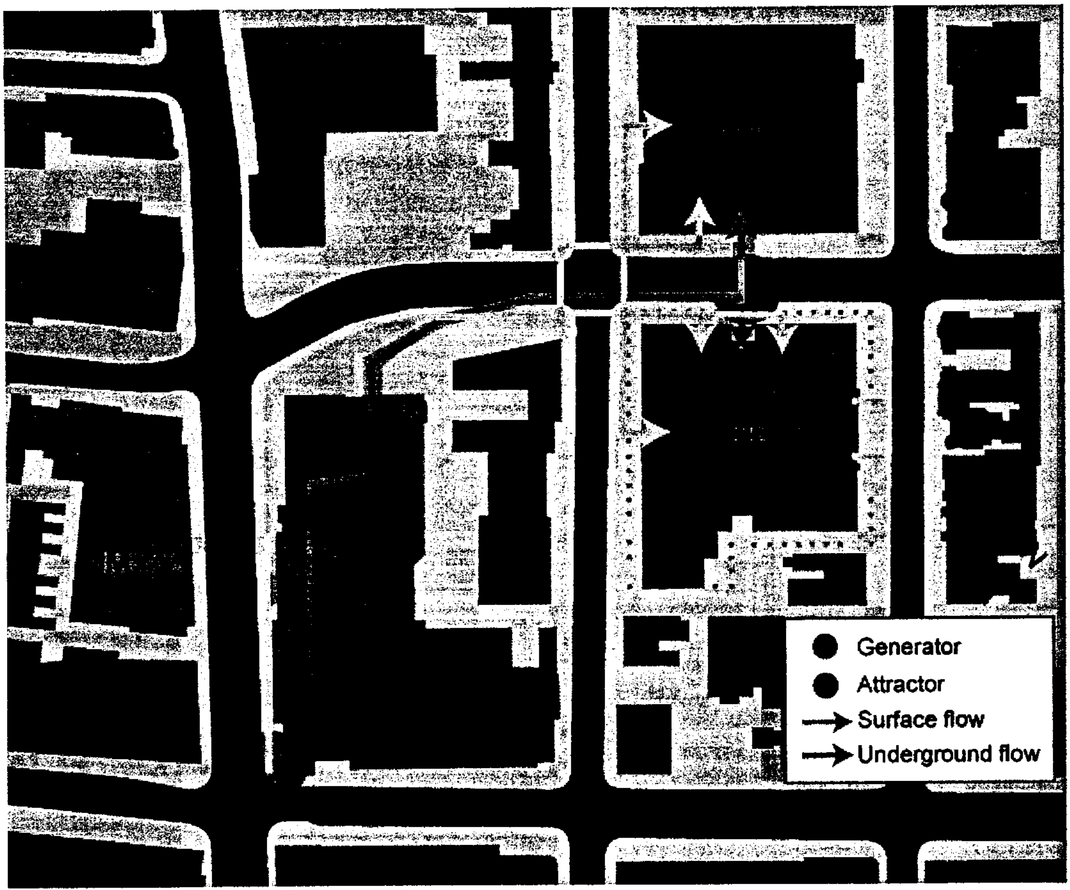

Figure 2.4-8: Second pair of O-D pedestrian flow from the street corner to H & LB

Figure 2.4-8 shows the second pair of O-D pedestrian flow from the street corner of Rue Guy & Rue Sainte-Catherine to H & LB. It can be calculated by the same technique applied in the analysis of the first pair of O-D flow with cordon counts and the apportionment system, which resulted in 54 persons per hour.

The ratio of assigning two alternative routes was decided by the mean value of the ratios obtained in the three operating tunnels, as shown in Table 1.5-1. In the summer season, the ratio choosing the underground route would be 0.25, while in winter season the ratio would be 0.45. Therefore, the number of the second pair of O-D flow choosing underground route in summer would be 14 persons per hour, and 40 persons per hour on surface route. In winter, the underground flow would be 24 persons per hour, and 30 persons per hour for surface flow, as shown in Table 2.4-2.

Pedestrian flow	**Assigning ratio**		**N (persons per hour)**	
	Summer	Winter	Summer	Winter
Total flow	100%	100%	54	54
Underground flow	25%	45%	14	24
Surface flow	75%	55%	40	30

Table 2.4-2: Assignment of the second pair of O-D pedestrian flow (11am-1pm)

