# Creating a Pedestrian Behaviour Prediction Model from an Empirical Study of the Xu Jia Hui Pedestrian Network in Shanghai

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## Abstract

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It is increasingly common for cities across the planet to intensify commercial and residential developments around transportation hubs. With these transportation hubs and the commercial nodes developed immediately around them comes a large volume of pedestrians. In order to have a functional network that does not hinder the operation and activities at the commercial node, there have to be well designed connections between the transportation hub and the various commercial spaces and outlets. In order to create a network that will be efficient and well used by the pedestrians, the future behaviour of pedestrians in such planned environments should be evaluated.

This study has utilized approaches from various studies of pedestrian behaviour in complex urban environments and combined them to create a predictive model for pedestrian behaviour at the Xu Jia Hui commercial node in Shanghai, China. The current pedestrian network was studied and analyzed. From those results an equation was developed to predict pedestrian movements; this equation was used to distribute flows heuristically around the proposed expansion of the network. This thesis demonstrates that such a predictive model can be created using a combination of previously used techniques. The results of running the model show that there are problems with the design of the new Xu Jia Hui network that should be addressed.

## Acknowledgments

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# 1-Introduction

## 1.1-Introduction:

An emerging area of urban planning is the study of pedestrian behaviour. Whether in a central business district, main shopping or entertainment streets and districts, or high density neighbourhoods, the quality of the pedestrian environment has an effect on the quality of people's lives. If people cannot get to where they have to go quickly and easily, time and money are wasted. The design of a commercial pedestrian environment determines the ease with which the pedestrians can move around, which in turn determines whether or not those pedestrians will return to shop in that commercial area. To understand the best way to design a pedestrian network, one must understand the behavioural patterns of pedestrians when it comes to route choice and use of space.

Currently there is little focus on the actual behaviour of pedestrians in the development of metro stations and the surrounding areas. The development of Line-11, a new subway line crossing Shanghai from north to south cutting across the Pudong District, is an example. The planning firm Atkins, together with SHKM Construction Management, are designing the line based on populations of areas it passes through and the assumption that people will be using the line to travel to work. They use studies and mathematical models to estimate peak period travel and are conducting small studies to get an idea of bus line interaction with the metro stations they are planning. Absent from this report on the progress of Line-11 is anything about pedestrian traffic at the metro stations and the connection of these metro stations to surrounding commercial buildings, outlets and places of work which the transit riders are supposed to be travelling to. This is an important element missing from the process of urban planning at the moment.

The purpose of this thesis project is to elaborate on a behavioural pedestrian model that examines the physical factors in pedestrians choosing to move through a complex, multi-level urban environment. This particular urban environment, Xu Jia Hui, is located in the city of Shanghai, China. It is currently going through a transformation in terms of new housing and commercial space construction and the addition of new public transportation facilities. This thesis project will analyze the effects of those changes on the existing pedestrian network, as well as the affects of new pathways and transit facilities to be added to the network. Another purpose is to determine if a valid predictive model of pedestrian behaviour can be designed based on a physical description of the site and conducted within the time constraints of ten days with limited numbers of people to carry out observations.

### 1.2-Xu Jia Hui:

Xu Jia Hui is a commercial node in the south-western part of the City of Shanghai. It is currently accessible by five major roads that form the intersection around which the node is built. Numerous bus routes, bike paths, and a subway line also provide access. At the center of this node are two malls, four large department stores and an electronics super-store located at the intersection of the five major roads intersecting at Xu Jia Hui. These large buildings are connected to the Xu Jia Hui subway station via a web of tunnels. There are two street level crossings for pedestrians and at the south-west side of the intersection, there is a pedestrian bridge with multiple exit points. The flow of pedestrian traffic, car traffic, bus traffic and bicycle traffic through this area is heavy. Surrounding this commercial core is a sea of high rise condominiums laid out in clusters of towers. Many more condominiums are currently under construction in the area, such that is expected that construction and expansion of the commercial core of Xu Jia Hui will continue. Yet the area is already congested with traffic and densely populated with commercial and residential uses. The further construction will cause traffic and pedestrian related complications that must be planned for in advance.