2.4.2.3 Pedestrian flow from JM to H & LB

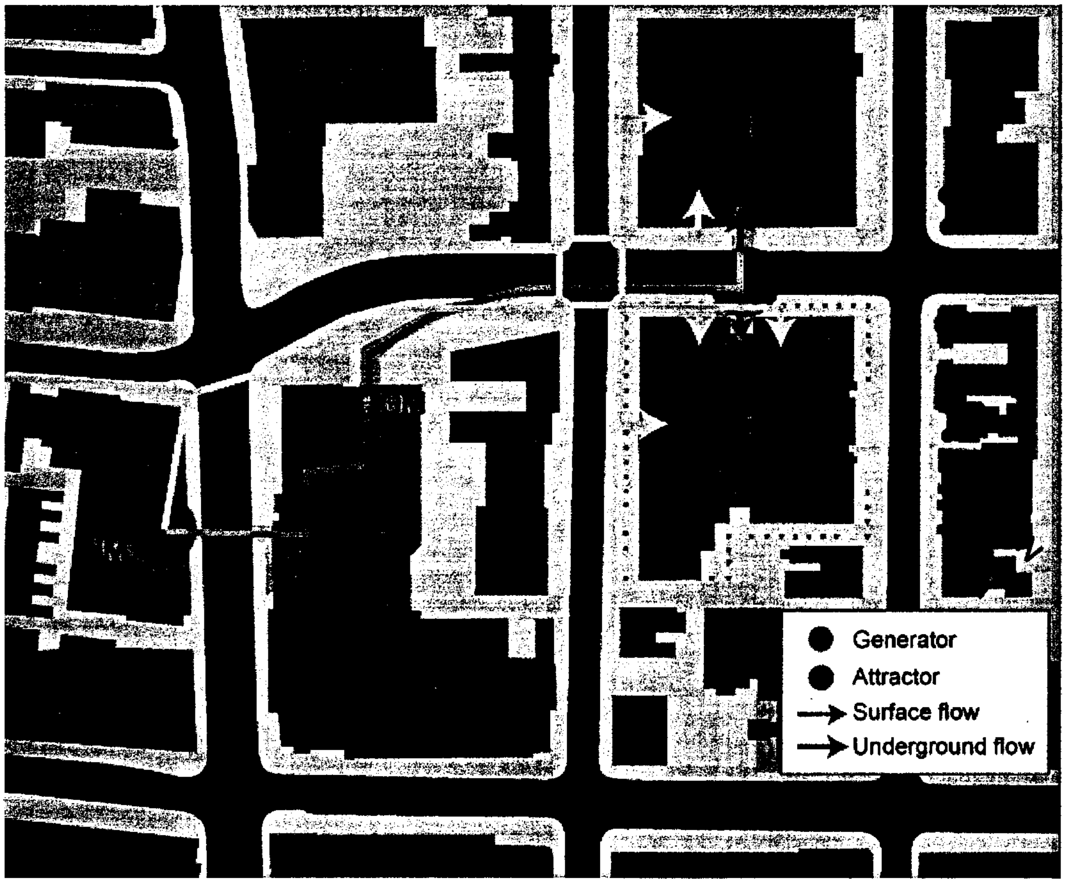

Figure 2.4-9: Third pair of O-D pedestrian flow from JM to H & LB

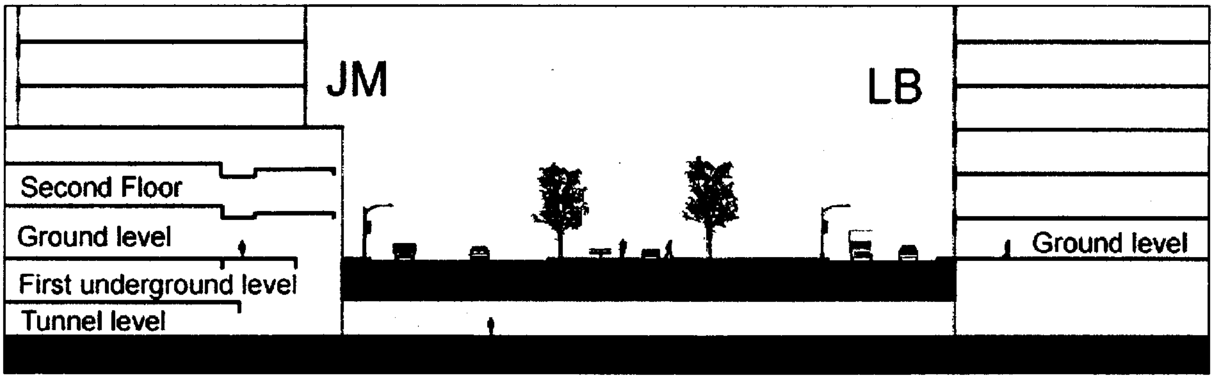

Figure 2.4-10: Section view of JM and LB

Figure 2.4-9 shows the third pair of O-D pedestrian flow from JM to H & LB. The O-D analysis of this flow was different from the other two pairs of flow described previously. According to JM building plans, the levels including first to six floors and two underground levels (Figure 2.4-10) would accommodate most of the classrooms and were expected to generate by far the largest part of the flow to the tunnel under Rue Guy. Therefore, the generation rate of pedestrian flow originating from JM, persons per hour, could be estimated by dividing the total capacity of the classrooms in these levels by an hour. Next, a survey was conducted to figure out how students used their time after class by another group of underground students (see Appendix G). The result shows that 50% of pedestrians from JM would go to H&LB. This percentage was used to calculate the total pedestrian flow in the third pair of O-D flow, which equalled 1409 persons per hour.

The ratios to assign pedestrian flow to two alternative routes can be distinguished by three sub-flows because of their difference in terms of starting points of O-D trips from JM building: the first to sixth floors, the first underground level, and the second underground level, as shown in Figure 2.4-10. For the sub-flow from the first to sixth floors, the ratio of choosing underground routes was the same one applied in the second pair of O-D flow from the street corner since their starting points were at the same level; for the sub-flow from the second underground level located at the same level of the tunnel, the ratio was the same one used in the first pair of O-D flow from the metro station; for the sub-flow from the first underground level located between the ground and tunnel level, the ratio was the mean value of two ratios mentioned above. Consequently, there would be 42% of the third pair of O-D flow from JM choosing underground route in summer season, while in winter season the proportion would be 55%, as shown in Table 2.4-3 and Table 2.4-4.

Building levels	**Total flow (persons per hour)**	**Surface flow**		**Underground flow**	
		Ratio	N	Ratio	N
First to six floors	767	75%	575	25%	192
First underground level	330	50%	165	50%	165
Second underground level	312	25%	78	75%	234
Total flow	1409	58%	818	42%	591

Table 2.4-3: Assignment of the third pair of O-D pedestrian flow in summer season

Building levels	**Total flow (persons per hour)**	**Surface flow**		**Underground flow**	
		Ratio	N	Ratio	N
First to six floors	767	55%	422	45%	345
First underground level	330	40%	132	60%	198
Second underground level	312	25%	78	75%	234
Total flow	1409	45%	632	55%	777

Table 2.4-4: Assignment of the third pair of O-D pedestrian flow in winter season

2.4.2.4 Total pedestrian flow from the generators to attractor

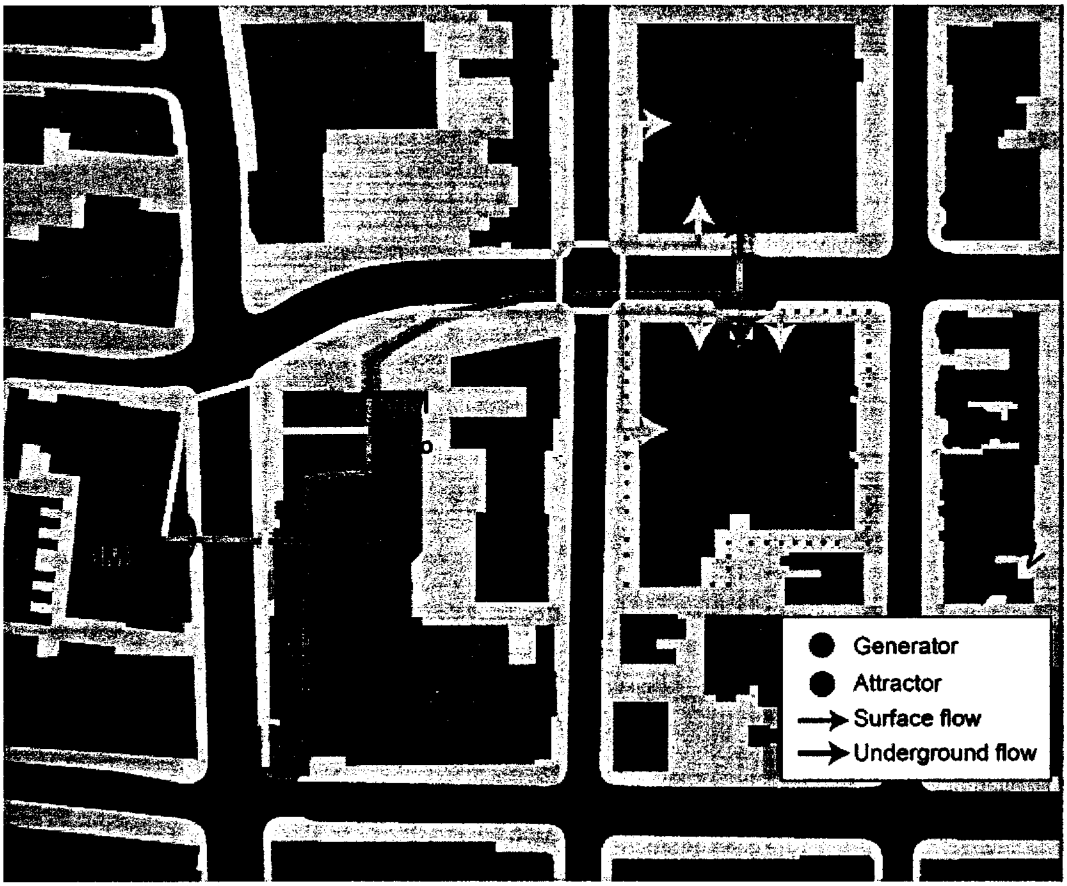

Figure 2.4-11: Total pedestrian flow from generators to attractors

Figure 2.4-11 shows the total pedestrian flow from the generators to attractor, which incorporated three flows from the metro station, the street corner, and JM. As Table 2.4-5 and Table 2.4-6 shows, the total flow from three generators was 1534 persons per hour, in which 43% of flow, or 658 persons per hour, were choosing the underground route in summer, and 56% of flow, or 854 persons per hour, in winter. It was also important to state that 92% of the total flow, or 1409 persons per hour, was from JM which played a key role in the use of the tunnel in this estimation.

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Flow from metro	5%	71	25%	18	75%	53
Flow from street corner	3%	54	75%	40	25%	14
Flow from JM	92%	1409	58%	818	42%	591
Total flow	100%	1534	57%	876	43%	658

Table 2.4-5: Assignment of three O-D flows in summer season (11am-1pm)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Flow from metro	5%	71	25%	18	75%	53
Flow from street corner	3%	54	55%	30	45%	24
Flow from JM	92%	1409	45%	632	55%	777
Total flow	100%	1534	44%	680	56%	854

Table 2.4-6: Assignment of three O-D flows in winter season (11am-1pm)

2.5 Discussion

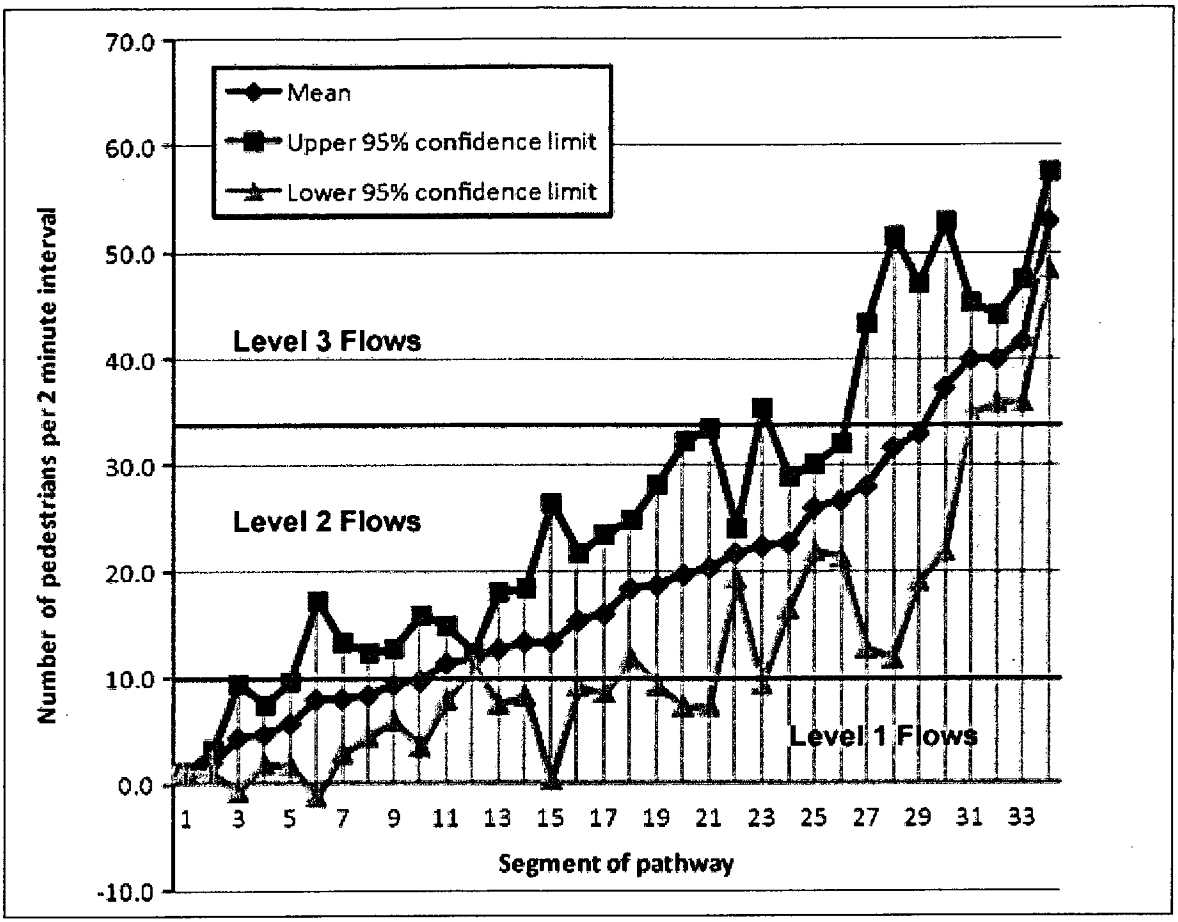

Figure 2.5-1: Levels of flows with 95% confidence interval (11am-1pm)

Figure 2.5-1 shows cordon counts in two minutes on 34 segment of pathway used for O-D analysis during the time period between 11am and 1pm. The cordon counts could be distinguished by three levels, 5 cordons in level 1, 6 cordons in level 2, and 4 cordons in level 3. However, there are still 19 out of a total of 34 cordons that do not fit within these levels due to their overlap of 95% confidence interval. For the time period between 8am and 10am, 15 cordons can fit within three flow levels, and14 cordons can be ranked for the time slot from 4pm to 6pm (see Appendix I). The low percentage of qualified cordon counts was caused by several flaws in the procedure of data collection. The first one came from the characteristics of pedestrian movement. Pedestrians tend to group together, or change direction frequently, which can cause high or low counts for the same counting period (Hocherman et al., 1986). Second, the three counts of two minutes interval on each segment during two hours period would also capture the unstable numbers since the small sample size and short counting time. In this case, other factors such as the schedule of class and arrival of metro cars could aggravate the fluctuation of pedestrian flow.

One solution to the fluctuating data is to increase sample size of flow counts. Using Route-23 which represents the pedestrian flow coming out from the metro station through GM building as an example (refer to Figure 5.4-1), pedestrian volumes in 2 minutes were counted with 12 times in the fall of 2008 (See Appendix J). Table 2.5-1 shows the difference between 3 counts and 12 counts in the time slot of 11am to 1pm, in which the group with 12 counts has higher mean value and shorter range of 95% confidence interval. The difference in other two time slots is reported in Appendix K.

Number of counts	**Mean (persons per 2 minutes)**	**Upper 95% confidence limit**	**Lower 95% confidence limit**
3 counts	28	43.3	12.7
12 counts	39.5	52.9	26.1

Table 2.5-1: Comparison of flows on Route-23 by different counts (11am-1pm)

The mean value calculated from 12 counts is used to produce the new O-D pedestrian flow from the metro station to H & LB, details of which can be seen in Appendix L. The changes of assignment of pedestrian flow can be depicted by three time slots in different seasons. First, in summer season between 8am and 10am, the first pair of O-D pedestrian flow from the metro station has 173 persons per hour based on 3 counts, and decreases to

158 persons per hour based on 12 counts. The share of this flow has decreased from 11% to 10% of total flow; however, the percentage choosing the underground route for total flow remains identical. This conclusion can be also applied to the flow between 8am and 10am in winter season. Next, in summer season between 11am and 1pm, the flow has 71 persons per hour based on 3 counts, and increases to 150 persons per hour based on 12 counts. The share of the flow has increased from 5% to 9% of total flow, which results in a small increase in ratio choosing the underground route for total flow, from 43% to 44%. There is also 1% of increase in ratio choosing the underground route for total flow between 11am and 1pm in winter season. Finally, in summer season between 4pm and 6pm, the flow has 25 persons per hour based on 3 counts, and increases to 45 persons per hour based on 12 counts. The share of the flow has increased from 2% to 3% of total flow, which results in a small increase in ratio choosing the underground route for total flow, from 42% to 43%. There is also 1% of increase in ratio choosing the underground route for total flow between 4pm and 6pm in winter season.

In general, the variance in the first pair of O-D pedestrian flows from the metro station based on 12 counts of pedestrian flow on Route-23 has a little of influence on the percentage choosing the underground route for total flow. This can be partly explained by the fact that the flow from the metro station only shares a small proportion of total flow, ranging from 2% to 11%.

2.6 Conclusion

The strategy of predicting pedestrian flow introduced in the study is a combination of several techniques applied to model aggregate pedestrian spatial behaviours, including cordon counts, apportionment system, and street interviews. In this way, the existing pedestrian dynamics and new generators of flow can be simultaneously considered to make predictions to guide urban development in multi-level urban environments, such as the feasibility of construction of an underpass.