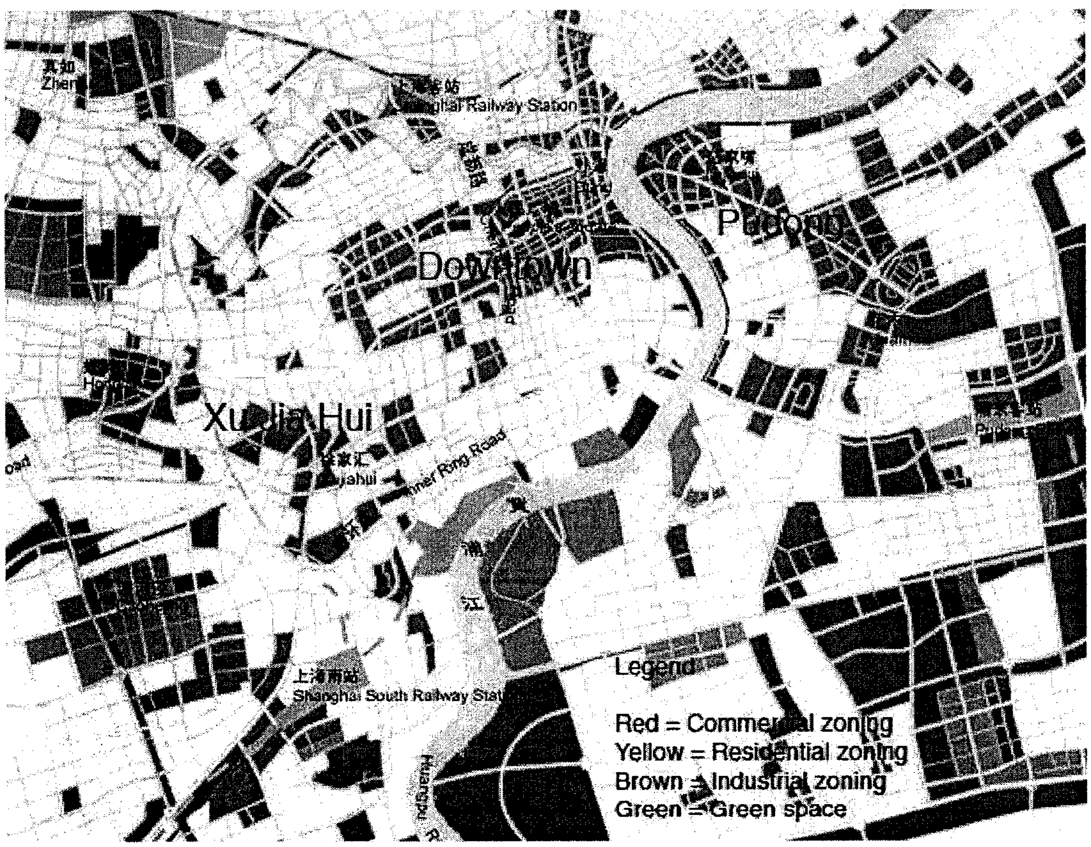


**Figure 1-1: Shanghai zoning use map** (Shanghai Urban Planning Administration Bureau, 2001)

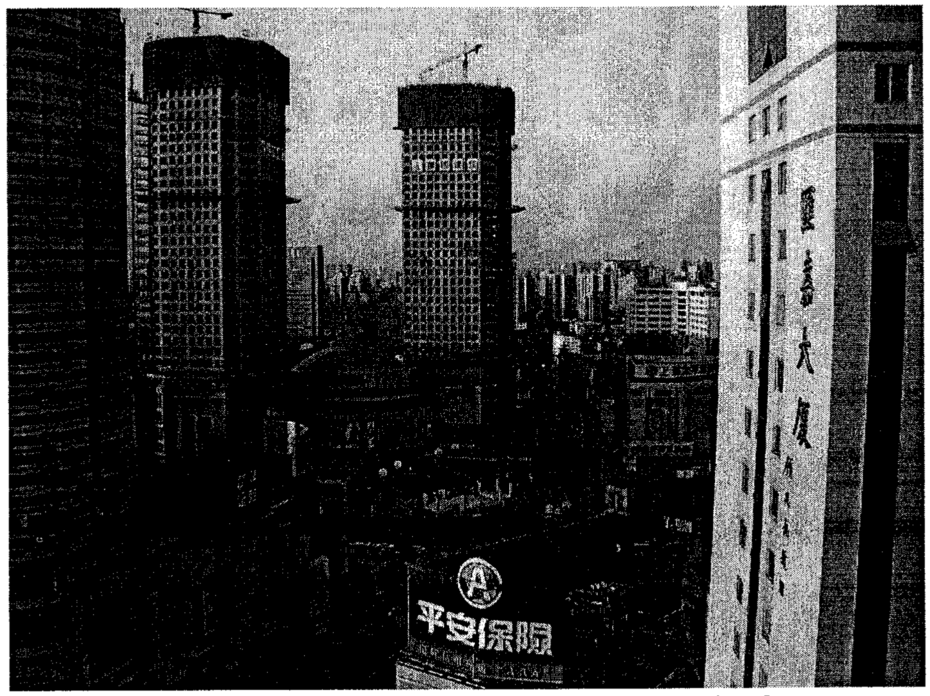


**Figure 1-2: Grand Gateway mall and office towers (under construction) December 2003**

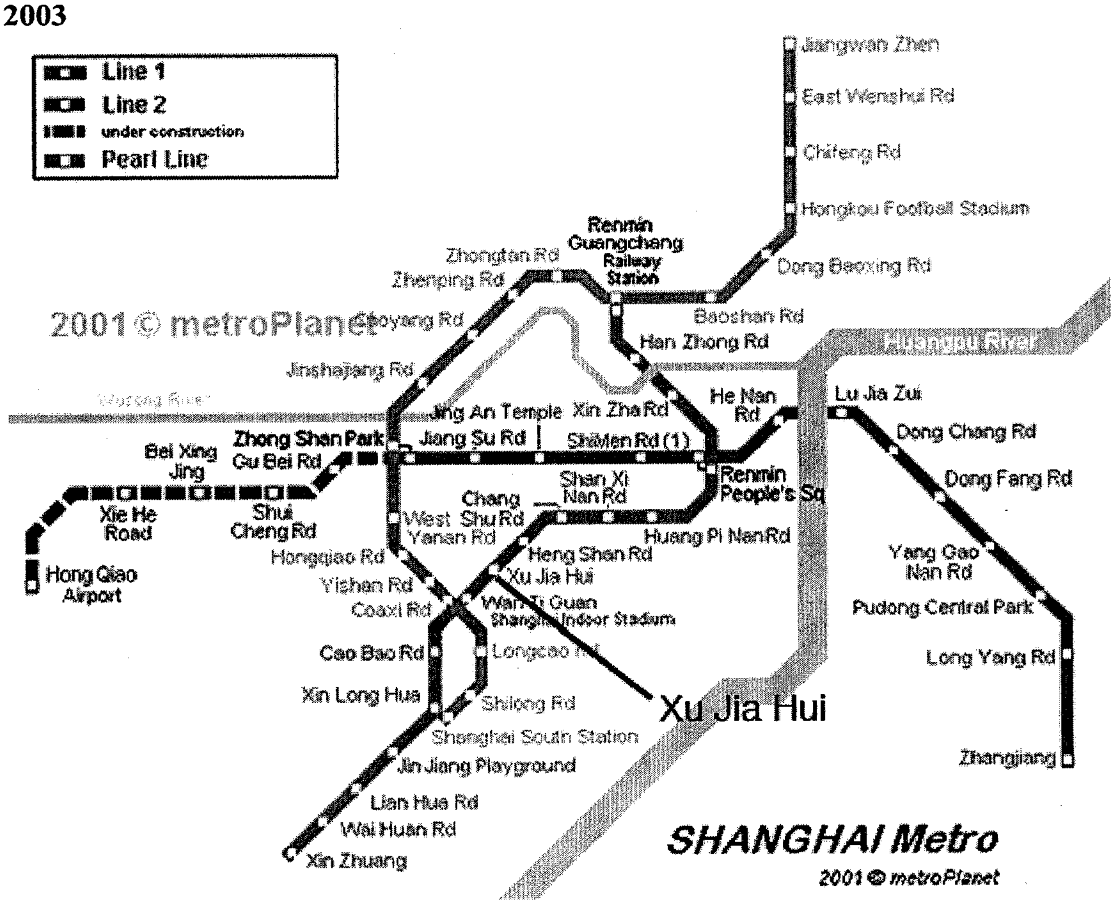


**Figure 1-3: Xu Jia Hui within the subway system** (Metro Planet, 2001)

## 1.3-The Future:

The Xu Jia Hui node is constantly evolving as the city of Shanghai carries out its comprehensive 1999-2020 plan (Shanghai Urban Planning Administration Bureau, 2001). This plan aims to maintain Shanghai's position as one of the main economic and shipping centres in China. One goal is that by the year 2020, the overall population of the Shanghai area will be 16 million, with 13.5 million in urbanized parts of the region and 8 million within the 600 square kilometre core city area. Sustainable development is a goal of the plan and a key element of sustainable development is a solid public transit system. One way to reduce vehicular traffic is to have satellite commercial centers outside the downtown to handle some office and retail activities for locals, therefore centres of activity and efficient transportation throughout the city are built into the plan. The new downtown is Pudong, the old downtown, including People's Square, becomes the main civic center, with four civic sub-centres already existing or under development. Xu Jia Hui is one such civic sub-center serving the Xu Hui district in the south-western part of Shanghai. Two new subway lines will converge at the sub-center to go along with the existing subway line and station. There is already a great deal of retail activity, and two large office towers have been added recently on top of Grand Gateway mall at the intersection. There are also a large number of high rise condominiums under construction. All of this will put stress on the current pedestrian network and therefore redevelopment of that network should be included as part of this development plan. It should be noted that literature is very sparse on how to design and lay out such areas, and literature is also sparse on determining what pedestrian facilities are required. The main focus in the literature is on evaluating existing networks for level-of-service and the effects that level-of-service has on movement of pedestrians within a pathway.