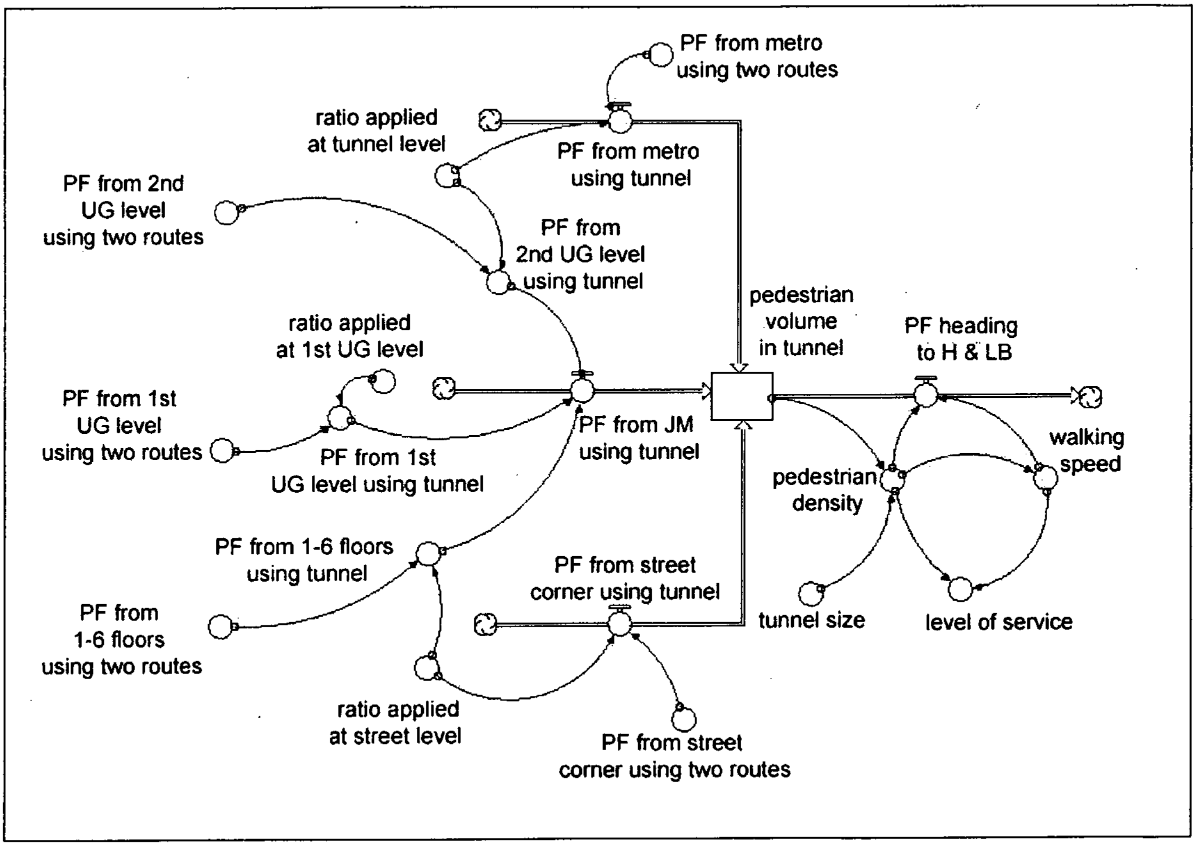

Figure 2.6-1: Model of the pedestrian dynamics in tunnel

Furthermore, the procedure of modelling pedestrian flow can be calibrated into a dynamic model, where PF stands for pedestrian flow, and UG stands for underground, as shown in Figure 2.6-1. The model was implemented by the software Stella (available on http://www.iseesystems.com), simulating three inflows and one outflow to calculate pedestrian volume in the tunnel. Using a systematic strategy, the model can produce the parameter of level-of-service in tunnel, which would be useful for tunnel design and facility management.

3 Summary of thesis

The first part of the thesis is intended to examine the related factors contributing to the preference in pedestrian path choices in a multi-level urban environment where two alternative routes are available to select, one on the surface and the other in the underground. Of those factors contributing to choice, the project firstly examine the effect of seasonal change on choice behaviour based on the common sense that underground space can provide a shelter from severe weather conditions, especially in winter in Canada. This leads to the supposition that the level of use of underground route competing with a parallel surface route will be higher in winter than summer. To prove this supposition, on February and May of 2009, the empirical study was conducted on three operating tunnels sites which offer two visible alternate routes for the researcher to collect pedestrian flow with the same pair of origin and destination. The difference of revealed route preference in the two months shows that weather associated with this change in season contributes to significantly different relative levels of use. The observation data are also used to give measure to the statistical relationship between five systematic factors and revealed route preference, including metric distance, direction change, presence of underground shops, street width, and vehicle traffic on surface. Furthermore, 90 respondents were interviewed on the same locations to examine the relationship between personal factors and stated route preference, to find out the order of importance for the factors concerning their route choice. The statistical analysis shows that there is no relationship between the factors of gender, age, familiarity, and trip purpose and stated route preference. It is not surprising to uncover that the respondents have ranked temperature and clear path, which relate to weather conditions, as the two most important factors affecting route choices.

The second part of the thesis focuses on the model of predicting the level of use of underground routes in a multi-level urban environment and its application on a planned tunnel in Concordia University. The model has incorporated several techniques including cordon counts and apportionment system to conduct origin and destination analysis of pedestrian flow between generators and attractors. Next, the projected flows on each alternative route are achieved by employing the distributing ratios obtained from empirical study. In the application of the Concordia case, the ratios are either produced from on-site survey or acquired directly from the findings on three operating tunnels cases, depending on the start point of pedestrian flow. The model demonstrates how an estimation model could work in such a case, and using the new empirical information. The real study requires more comprehensive cordon counts to project more accurate flow for better decision on facility design and management.

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5 Appendices

5.1 Appendix A: Survey questionnaire

Survey Questionnaire

Date and Time ____________________
Day of week ____________________
Location ______________________
Weather _______________________

I am carrying out a survey for my Master's degree research in the Department of Geography, Planning, and Environment of Concordia University, to determine pedestrian movement patterns in downtown Montreal. Would you please help me by answering a few questions?

Gender: Male____Female____
Age: 15-30____30-50____50-60____60+_____

1. Are you familiar with this area? Yes / No. If yes, how many times a week you visit this area?
   a. less than two times b. 2 to 5 times c. more than 5 times

2. What is the main purpose of your visit to this area?
   a. Work b. School c. Shopping d. Other

3. What is your route choice of walking between these two buildings?
   a. Ground-level route b. Tunnel route

4. Please specify the reasons why you make such route choice.

5. In what circumstances, you will change your decision of route choice?

6. Below is a list of factors that other researchers have found to influence your decision of route choice. For each one, please mark how important it is to you.

Factors	5.Very important	4.Important	3.Moderately important	2.Of little importance	1. Unimportant
Shorter distance (F1)					
Less changes of direction (F2)					
Less changes of level and less use of stairs, ramps, escalators, or lifts (F3)					
Less crowding (F4)					
Presence of shops, stores, restaurants, etc. (F5)					
Clear path surface without snow (F6)					
Moderate air temperature (F7)					
Feel safe without crossing street (F8)					

7. Are there any other factors influence your route choice? If yes, please specify them.

Thanks!

5.2 Appendix B: Pedestrian volume in 5 minutes counted in three operating tunnels

Location	Route choice	c1	c2	c3	c4	c5	c6	c7	c8
Tunnel #1	Underground	3	4	5	7	4	8	4	13
	Surface	12	11	6	14	10	13	12	9
Tunnel #2	Underground	7	12	10	22	16	14	8	14
	Surface	18	27	31	36	22	31	18	23
Tunnel #3	Underground	3	2	4	2	2	3	3	7
	Surface	55	29	54	32	57	47	46	74

Table 5.2-1: Pedestrian volume in 5 minutes counted in three operating tunnels (summer)

Location	Route choice	c1	c2	c3	c4	c5	c6	c7	c8
Tunnel #1	Underground	12	8	11	11	8	11	14	13
	Surface	7	11	1	5	8	12	12	10
Tunnel #2	Underground	49	31	54	29	46	34	27	29
	Surface	28	40	50	17	33	20	23	22
Tunnel #3	Underground	29	32	34	18	20	22	22	17
	Surface	59	105	73	80	82	83	100	75

Table 5.2-2: Pedestrian volume in 5 minutes counted in three operating tunnels (winter)

5.3 Appendix C: Personal information of respondents (n=90)

Gender	Tunnel #1		Tunnel #2		Tunnel #3		Total	
	N	Ratio	N	Ratio	N	Ratio	N	Ratio
Male	17	57%	17	57%	15	50%	49	54%
Female	13	43%	13	43%	15	50%	41	46%
Total	30	100%	30	100%	30	100%	90	100%

Table 5.3-1: Gender information on respondents in three locations

Age	Tunnel #1		Tunnel #2		Tunnel #3		Total	
	N	Ratio	N	Ratio	N	Ratio	N	Ratio
15-30	7	23%	8	27%	7	23%	22	24%
31-50	16	54%	15	50%	15	50%	46	51%
51-60	6	20%	3	10%	6	20%	15	17%
Over 60	1	3%	4	13%	2	7%	7	8%
Total	30	100%	30	100%	30	100%	90	100%

Table 5.3-2: Age information of respondents in three locations

Familiarity	Tunnel #1		Tunnel #2		Tunnel #3		Total	
	N	Ratio	N	Ratio	N	Ratio	N	Ratio
None	4	13%	5	17%	3	10%	12	13%
Less than 2 times	20	67%	16	53%	15	50%	51	57%
2 to 5 times	6	20%	6	20%	7	23%	19	21%
Over 5 times	0	0%	3	10%	5	17%	8	9%
Total	30	100%	30	100%	30	100%	90	100%