### 1.4-Thesis Layout:

The chapters in this thesis project are arranged in a progression moving from studying the pedestrian network, to predicting pedestrian dynamics of the expanded network of the future, to discussing the policy implications of this study. Next, a review of literature exploring important themes including pedestrian dynamics, environment and behaviour, and pedestrian modelling will give the reader insight into the state of pedestrian behaviour studies. This is followed by the methodology chapter which takes the reader through the detailed process of data collection, dealing with holes in the data, analyzing the data, creation of the model and testing of the model. Analysis is the start of the second half of this thesis project. The knowledge gained through analysis of the current situation at Xu Jia Hui was used in creation of a model and testing the feasibility of the changes proposed at the site. The pedestrian flow levels and levels-of-service are determined for the proposed expansions to the network. The Error Analysis chapter provides the reader with an analysis of design flaws and errors in the study. The results of the study are discussed in the beginning of the concluding chapter followed by the policy implications of these results. A discussion of the contribution to pedestrian studies that are made by this thesis follows the policy discussion. Suggestions for improvements to the Xu Jia Hui pedestrian network and guidelines that could apply to other such networks, as well as recommendations on improvements to the model are discussed in the concluding statements.

## 2-Literature Review

### 2.1-Introduction:

The purpose of this chapter is to explore the present state of modelling pedestrian dynamics in environments and review the analytical techniques which are available. Pedestrian movement prediction models are still in an early stage of development. There is not yet a model that is comprehensive in covering all factors required to accurately predict human spatial behaviour in a pedestrian environment. In this chapter the following topics are discussed: pedestrian dynamics, behaviour and environment, wayfinding, describing the pedestrian environment, and pedestrian models. The "Pedestrian Dynamics" section is about the effects on the given pedestrian network of the aggregate flow of pedestrians. This section looks at pedestrians' behaviour and the factors affecting it. The behaviour and environment section explores the effects that physical aspects of a pedestrian environment have on the pedestrians. The important concept of spatial depth is handled in the section called "Descriptions of the Environment". Next, wayfinding and spatial orientation in pedestrian environments are discussed. The application of modelling by urban planners and a description of various pedestrian behaviour models are discussed towards the end of the chapter. This review of literature explores the various methods of studying pedestrian behaviour and considers which of those methods are appropriate in this study.

### 2.2-Pedestrian Dynamics:

Pedestrian dynamics are the observed behaviour of people in pedestrian environments over space and time that are affected by design factors and level-of-service of the environment. Different aspects of pedestrian dynamics have been explored by different authors. Helbing (2001) explored the "behaviour force" of pedestrian dynamics. This focussed on how crowding affected pedestrian behaviour and proposed that, upon reaching a certain density, pedestrian movement is self organizing. The capacities of pathways on a pedestrian network are determined by the interaction between pedestrians and the techniques of avoidance they use to navigate through the environment (Helbing, 1998, pg. 4). This is an extension of the work by Fruin (1971) which formulated the concept of level-of-service to measure crowding on pedestrian pathways. As pathways become more crowded, there tends to also be a separation of opposite flows. This reduces the need of pedestrians to stop or use avoidance techniques because in large flows, pedestrians heading in the same directions gravitate towards the same side of the pathway (Helbing, 1998, pg. 4). The speed at which pedestrians move is also affected by this crowding. Polus et al. (1983), determined that even at low speeds, an increase in the density of pedestrian traffic will decrease the speed at which that traffic flow is moving. That study also served as an extension to Fruin's development of the level-of-service concept relating pedestrian movement abilities and behaviour to the level of crowding which is influenced by the layout and design of the pedestrian environment. Willis and colleagues (2004) also looked at pedestrian dynamics using this approach but their study focussed on pedestrian dynamics in environments with a low level of flow and traffic density. Focus on the level-of-service, explained in the section on application of pedestrian modelling to urban planning, was formulated by Fruin (1971) and pursued by researchers like Landis et al. (2001) who focused on the sidewalk environment for pedestrians.

An important factor in pedestrian dynamics is that of pedestrians' tendency to minimize distance and maximize utility of their trip (Gårling and Gårling, 1987). Their detailed study of distance minimization was conducted in 1987 in a small Swedish city. The researchers interviewed pedestrians returning to a parking lot after shopping in a downtown district. The goal of the interviews was to find out on how people choose to organize multi-stage trips to determine if the shoppers were minimizing distance and if so, if they were minimizing locally between stores, or minimizing for total distance. An important part of this research is the sequence of choices made by pedestrians minimizing distance locally from store to store versus conjoint route choices made by pedestrians which minimize overall distance. "In conjoint choices, but not a sequence of single choices, total distance rather than local distances may therefore be minimized" meaning two types of distance minimization must be observed and tested in any study on distance minimization (Gårling and Gårling, 1987, pg. 548). This relates to pedestrians' trip organization in the Xu Jia Hui network. If pedestrians are more likely to minimize distance locally, then they will move from one mall or department store to the one on an adjacent corner nearest to the mall or department store they left. If pedestrians aim to minimize overall distance, depending on where the pedestrian has to go on that trip, the pedestrian may have to cut right across the network going from one store to another.

The methods used by Gårling and Gårling (1987) were not employed in this study of pedestrian behaviour in China which was conducted without interaction between the observers and the pedestrians being studied. The concept that pedestrians aim to minimize their trip distance is of importance. These pedestrian behaviours and decisions are heavily influenced by the environments in which they take place. The next section addresses the notion of "environment" as it relates to the study of pedestrian behaviour.

### 2.3-Behaviour and Environment:

There is a correlation between the behaviour of pedestrians and the environment in which that behaviour takes place. The modelling of individual pedestrian movements and behaviour must take into consideration pedestrians' intentions within the given environment, as well as the microscopic movements of pedestrians (Helbing, 1998). There are normally specific points at which pedestrians' movements in an environment originate; traffic generators or 'entry points'. These generators include bus stops, metro stations and parking lots (Helbing, 1998, pg. 4). Once pedestrians leave these generators, much of their movement includes avoiding obstacles and other pedestrians when the pathways become increasingly busy.

Different types of pedestrian environments produce different behaviour in the pedestrians. Whether the system is an indoor or outdoor one has an effect on scale of the environment and the connectedness of it to the surroundings. Indoor systems tend to have fewer intersections relative to the total number of paths when compared with outdoor systems. The land uses will also be different in these two types of systems. "The land uses and activities present in a pedestrian system will largely determine its temporal dynamics and the characteristics of individual itineraries" (Zacharias, 2000, pg. 406). Overall, the design and topology of the pedestrian environment has a greater effect on the use of that environment than does the land use as emphasized by the results of the study by Helbing (1998) where aggregate behaviour of pedestrians was influenced by the levels of crowding caused by the design of the pathways. It has been found that shopping centers connected to Montreal's underground network tend to have heavy activity only on two levels due to the tunnels being connected just below street level (Zacharias, 2000, pg. 407). The behaviour of other pedestrians ties in with these trends as well. The Montreal Underground study states "other people are an important part of the experiential field and may in some instances dominate decision making. People are sensitive to pedestrian flows, will tend to follow others, and will form opinions about the social environment that may influence their behaviour" (Zacharias, 1997, pg. 25).

Borgers and Timmermans (1986) micro-level pedestrian simulation model paper has been cited by many in the field of pedestrian modelling. The researchers tested this Monte Carlo simulation model on route choice behaviour of pedestrians in the city of Maastricht, the Netherlands. Borgers and Timmermans wanted to model the behaviour of pedestrians in terms of route choice and destination selection. The entry point of pedestrians to this city center area, the places they shopped at in sequence and the route that they took to do so were determined using on street interviews. People leaving the shopping district were asked to fill out a questionnaire and included in this was a question about how often they came to the area. People also marked the route that they travelled on a small map of the shopping area. Only those participants who were regular users of the shopping area were used to calibrate this model (Borgers and Timmermans, 1986, pg 28). A sub-model was used to determine distribution of these regular users across the various entry points to this shopping district. After this the actual model was run. This included determining the total number of stops, types of goods purchased and the order of purchase. Several measures, including Pearson's product-moment correlation coefficient, are used to calculate goodness of fit to determine the validity of the model. It was determined that the Monte Carlo simulation model was valid and could likely predict the impact on pedestrian behaviour when there is a relocation of shops within the commercial area (Borgers and Timmermans, 1986). This model has helped demonstrate that pedestrian route choice often relates to the pedestrian's shopping behaviour activity in that the order of product purchases determines the route which the pedestrian travels through the commercial area. This model was said to be able to predict changes in pedestrian behaviour based on changes to entry points to shopping districts as well. These simple findings have been the basis of many studies and models published since 1986 but since there is a heavy focus on retail activity and the data collection method relies on surveys and interaction with the subjects, the methods used were not included in the methodology of this study of Xu Jia Hui.

One last area related to behaviour and environment is the study of pedestrians walking speeds and use of pathways. In their study "Human movement behaviour in urban spaces", Willis and colleagues (2004) studied pedestrian behaviour in low traffic pedestrian environments to look at some specific movement behaviours of individuals. Walking speeds, preferences for position on the pathways, and spacing between pedestrians and objects or other pedestrians were all factors that were investigated (Willis et al., 2004). The study carried out by Willis (2004) employed a similar method to the study conducted by Polus et al. (1983), in that videotape observation of pedestrian behaviour on sidewalks was the technique employed. The difference was that, while Polus and colleagues focused on the inverse effect of increasing density of flow on speed of flow, Willis et al. (2004) specifically chose to use 'uncluttered' environments for the pedestrians to be observed in. This was because they wanted each individual to have total freedom of movement, position and walking speed (Willis et al., 2004, pg. 824). The results of this study determined that one of the most important factors in pedestrian behaviour was group size. This affected the walking speeds, spacing and position, but also, those walking in groups had greater reactions to the surrounding environment's design features (Willis et al., 2004, pg. 825). It was also found that age, mobility, and perceived space given for pedestrians were also important factors in determining pedestrian movement behaviour (Willis et al., 2004, pg. 825). This study gives important insight into how the pedestrian, or group of pedestrians, is affected by design of the environment in the absence of high density traffic flow. This insight, while useful, was not employed in the study of the Xu Jia Hui pedestrian network which is a high density traffic flow environment.

**2.4-Wayfinding and Spatial Orientation:**

This section deals with wayfinding, cognition, and visual representations of the environment. Wayfinding is about how people find their way through the environment using their spatial knowledge of landmarks, routes and recognizing familiar objects along the way (Raubal et al., 1997, pg. 87). This area of research has its roots in the writings of Kevin Lynch and his method of evaluating cities explored in *The Image of the City*

(1960). One way that wayfinding can be defined is that it is the ability of a pedestrian to navigate through a given environment to reach a predetermined destination and carry out planned activities. Cornell et al. (2003) conducted four studies that measured the orientation and wayfinding abilities of their subjects via four different. Their studies all related to pedestrians' sense of direction and its relation to wayfinding. They asked subjects to rate their own sense of direction in the environment and in the end it was found that there was a connection between the self rated sense of direction and ability to wayfind (Cornell et al., 2003). Though females rated themselves lower for sense of direction, they were found to wayfind about as well as males and everyone tended to use route based knowledge of landmarks and paths to get around (Cornell et al., 2003). This relates directly to the concept of cognitive maps. Cognitive maps are one way that people are able to recognize landmarks and objects along the pathways of a pedestrian environment or network. "As people move through the environment, they acquire knowledge about the spatial relationship between places and they structure this information into some type of mental representation or cognitive map" (van de Voort, 2002, pg. 14). Raubal et al. (1997) focused on imaginative patterns or image schemata to understand the wayfinding behaviour of pedestrians. "Image schemata are supposed to be pervasive, well-defined, and full of sufficient internal structure to contain people's understanding and reasoning" (Raubal et al., 1997, pg. 87). Basically, image schemata are detailed cognitive maps with a focus on the topology of a pedestrian environment.

The idea of cognitive maps was created by Lynch (1960) and ties directly to pedestrians' ability to navigate through a pedestrian environment. Image schemata and cognitive maps are not perfect representations; there are sketchy details and small errors throughout people's cognitive maps and images of a pedestrian environment. These discrepancies have to be taken into consideration when using the findings of research for planning purposes (van de Voort, 2002, pg. 20). With each person having their own unique view of a pedestrian environment, the aggregate data collected may be scattered and not converge on a single conclusion about the use of spaces in the environment by pedestrians. In spite of any imperfections, the information collected is valuable; "the basic idea for facilitating wayfinding is to organize space and spatial design models based on users' cognitive perceptions" (Raubal et al., 1997, pg. 87). This concept in itself is useful to the process of planning since it focuses on those who will eventually use the pedestrian environment to gain information on how to design it.

**2.5-Descriptions of the Environment:**

While pedestrian behaviour, discussed earlier, is one major building block of pedestrian dynamics, another is the understanding of pedestrian networks and how their design and layout affects those pedestrians using them. "Pedestrian movement in an urban area can be visualized as a set of complex streams joining, separating, and intersecting over the available channel system" (Zacharias, 2000, pg. 405). Being able to descriptively analyze a pedestrian environment is essential to understanding how pedestrians will move through it using their wayfinding techniques. A major field related to pedestrian dynamics that is used to explain and understand human behaviour in many types of environments is space syntax. "Space syntax is a theory and a set of tools associating architectural or spatial variables to social behaviour in a way that can better help research and consequent action" (Gabbay and Averot, 2003, pg. 1). Space syntax aims to form theories of how cities, landscapes, buildings, settlements and pedestrian environments are structured. The relationship between humans and these constructs is addressed in this body of theory. Bafna (2003), with reference to space syntax, states that "a central premise within the space syntax research program is that social structure is inherently spatial and inversely that configuration of inhabited space has a fundamentally social logic" (Bafna, 2003, pg. 18). Once continuous spaces have been divided up into several connected sections using space syntax, each of those spaces is classified and given a meaning for their existence in the network or urban space. This meaning has to do with the rules and restrictions put on those spaces by people, society and the effect the design of the space has on people's behaviour. Social rules and standards of any society come into play during the use of public spaces making the connection between space syntax and social logic a strong one. Bafna states that: "The aim of space syntax research is to develop strategies of description for configured, inhabited spaces in such a way that their underlying social logic can be enunciated" (Bafna, 2003, pg. 18).