Table 5.3-3: Familiarity information of respondents in three locations

Purpose	Tunnel #1		Tunnel #2		Tunnel #3		Total	
	N	Ratio	N	Ratio	N	Ratio	N	Ratio
Work	13	43%	4	13%	17	57%	34	38%
School	1	3%	1	3%	0	0%	2	2%
Shopping	5	17%	10	34%	3	10%	18	20%
Other	11	37%	15	50%	10	33%	36	40%
Total	30	100%	30	100%	30	100%	90	100%

Table 5.3-4: Purpose information of respondents in three locations

5.4 Appendix D: Pedestrian volume in 2 minutes in SGW (3 counts)

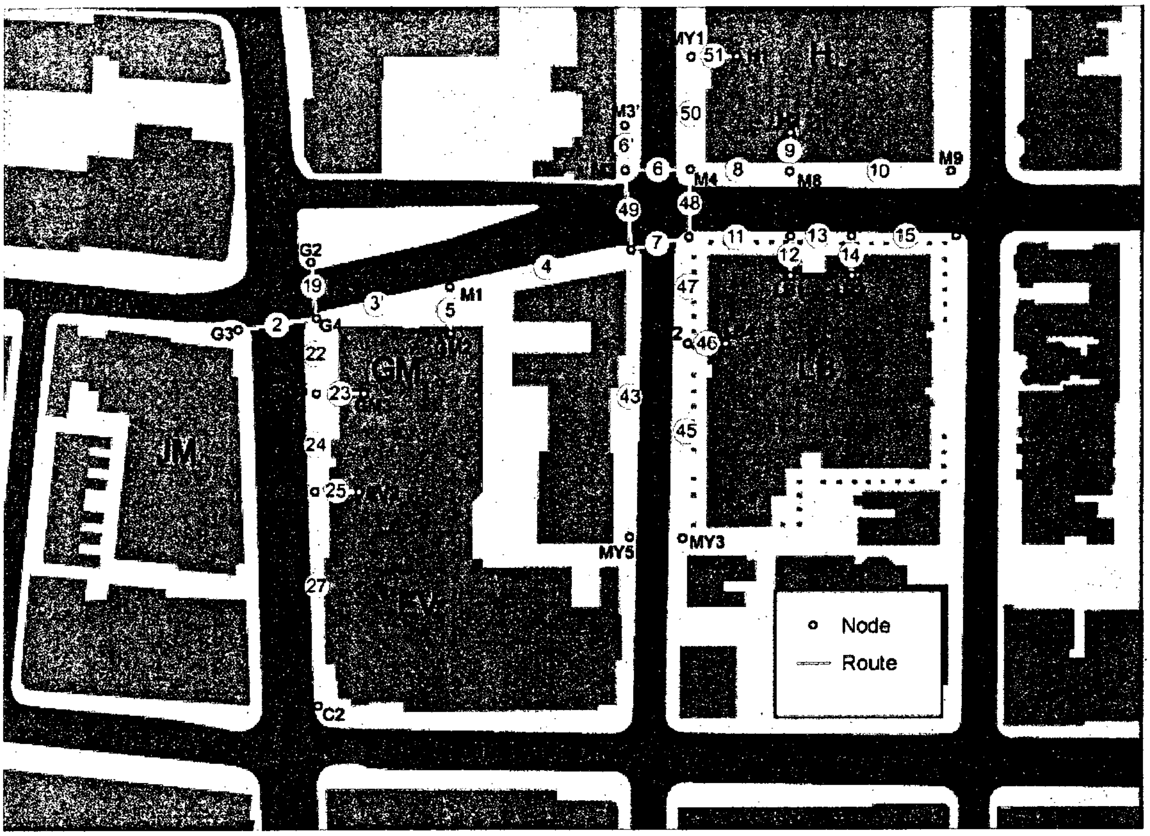

Figure 5.4-1: Map of routes and nodes for cordon counts in SGW campus

Cordon counts in 2 minutes (8:00am-10:00am)								
Routes	Direction	C1	C2	C3	Mean	SD	Upper 95% confidence limit	Lower 95% confidence limit
50	M4-MY1	0	2	1	1.0	1.0	2.1	-0.1
6'	M3-M3'	1	1	1	1.0	0.0	1.0	1.0
52	MY1-MY6	1	3	1	1.7	1.2	3.0	0.4
14	M7-LB2	1	1	3	1.7	1.2	3.0	0.4
43	M2-MY5	1	4	3	2.7	1.5	4.4	0.9
51	MY1-H1	2	3	3	2.7	0.6	3.3	2.0
25	G6-EV2	6	1	5	4.0	2.6	7.0	1.0
15	M7-M10	6	8	6	6.7	1.2	8.0	5.4
5	M1-GM2	9	6	6	7.0	1.7	9.0	5.0
10	M8-M9	6	14	1	7.0	6.6	14.4	-0.4

13	M6-M7	3	13	7	7.7	5.0	13.4	2.0
6	M4-M3	2	18	4	8.0	8.7	17.9	-1.9
47	M5-MY2	5	7	12	8.0	3.6	12.1	3.9
45	MY2-MY3	3	1	21	8.3	11.0	20.8	-4.1
11	M5-M6	5	7	13	8.3	4.2	13.0	3.6
49	M2-M3	6	10	10	8.7	2.3	11.3	6.1
9	M8-H2	6	11	10	9.0	2.6	12.0	6.0
19	G4-G2	7	5	19	10.3	7.6	18.9	1.8
48	M4-M5	10	18	4	10.7	7.0	18.6	2.7
24	G6-G5	4	20	10	11.3	8.1	20.5	2.2
6	M3-M4	10	13	11	11.3	1.5	13.1	9.6
46	MY2-LB4	8	12	18	12.7	5.0	18.4	7.0
48	M5-M4	8	12	20	13.3	6.1	20.2	6.4
27	C2-G6	16	14	11	13.7	2.5	16.5	10.8
12	M6-LB1	2	22	18	14.0	10.6	26.0	2.0
8	M4-M8	7	15	25	15.7	9.0	25.9	5.5
2	G4-G3	38	7	5	16.7	18.5	37.6	-4.3
23	G5-GM3	12	52	12	25.3	23.1	51.5	-0.8
22	G5-G4	51	30	11	30.7	20.0	53.3	8.0
4	M1-M2	6	33	58	32.3	26.0	61.8	2.9
24	G5-G6	20	46	48	38.0	15.6	55.7	20.3
23	GM3-G5	0	37	110	49.0	56.0	112.3	-14.3
7	M2-M5	53	41	58	50.7	8.7	60.6	40.8
3'	G4-M1	70	47	43	53.3	14.6	69.8	36.8

Table 5.4-1: Cordon counts of pedestrian volume in 2 minutes in SGW (8am-10am)

Cordon counts in 2 minutes (11:00am-1:00pm)								
Routes	Direction	C1	C2	C3	Mean	SD	Upper 95% confidence limit	Lower 95% confidence limit
6'	M3-M3'	1	1	1	1.0	0.0	1.0	1.0
51	MY1-H1	2	3	1	2.0	1.0	3.1	0.9
52	MY1-MY6	9	0	4	4.3	4.5	9.4	-0.8
14	M7-LB2	5	7	2	4.7	2.5	7.5	1.8
50	M4-MY1	9	2	6	5.7	3.5	9.6	1.7
15	M7-M10	6	17	1	8.0	8.2	17.3	-1.3
10	M8-M9	9	12	3	8.0	4.6	13.2	2.8
13	M6-M7	5	12	8	8.3	3.5	12.3	4.4