Building floor plans and city area plans are the objects of analysis in space syntax studies and the descriptions of the areas and environments they represent are given in an abstract way so to eliminate small unimportant differences between different environments (Bafna, 2003, pg. 18-19). In the study Bafna conducted, the focus was on office space; whereas the studies carried out by Gabbay and Averot (2003) were on high density multi-level pedestrian environments. They used the body of theory to determine if the multi-level pedestrian environments integrated well into the surrounding city or not, and found that some of these environments definitely did not integrate in to the surroundings (Gabbay and Averot, 2003). One other element that can be tested under this body of theory is spatial depth. "Depth of one space from another can be directly measured by counting the intervening spaces between the two spaces" (Bafna, 2003, pg. 21) This definition was written with the office layout case study in mind, and it differs slightly from the definitions that follow, but still tie into those bodies of theory.

The concept of spatial depth is an important one in the study of pedestrian behaviour and pedestrian networks. Spatial depth is a measure of accessibility of a space from all other spaces taking into account any changes in direction, level changes and overall difficulty involved in reaching the space in question. A hard-to-access space is considered to be spatially deep, while an easy-to-access space is considered to be shallow (Chang, 2002). An alternative view of spatial depth is that it is a measure of the number of intervening spaces between any two spaces and the more intermediate spaces one must pass through to reach the destination space, the more spatially deep that space is (Bafna, 2003). The spatial depth described by Chang and Penn (1998) is more appropriate to this review of literature as it relates to complex pedestrian environments similar to the Xu Jia Hui pedestrian network. Chang and Penn speak of two different measures of spatial depth; horizontal depth or axial depth, and point depth which use the number of segments of pathways, which are the sections in between intersections, as a measure of the depth between two spaces (Chang & Penn, 1998). They found a strong correlation between movement and spatial depth in their studies. According to the article, "a model intended to predict pedestrian flows within a multi-level complex would need to include some form of weighting in terms of depths from specific origin and destination facilities" (Chang & Penn, 1998, pg 523-525). In a follow-up study on multi-level pedestrian environments it was found that "between origins and destinations minimizing spatial depth is regarded as the most important controlling factor in pedestrian route choice and decision behaviour" (Chang, 2002, pg. 604) All of this knowledge of pedestrian environments, pedestrian behaviours and wayfinding techniques, facilitate the creation of pedestrian models to predict pedestrian behaviour in newly developed and redeveloped urban landscapes. These concepts are essential to the study of the Xu Jia Hui pedestrian network.

**2.6-Application of Pedestrian Modelling in Urban Planning:**

The creation of pedestrian models is useful for giving planners and engineers an understanding of how people move through space and what designs are will provide a safe, functional and successful pedestrian network. These models can aid in designing an environment to meet safety regulations, and at the same time aid in designing a successful commercial space. As the technology has advanced, computer-aided pedestrian simulation models have become part of the design process, as well as the evaluation process, for pedestrian environments. "The model for the behaviour of individual pedestrians is an ideal starting point for computer simulations of pedestrian crowds. Such simulations take into account limited capacity of pedestrian ways and places, and allow (planners) to determine optimal design of pedestrian areas and optimal arrangement of store locations" (Helbing, 1998, pg. 2) Older pedestrian models were aggregate models and had geometric approaches to explaining pedestrians' use of space, while the newer agent-based models are basically "structures in which the behaviour of any agent or object is always a function of other objects in the system" (Batty, 2001, pg, 324). It is stated however in the pedestrian movement study by Willis et al. (2004), that agent-based models have limited use to researchers interested in individual behaviour and microscopic movement because the differences in methodology; "and the nature and density of the prevailing pedestrian population make valid comparisons between studies almost impossible" (Willis et al., 2004, pg. 807).

John Fruin (1971) came up with the idea of "levels of service". This is a way to describe the volumes of traffic and crowding on a given path using a six-level scale ranging from "A" to "F". The A level is the least crowded level-of-service with the lowest volume of traffic allowing pedestrians to move freely. The F level-of-service is the most crowded with the highest traffic volumes and most restricted pedestrian movement (Fruin, 1971, pg. 8). This is the aspect of pedestrian modelling that will determine if a design will meet safety regulations set out by the municipality given the number of pedestrians expected to use the network on a daily basis. Also, this method of evaluation will determine if pedestrian traffic will flow, or if there will be stoppage of flow due to crowding. The higher the density of pedestrian traffic expected, the greater the chances of a code violation and stoppage of traffic flow. This level-of-service evaluation method is applicable and essential to this study of the Xu Jia Hui pedestrian network which has crowded conditions in its current state.

There has been a huge focus on crowded pedestrian network conditions (level F) while not enough attention has been paid to ideal conditions (level A), meaning that very few studies existing have really detailed information on individual pedestrian movement. Willis et al. state—"in order to be of value as a predictive tool, any microscopic model must be able to simulate realistic pedestrian behaviour" (Willis et al., 2004, pg. 806). The study that Willis et al. conducted did get detailed results on individual pedestrian behaviour and the information can be applied by planners when designing pedestrian facilities. Knowing how pedestrians move about in the lower levels-of-service with ideal conditions allows planners to design a comfortable space in which pedestrians would want to spend time and shop. Knowing the highest levels-of-service and the worst conditions possible allows the planners to know the minimum widths and dimensions of the pathways required for the network to be functional.

**2.7-Pedestrian Behaviour Models:**

Pedestrian modelling is essential to the process of creating successful pedestrian environments and improving on existing environments. A research team headed by Bruce Landis (2001) proposed a 'pedestrian level-of-service' model for roadside walking environments. They created an event to get a large number of people to walk a course through a typical American city and drew their observations and information from those pedestrians (Landis et al., 2001). They had an interest in the walking environment and design factors such as width of sidewalks and street furniture and the effect this had on pedestrians' movement patterns. The safety of the environment in terms of separation from vehicular traffic was a factor in this investigation. The most important factor was that of crowding and level-of-service; this was also studied by Polus, Schofer and Ushpiz (1983), as part of a study on characteristics of pedestrian flow on sidewalks. The definition of level-of-service, developed by Fruin (1971), is a qualitative measurement of the personal space each pedestrian has surrounding them as they move through an environment based on the dimensions of the pathway and number of pedestrians on a section of it at any given time; this is measured in square feet per pedestrian (Fruin, 1971). "The collection of these factors into a mathematical expression, tested for statistical reliability, provides a measure of the roadway segment's level of service to pedestrians. This measure evaluates the conditions along roadway segments between intersections" (Landis et al., 2001, pg. 4). There were three main measures of the pedestrian environment that went into the creation of this pedestrian model; capacity of the sidewalk, the quality of the pedestrian environment, and the perceived safety of pedestrians moving through the environment (Landis et al., 2001). The usefulness of this model is in the areas of understanding current sidewalk conditions, designing new pedestrian pathways, and also providing information to help with retrofits of pedestrian facilities to existing roads. When the network is heavily used and level-of-service is a main factor, this model is a good tool to use.

Modelling of pedestrian behaviour using flow characteristics and the speed-density relationship is another approach that ties into the methods of Fruin (1971) and Landis (2001). Polus et al. (1983) conducted a study called "Pedestrian Flow and Level-of-Service" in which flow characteristics, number of pedestrians, the density of pedestrians given the space available and the speed of movement were factors. Virkler and Elayadath

(1994) also dedicated a study to speed-flow-density relationships that tested seven established models that describe the mathematical relationships between speed and density of pedestrian flows, against a set of pedestrian data. The Polus study (1983) determined that with an increase in density the speed at which pedestrians moved increased significantly (Polus et al., 1983). Useful classifications for defining the levels-of-service for pedestrian flow in terms of the speed-density relationship result from these studies. The speed-density relationship is related to the level-of-service of a pedestrian environment, discussed earlier. Characteristics of the pedestrians themselves such as gender were evaluated to determine if they had any affect on the pedestrians' behaviour with respect to speed of movement and density of the traffic flow. The study conducted at Xu Jia Hui is not concerned with speed-density relationships, and since the method of data collection used in the Polus study was a videotape observation technique which was not employed at Xu Jia Hui, the Polus analytical technique was not applied in the methodology of this study.

Models used to predict pedestrian behaviour may use information on the characteristics of the pedestrians and route characteristics. Daamen and Hoogendoorn (2003) used previously developed simulation models to aid their research on pedestrian behaviour. These two models—NOMAD and SimPed—are well known in the area of pedestrian dynamics and pedestrian studies. For the study, NOMAD was being used to determine level-of-service for pedestrians moving through a train station, while SimPed was being used to "estimate both mean and variability of walking times incurred by transferring passengers and to visualize walking patterns inside transfer stations and other pedestrian areas" (Daamen and Hoogendoorn, 2003). NOMAD is not one single model, but in fact two models that depend reciprocally on one another. The top level model makes predictions about scheduling, area choice and route choice of pedestrians; the bottom level model describes the walking behaviour of the pedestrians (Daamen and Hoogendoorn, 2003). The SimPed model can be used to quantify level-of-service along pathways and pedestrian areas as well as visualize the pedestrian activity. These situations can be simulated for existing pedestrian facilities or for planned, or under-construction, facilities. Technical visualizations of level-of-service data and three dimensional visualizations of the pedestrians themselves are available through SimPed (Daamen and Hoogendoorn, 2003).

SimPed is one example of agent-based modelling. Agent-based modeling is a recent improvement for the field of pedestrian modelling. It is still just emerging into pedestrian studies. "Agent based models are essentially structures in which the behaviour of any agent or object is always a function of the other objects in the system. Applying this criterion to existing approaches to pedestrian modelling, [...], reveals that most approaches to date do not enable such interaction to be simulated" (Batty, 2001, pg. 324). Agent-based models are seen by Batty as the replacement of, or alternative to, older models that are based on aggregate data and geometric approaches. It was mentioned that studies have become more object-oriented, focussing on the behaviour of individuals instead of aggregates. Also, new forms of data collection such as automatic counters and remote sensing, as well as many different surveys, all cater to this new agent-based form of pedestrian modelling that is gaining popularity (Batty, 2001). This type of pedestrian modelling is still emerging and does not relate to the techniques employed previously in studies and therefore will not be used as a guide for conducting this study.

Thornton and the Retail Analysis Team (1987) employed many of the previously mentioned factors in their flow analysis model for the book *Shops, Pedestrians and the CBD* (1987). The personal characteristics of pedestrians, level of crowding and the speed of movement of pedestrians all factored into the calibration of this flow analysis model. This model included a unique flow analysis method for determining the flow directions in a pedestrian network using cordon counts. What the direct measurement technique actually does is attempt to calculate the number of pedestrians that go straight, turn left, and turn right when they enter an intersection from a link (Thornton et al., 1987). The Retail Analysis Team fed their data into a mathematical simulation program called WONKA to get their results. This turning flow matrix provided a more accurate account of what was happening than purely studying point counts and link counts. These techniques are somewhat dated but still of use to understanding pedestrian networks to this day. This thesis employs the flow analysis technique used by the Retail Analysis Team as well as the methods of other published studies.

**2.8-Conclusions:**

The purpose of this review of literature was to survey the modelling of pedestrian dynamics and analytical techniques available. This review of literature has revealed that many different types of studies must be conducted on any pedestrian environment to get a true picture of how the pedestrian facilities are being used and why pedestrians behave the way they do in the environment. This is the kind of information that is useful to urban planners, builders and designers, when they are creating, expanding or restructuring a pedestrian network. Not all the methods and models reviewed in this chapter are used in this project. The NOMAD and SimPed pedestrian models were not employed for this particular study due to their designs, requirements, and what they are used to study. NOMAD is an activity based model that uses video footage of pedestrians to determine where the activities they participate in will be performed. It takes into account speed of traffic, comfort, attractiveness of the corridor, and crowding of the pathway. SimPed is a macroscopic model that measures levels-of-service for pedestrians in stations and on platforms whether they are waiting or in motion. It takes into account what occurs upon the arrival of a train. The relationship between pedestrian density and speed of flow is measured with this model (Daamen and Hoogendoorn, 2003). Polus et al. (1983), Landis et al. (2001) and Willis et al. (2004) also evaluated speed-density relationships for pedestrians. These studies required video tape footage and had a focus on specific behaviours of pedestrians in sidewalk conditions rather than overall flows and how they are affected. In every case video taped footage was used to observe pedestrians behaviour according to the density of pedestrians on the pathway. The Willis study, (2004), differed from the other two in that the focus was on pedestrian behaviour in low density situations. All three studies had a focus on the use of the sidewalk in an urban area and due to their focus and design they did not fit within the scope this study. Borgers and Timmermans (1986) and Gårling and Gårling (1986) conducted studies that required interviews and surveys of the pedestrians to take place. This was not something possible for my research team in China. Borgers and Timmermans model was a Monte Carlo simulation model that studied the behaviour of pedestrians in the shopping environment according to their purchasing behaviour. Gårling and Gårling also had a focus on the order in which people shopped and how they chose to minimize distance travelled during the shopping trip. This study does not deal with purchasing behaviour or the details of how distances of individuals' trips are minimized and therefore these studies were not employed. Elements of the techniques employed by Chang and Penn (1998), Chang (2002), Thornton et al. (1987), and Fruin (1971) will be used in the methodology of this thesis.

# 3-Methodology

## 3.1-Purpose:

The purpose of this chapter of the thesis is to guide the reader through the process of conducting this particular study in preparation for the analysis, equation creation and equation application chapters that follow. The analysis of pedestrians' route choice behaviour at Xu Jia Hui involves the use of large amounts of primary and secondary data including tracking data, cordon count data, land use data, and various maps of the area. The focus of the first half of this chapter is to explain the methods used to collect the tracking and cordon count data, and to set up the results to be used for this study of pedestrian behaviour in a complex urban environment. The second half of the chapter is about procedure; it lays out the procedures involved in carrying out the study. The process of calculating spatial depth, level of use in terms of pedestrians per minute on network links, comparing the tracking results with cordon count results, and determining the most important factors in the causality of pedestrian path choices are detailed in this chapter. Creating an equation to predict people's walking behaviour in the multi-level pedestrian network of Xu Jia Hui is the final stage of the analysis. The results from data analysis of pedestrian behaviour can be used to guide urban planners in the design of new pedestrian environments. Understanding what types of pathways attract pedestrians and which types remain unused or under-used is very important to both creating successful pedestrian environments and writing guidelines for pedestrian network development projects within a city.