25	G6-EV2	12	10	6	9.3	3.1	12.8	5.9
43	M2-MY5	6	7	16	9.7	5.5	15.9	3.4
5	M1-GM2	14	8	12	11.3	3.1	14.8	7.9
49	M2-M3	11	12	12	11.7	0.6	12.3	11.0
2	G4-G3	18	10	10	12.7	4.6	17.9	7.4
45	MY2-MY3	18	9	13	13.3	4.5	18.4	8.2
47	M5-MY2	25	2	13	13.3	11.5	26.4	0.3
46	MY2-LB4	21	15	10	15.3	5.5	21.6	9.1
12	M6-LB1	15	23	10	16.0	6.6	23.4	8.6
11	M5-M6	15	25	15	18.3	5.8	24.9	11.8
48	M5-M4	12	28	16	18.7	8.3	28.1	9.2
6	M4-M3	9	19	31	19.7	11.0	32.1	7.2
48	M4-M5	20	32	9	20.3	11.5	33.4	7.3
19	G4-G2	21	24	20	21.7	2.1	24.0	19.3
27	C2-G6	34	11	22	22.3	11.5	35.4	9.3
24	G5-G6	17	23	28	22.7	5.5	28.9	16.4
7	M2-M5	30	23	25	26.0	3.6	30.1	21.9
24	G6-G5	23	25	32	26.7	4.7	32.0	21.3
23	GM3-G5	15	27	42	28.0	13.5	43.3	12.7
6	M3-M4	30	15	50	31.7	17.6	51.5	11.8
23	G5-GM3	47	24	28	33.0	12.3	46.9	19.1
3'	G4-M1	52	25	35	37.3	13.7	52.8	21.9
4	M1-M2	41	35	44	40.0	4.6	45.2	34.8
8	M4-M8	37	44	39	40.0	3.6	44.1	35.9
22	G5-G4	41	47	37	41.7	5.0	47.4	36.0
9	M8-H2	53	49	57	53.0	4.0	57.5	48.5

Table 5.4-2: Cordon counts of pedestrian volume in 2 minutes in SGW (11am-1pm)

Cordon Counts in 2 minutes (4:00pm-6:00pm)								
Routes	Direction	C1	C2	C3	Mean	SD	Upper 95% confidence limit	Lower 95% confidence limit
6'	M3-M3'	1	1	1	1.0	0.0	1.0	1.0
25	G6-EV2	5	3	1	3.0	2.0	5.3	0.7
14	M7-LB2	1	12	10	7.7	5.9	14.3	1.0
15	M7-M10	4	8	15	9.0	5.6	15.3	2.7
47	M5-MY2	11	3	14	9.3	5.7	15.8	2.9
52	MY1-MY6	6	17	6	9.7	6.4	16.9	2.5

46	MY2-LB4	12	8	16	12.0	4.0	16.5	7.5
51	MY1-H1	2	20	16	12.7	9.5	23.4	2.0
50	M4-MY1	4	27	10	13.7	11.9	27.2	0.2
48	M5-M4	7	22	15	14.7	7.5	23.2	6.2
13	M6-M7	3	17	25	15.0	11.1	27.6	2.4
19	G4-G2	31	2	14	15.7	14.6	32.2	-0.8
10	M8-M9	13	18	18	16.3	2.9	19.6	13.1
48	M4-M5	15	17	22	18.0	3.6	22.1	13.9
49	M2-M3	6	32	17	18.3	13.1	33.1	3.6
11	M5-M6	12	28	18	19.3	8.1	28.5	10.2
45	MY2-MY3	14	24	22	20.0	5.3	26.0	14.0
6	M3-M4	12	8	40	20.0	17.4	39.7	0.3
7	M2-M5	20	3	40	21.0	18.5	42.0	0.0
3'	G4-M1	38	0	26	21.3	19.4	43.3	-0.6
2	G4-G3	22	11	32	21.7	10.5	33.6	9.8
43	M2-MY5	10	35	22	22.3	12.5	36.5	8.2
6	M4-M3	21	17	40	26.0	12.3	39.9	12.1
22	G5-G4	46	11	22	26.3	17.9	46.6	6.1
5	M1-GM2	14	41	25	26.7	13.6	42.0	11.3
23	GM3-G5	42	2	42	28.7	23.1	54.8	2.5
23	G5-GM3	43	5	40	29.3	21.1	53.2	5.4
8	M4-M8	13	48	28	29.7	17.6	49.5	9.8
12	M6-LB1	34	28	31	31.0	3.0	34.4	27.6
9	M8-H2	14	56	30	33.3	21.2	57.3	9.3
27	C2-G6	31	63	20	38.0	22.3	63.3	12.7
24	G5-G6	35	38	62	45.0	14.8	61.7	28.3
24	G6-G5	43	45	60	49.3	9.3	59.8	38.8
4	M1-M2	58	31	60	49.7	16.2	68.0	31.3

Table 5.4-3: Cordon counts of pedestrian volume in 2 minutes in SGW (4pm-6pm)

5.5 Appendix E: Pedestrian volume per hour in SGW campus

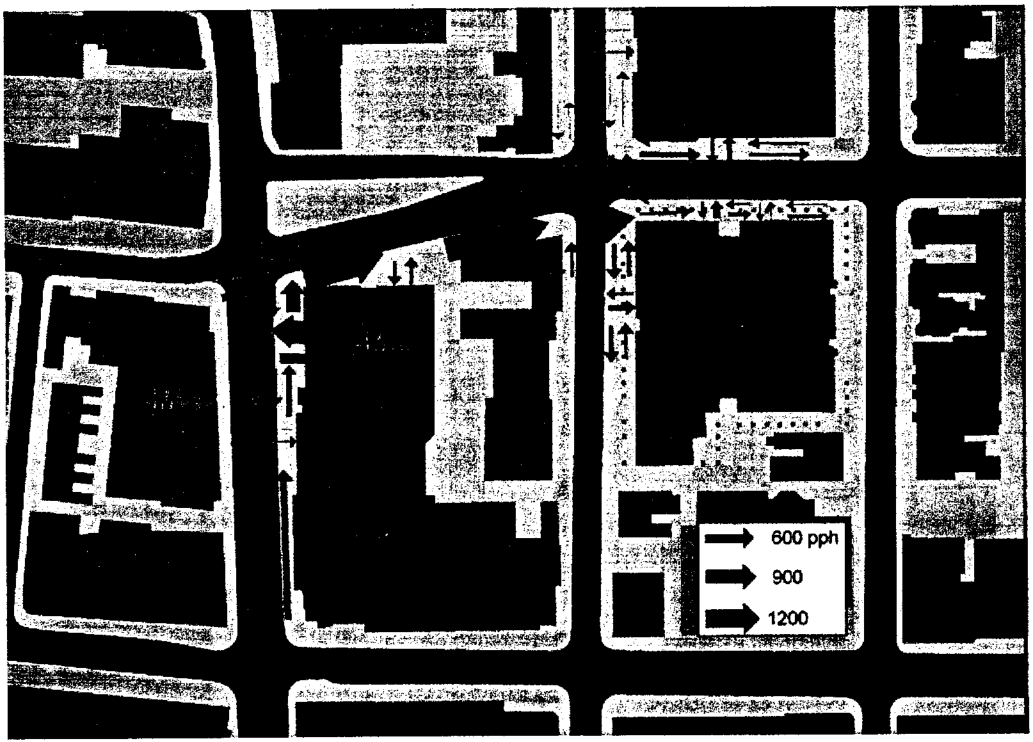

Figure 5.5-1: Pedestrian volume per hour in SGW (8am-10am)