### 3.2-Collection of Data:

**Types of data:** Most of the data that was used for this research project was primary data collected on site at Xu Jia Hui. Recording of individual pedestrian path choices and routes by following, or 'tracking', individuals and marking on a map the path they travelled was carried out by six Urban Studies students on four days of the study in December 2003. Cordons were laid out on a map and this same group of students also conducted five-minute interval cordon counts across the network. Information on the traffic generators related to land use was collected. Land-use data was collected directly by touring the site and making observations of the uses present throughout the network and the buildings attached to it. Network maps and plan view maps of the study area were collected during the research trip and were used to plan cordon counts and get an understanding of the network. New network maps were created, during the process of analysis, from incomplete maps of the site. Observations of structure land uses were made by walking and surveying the entire network.

**Tracking:** Individual pedestrian path choices and routes were studied by following pedestrians unobtrusively through the Xu Jia Hui pedestrian network and recording their movements. Individual pedestrians or groups of pedestrians were followed from various traffic generators in the network and trailed by the research assistant until reaching a major traffic generator, or were lost. This is a method that has been used in many different studies. It is sometimes referred to as 'stalking observation' as in Chang (2002). "The log of an individual's exact movement paths obtained by stalking observation (the process of following people and recording their movements) should ascertain how the multiple design factors in multilevel systems affect the patterns of individual route choice and movement behaviour" (Chang, 2002, pg. 583). For this particular study, each of the research assistants was given a scale map of the pedestrian network and told to select pedestrians at particular starting points, using a random selection protocol. They followed the pedestrians to their destination, or to the entrance of one of the major generators of pedestrian traffic in the area. When more than one track was marked on one map, the tracker assigned a number to each track for clarity. In most cases the tracker noted the gender of the person being tracked; however, for the purposes of this study gender is not relevant. Those studies that used gender in their observations also collected other demographic information by surveys handed out to pedestrians using the study areas and pedestrian facilities. Thornton et al. (1987), and Chang (2002 and 1998), report studies that had a focus on the purpose of people's trips as well as the dynamics of how they moved through space, while Bafna (2003) gave an overview of space syntax. In this study, I am interested in the dynamics of how the people move through the network and not why they are there. At the end of each day all tracks were placed in a folder and kept in one place. An Excel spreadsheet was created so that information gained through tracking could be directly accessed. A matrix was created in which the nodes and individual path choices contained within each were the columns, and the individual trips recorded, including the start node, were the rows. The total numbers of tracked individuals who entered and left any particular node from any of its access points, is directly accessible at the bottom of the chart where the 1's (indicating an entry to the node) and the 0's (indicating an exit from the node) are summed.

**Cordon Counts:** Overall traffic flow data were collected by cordon counts. After the data collection team that had been involved in tracking was familiarized with the area, we set up cordons, also known as 'gates', to determine the flows of traffic on as many important links in the network as possible. At each of these cordon points, the observer drew an imaginary line and counted everyone that crossed the line in both directions. These counts were carried out during weekdays in the afternoon between 4pm and 6pm. The time intervals were five minutes, which is the upper end of the range of time Chang suggests should be spent per trial on each cordon. "The observation time varies from 2 to 5 minutes, but essentially, the longer the better" (Chang, 2002, pg. 589). Throughout the cordon count trial period, only two trials were conducted for each point on any given day, due to the fact that we had less than a dozen observers and about sixty cordon points. Each person had a set of cordons to handle rotating from one to the next doing the five minute trials. The time, date and cordon numbers were noted at the top of each observer's cordon count sheet for each day. The day's count sheets were collected and reviewed by me each day that the cordon counts were conducted.

During the cordon count trials some complications led to some missing cordon values and certain cordons were completely unaccounted-for in the data set. This left columns in the data chart representing each trial with missing values. To fill in the missing values, dummy numbers were created for each of the missing values in the raw data chart. The numbers were later converted to pedestrians per minute crossing the cordons. To create these dummy numbers, first a trial with the majority of the link values filled in was selected. Other columns (trials) were then compared to this one. The missing values in the incomplete columns were filled out by finding out what proportion of the complete trial that value for that link accounted for. That proportion was then applied to the column with the missing values. This process had to be done one column at a time for accuracy.

After six usable cordon count trials were completed with dummy numbers, it became clear that on two of the trials, the numbers were much higher. On the trials in question, nearly twice as many pedestrians were counted in total during the five minute time intervals. A decision was made to pro-rate these values to bring them in line with the other four pedestrian trials for the sake of analysis. This was done by first calculating the mean for the totals of the trials with similar counts. This mean was then divided by the total for the trial with the abnormal count and this value is multiplied by each cordon value in the particular trial to get the new pro-rated set of cordon counts.

$$\text{Pro-Rated Values} = (\text{Each link in abnormal count}) \times \frac{(\text{Mean total of normal counts})}{(\text{Total for abnormal count})}$$

The counts for two key cordons in the Xu Jia Hui network were completely missing from the cordon count data set. To make a more complete data set, calculations and knowledge of area flows were used to estimate the approximate flows per five-minute interval on each of the links. To do this the two cordons, which were representing two sides of an exit from the tunnel system up to street level, were treated as one. This exit connects to two hallways at an intersection. This was treated as a three-way intersection and the flow analysis calculation mentioned earlier in this chapter was used to determine the number of pedestrians turning from the exit in question onto the two underground hallways. The reasonable assumption was made that the traffic flow from the hallway containing cordon 17, which has a small flow, was divided evenly between turning to the other hallway and turning to the exit. The flow was considered to be equal between the exit and the cordon 16 covering the other hallway. So for the purpose of filling out the missing data, the values for cordons 13 and 15 together equal the values for cordon 16, therefore each of cordon 13 and 15 equal half of the value for cordon 16.

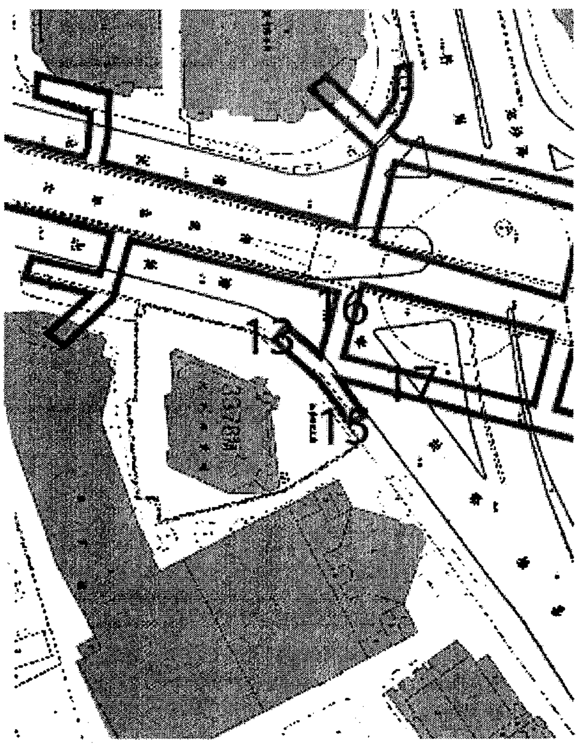


**Figure 3-1: Missing cordons**

Once the data set was complete, the mean and standard deviation for each cordon were calculated from the six trial values. The confidence levels were then calculated. Since the units in this study are people, the mean and the confidence levels were rounded to whole numbers before being charted. A chart of the mean and 95% confidence levels, sorted ascending by the mean value, was created. From this, a visual analysis was made to determine how many distinct levels of flow existed within the data set. These levels enable the links covered by the cordons to be classified for the sake of understanding the main routes travelled, and also categorized for the graphic display of network flows. The levels were created by strategically placing horizontal lines on the graph to try and fit as many cordon values (including the upper and lower confidence limits) exclusively in each level.