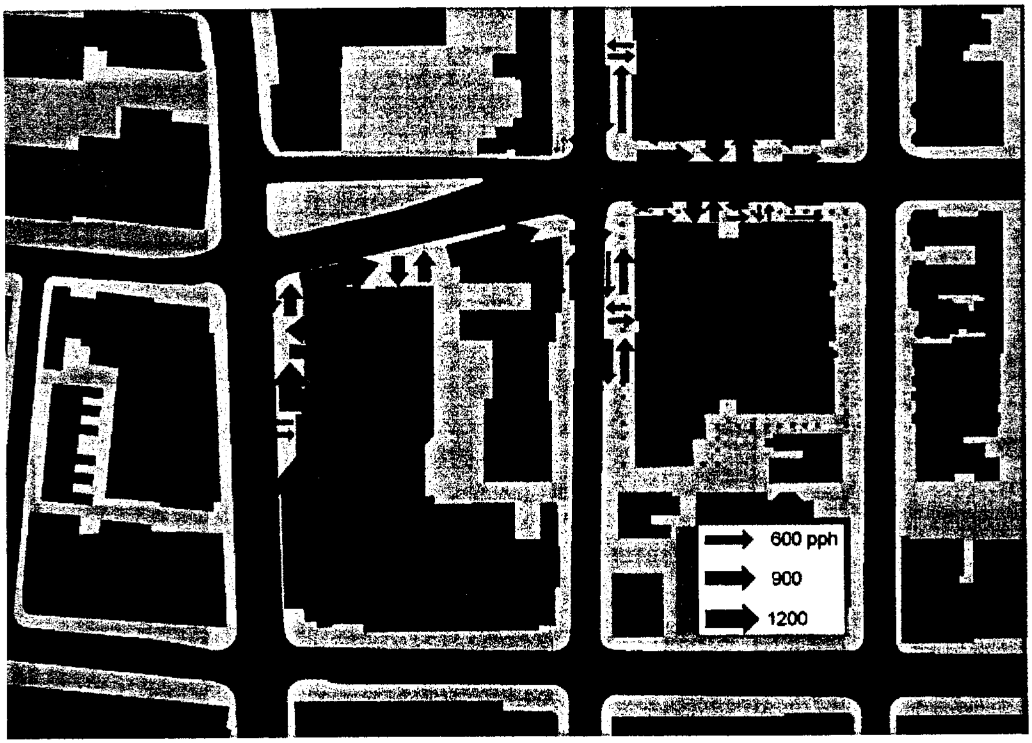

Figure 5.5-2: Pedestrian volume per hour in SGW (4pm-6pm)

5.6 Appendix F: Survey on commercial establishments and university facilities

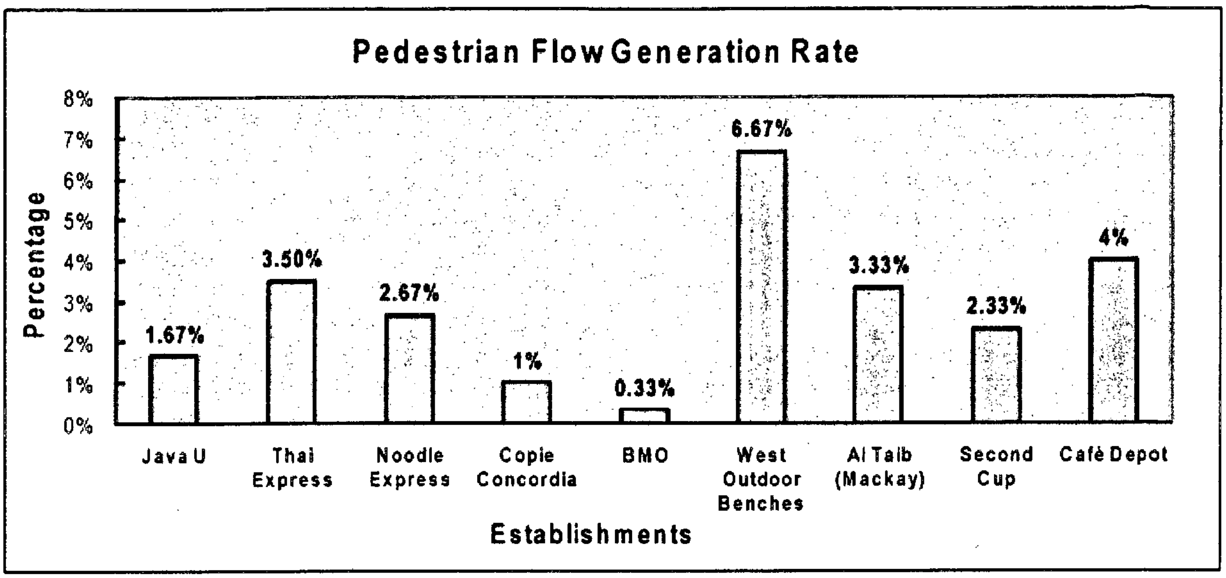

Figure 5.6-1: Generation rate of commercial establishments and university facilities

Note: The total generation rate is 25%.

5.7 Appendix G: Survey on distribution of students in SGW campus

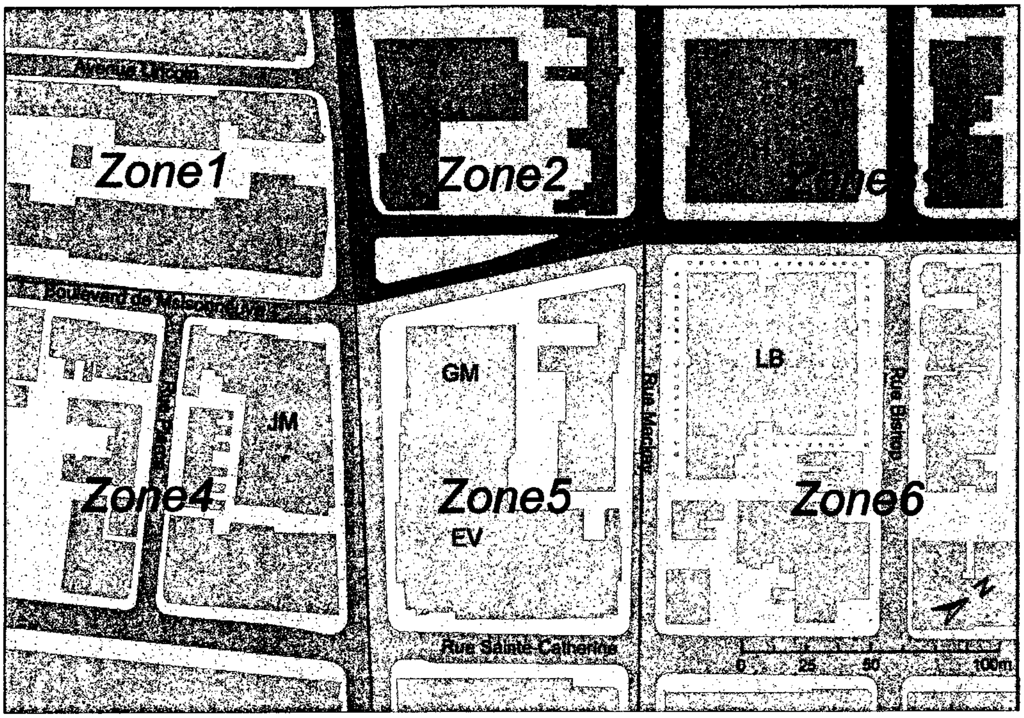

Figure 5.7-1: Map of distribution zones

Zone	1	2	3	4	5	6
Distribution rate	2%	4%	35%	10%	34%	15%

Table 5.7-1: Distribution rate of students by zones

5.8 Appendix H: Assignment of three O-D pedestrian flows in SGW

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	11%	173	25%	43	75%	130
Street corner-->H&LB	3%	44	75%	33	25%	11
JM-->H&LB	86%	1409	58%	818	42%	591
Total flow	100%	1626	55%	894	45%	732

Table 5.8-1: Assignment of three O-D flows in summer season (8am-10am)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	11%	173	25%	43	75%	130
Street corner-->H&LB	3%	44	55%	24	45%	20
JM-->H&LB	86%	1409	45%	632	55%	777
Total flow	100%	1626	43%	699	57%	927

Table 5.8-2: Assignment of three O-D flows in winter season (8am-10am)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	2%	25	25%	6	75%	19
Street corner-->H&LB	3%	39	75%	29	25%	10
JM-->H&LB	95%	1409	58%	818	42%	591
Total flow	100%	1473	58%	853	42%	620

Table 5.8-3: Assignment of three O-D flows in summer season (4pm-6pm)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	2%	25	25%	6	75%	19
Street corner-->H&LB	3%	39	55%	21	45%	18
JM-->H&LB	95%	1409	45%	632	55%	777
Total flow	100%	1473	46%	659	55%	814

Table 5.8-4: Assignment of three O-D flows in winter season (4pm-6pm)

5.9 Appendix I: Levels of flows with 95% confidence interval

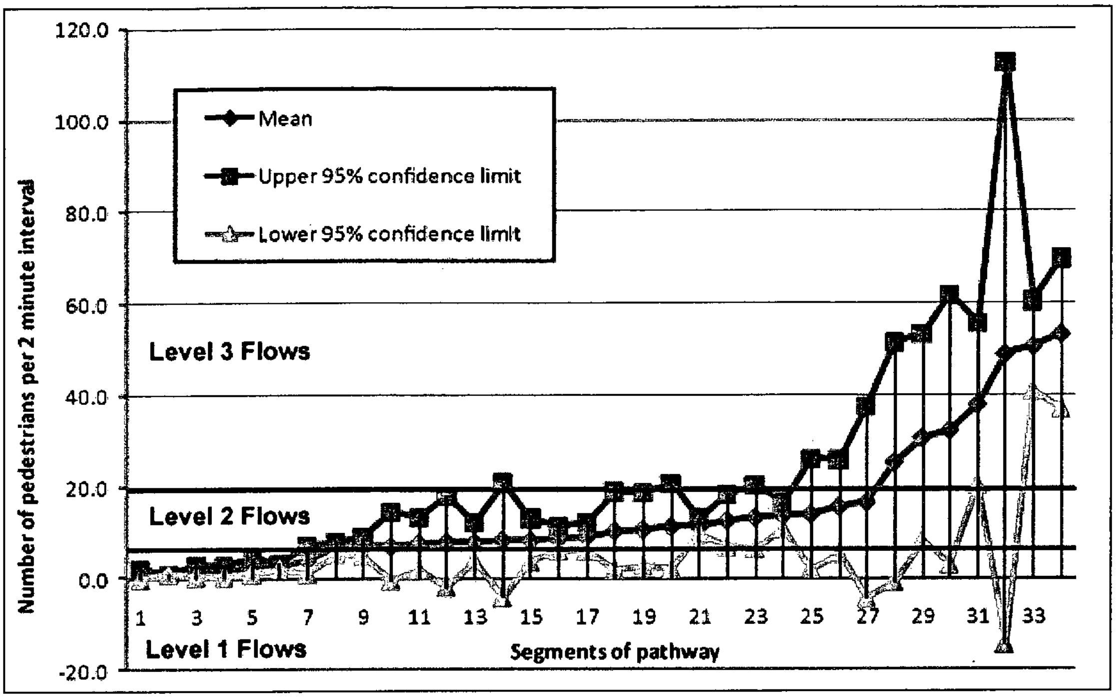

Figure 5.9-1: Levels of flows with 95% confidence interval (8am-10am)

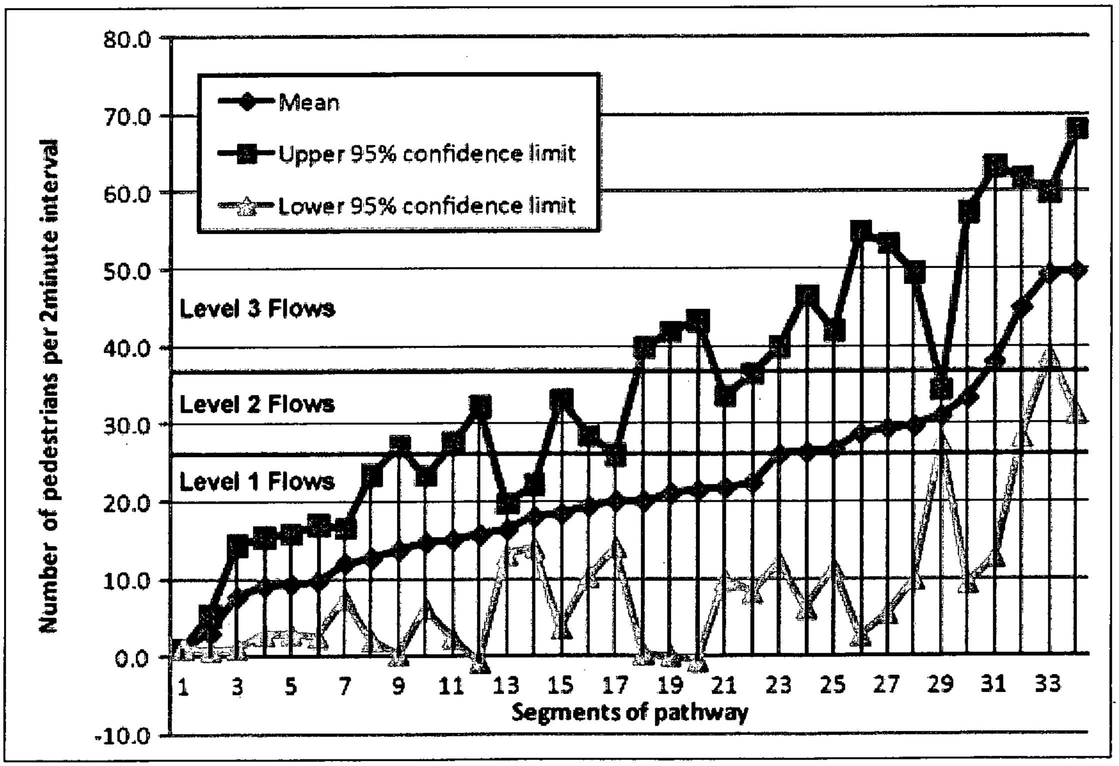

Figure 5.9-2: Levels of flows with 95% confidence interval (4pm-6pm)

5.10 Appendix J: Pedestrian volumes in 2 minutes of Route-23 (12 counts)

Time slots	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12
8am-10am	54	46	45	43	34	78	86	71	41	18	9	13
11am-1pm	30	24	18	16	11	24	33	42	67	77	76	56
4pm-6pm	79	67	66	61	46	43	47	79	47	27	27	48

Table 5.10-1: Pedestrian volumes in 2 minutes of Route-23 (12 counts)

5.11 Appendix K: Comparison of flows on Route-23 by different counts

Number of counts	Mean (persons per 2 minutes)	Upper 95% confidence limit	Lower 95% confidence limit
3 counts	49.0	112.3	-14.3
12 counts	44.8	58.8	30.8

Table 5.11-1: Comparison of flow on Route-23 by different counts (8am-10am)

Number of counts	Mean (persons per 2 minutes)	Upper 95% confidence limit	Lower 95% confidence limit
3 counts	28.7	54.8	2.5
12 counts	53.0	63.0	43.2

Table 5.11-2: Comparison of flow on Route-23 by different counts (4pm-6pm)

5.12 Appendix L: Assignment of three O-D pedestrian flows in SGW (revised)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	10%	158	25%	40	75%	118
Street corner-->H&LB	3%	44	75%	33	25%	11
JM-->H&LB	87%	1409	58%	818	42%	591
Total flow	100%	1611	55%	891	45%	720

Table 5.12-1: Revised assignment of three O-D flows in summer season (8am-10am)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	10%	158	25%	40	75%	118
Street corner-->H&LB	3%	44	55%	24	45%	20
JM-->H&LB	87%	1409	45%	632	55%	777
Total flow	100%	1611	43%	696	57%	915

Table 5.12-2: Revised assignment of three O-D flows in winter season (8am-10am)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	9%	150	25%	38	75%	112
Street corner-->H&LB	3%	54	75%	40	25%	14
JM-->H&LB	88%	1409	58%	818	42%	591
Total flow	100%	1613	56%	896	44%	717

Table 5.12-3: Revised assignment of three O-D flows in summer season (11am-1pm)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	9%	150	25%	38	75%	112
Street corner-->H&LB	3%	54	55%	30	45%	24
JM-->H&LB	88%	1409	45%	632	55%	777
Total flow	100%	1613	43%	700	57%	913

Table 5.12-4: Revised assignment of three O-D flows in winter season (11am-1pm)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	3%	45	25%	11	75%	34
Street corner-->H&LB	3%	39	75%	29	25%	10
JM-->H&LB	94%	1409	58%	818	42%	591
Total flow	100%	1493	57%	858	43%	635

Table 5.12-5: Revised assignment of three O-D flows in summer season (4pm-6pm)

Pedestrian flows	Total flow		Surface route		Underground route	
	Ratio	N (pph)	Ratio	N (pph)	Ratio	N (pph)
Metro-->H&LB	3%	45	25%	11	75%	34
Street corner-->H&LB	3%	39	55%	21	45%	18
JM-->H&LB	94%	1409	45%	632	55%	777
Total flow	100%	1493	44%	664	56%	829

Table 5.12-6: Revised assignment of three O-D flows in winter season (4pm-6pm)