### 3.3-Objectives and Methodological Questions:

**Overall objectives:** There were three objectives to this research project. The first objective was to determine the pedestrian flow and path choice dynamics of the Xu Jia Hui network. In this objective it was determined how people moved around the network and levels of usage of network paths. I wanted to understand the relationship between the data collected, and people's choice of path regarding length, level changes, spatial depth and type of route. I determined the main routes pedestrians were travelling between major generators to achieve this. The second objective was to create a predictive model for pedestrian networks based on this information and generalize for use on any pedestrian network. For this objective I created a linear equation that takes into account all of the main factors of pedestrian movements in a multi-level network that were determined in the study of pedestrian dynamics at Xu Jia Hui. The third objective was to test the model on the site in question to determine the external validity of the model. External validity is the degree to which the conclusions of a specific study of people at a specific location can be generalized to other people at other locations (Trochim, 2002). The external validity of this model was explored to determine if it was usable in situations other than Xu Jia Hui. The knowledge that a valid model of pedestrian behaviour in these multi-level pedestrian environments can assist urban planners in designing new environments like this, or redeveloping existing environments that will become more complex with the addition of pathways and traffic generators. The model will serve as an organizational tool for the development of pedestrian environments.

**Methodological Questions:** Six methodological questions have been defined and were answered in order to complete the first objective of this research:

1. What are the main traffic generating buildings and transit facilities in the Xu Jia Hui study area?
2. What are people's preferences when moving between the main traffic generators in Xu Jia Hui?
3. Do people have a preference for direct routes and ignore spatial depth of the route when moving through the network?
4. Do people have a preference for the surface and bridge routes over the tunnel/underground routes when moving through the network?
5. What are the network factors that cause people to choose the routes they do between traffic generators at Xu Jia Hui?
6. What are the personal preference factors that cause people to choose the routes they do between traffic generators at Xu Jia Hui?

### 3.4-Internal and Construct Validity:

Internal validity is relevant to the design of studies and experiments that attempt to establish a cause and effect connection. It is "the approximate truth about inferences regarding cause-effect or causal relationships" (Trochim, 2002). It is important to explore the causal factors of specific factors on the behaviour of pedestrians at Xu Jia Hui. Construct validity is defined as: "an assessment of how well you translated your ideas or theories into actual programs or measures" (Trochim, 2002). This is basically the ability to draw conclusions out of your study that are connected to the theory involved, based on how well designed the study was. For this study the focus of the internal validity and construct validity measures is on relating the tracking and cordon counts.

**Tracking Data:** The Xu Jia Hui pedestrian network is part of a very large commercial node. There are many traffic generators including several large retail centres, a subway station and numerous bus stops. Each day tens of thousands of people pass through. Due to limited resources, time and people, only 124 trackings were conducted. The possibility of such a small number of tracks to be representative of the traffic flows in a pedestrian network with such high volumes of pedestrians is questionable. Zacharias (1997) used 155 tracks of individuals in studying the Jean Talon market in Montreal, and Chang (2002) used 300 tracks for his analysis of multi-level pedestrian environments in London, England. These numbers show that the results for this particular case must be tested to make sure that the tracks are representative of people's behaviour in the network. It is important to determine if the aggregate trackings and aggregate cordon counts are correlated.

First, the coded data from the trackings was used to determine how many of the trips passed on each link of the network. These were ranked and grouped into levels so that the data could be displayed in a density diagram. After that, a density diagram was created from the completed cordon count data set, employing dummy numbers, to know the mean distribution of pedestrians in the system during high traffic periods. What resulted was a single representation of the distribution of pedestrians in the whole network. This data was fed into Adobe Illustrator and the line representing links with cordons on them can be made to a thickness proportional to the number of people counted. The individual links were ranked according to the number of pedestrians that passed on them. These data were grouped according to level of traffic flow. A standard deviation was calculated for the ranked links to determine the level of difference in traffic flow and how significant those differences were. The next step was to check the correlation between the actual number of pedestrians that passed on each link, and the number of people that were tracked that passed each of those links. This helped determine if the heavily used routes were the ones where the tracks were concentrated; which would indicate if the trackings were a reasonable representation of reality in this case.

**Cordon Count Data:** There were numerous holes in the cordon count data when certain cordons were missed and not counted during the trials. These numbers had to be filled out with 'dummy numbers' as described earlier. This can lead to less accuracy and less reliable numbers which could distort the conclusions. To check and make sure that these numbers were accurate enough to give a realistic picture of traffic flows in the Xu Jia Hui pedestrian network, they were tested. First the overall numbers were analyzed to see variation in number of people counted on each day of the trials. Then selected links were tested to see what proportion of the totals they account for. If it was found that many links do not hold roughly the same proportion of pedestrians on different days regardless of the total count, then the data could not be considered reliable enough to draw conclusions.

### 3.5-Methods of Analysis:

**Analyzing pedestrian traffic flows:** The first two questions were as follows-- What are the main traffic generating buildings and transit facilities in the Xu Jia Hui study area? What are people's preferences when moving between the main traffic generators in Xu Jia Hui?

To answer methodological questions one and two, the cordon counts and tracking data were used. Once the flows of traffic on each link in the network were determined and mapped as was explained earlier, the next stage was to determine how the flows moved through the network. In other words, this was the conversion of simple cordon count information into a description of aggregate flows. To do this, a method was used to determine what proportion of a flow of traffic turns right, left or goes straight through each intersection of links. These data were much more descriptive than simply knowing how many people were at given points in the system; they show where pedestrians were coming from and where they were heading.

The flow analysis from cordon count data used in this study comes from a method used by Thornton and the Retail Analysis Team (1987). This is a system of apportionment where the flow entering a junction is determined and based on the flows on each of the other links connecting to the junction; it is determined what proportion from the first link turned onto each of the others after the junction. If there are four links connecting to a junction—a, b, c, and d—then the equation to determine what proportion of people turn from link 'a' to link 'b' is as follows:

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

Where $N_b$, $N_c$ and $N_d$ are the numbers of people exiting the junction along each of those links (Thornton et al, 1987, pg. 80-81). To get the numbers to conduct this part of the study, the cordon count numbers needed to be divided by two since the count was bi-directional and we were interested in a directional flow here. It is accepted that flow is usually the same in both directions on a standard cordon count in these kinds of environments (Zacharias, 2000). An Excel spreadsheet was created in order to do these calculations. Columns were set up to show the direction of flow through the intersection, the number of pedestrians entering the intersection from the link being turned onto, and the number entering the intersection from the other links. The number of people entering the link being analyzed for flow (example "a" for the above equation) is the last raw data column. The equation to derive the proportion turning was entered into a column multiplied by the number of people entering the intersection at the link being analyzed. This gave the predicted numbers turning in each direction. A graphic display of pedestrians' turning behaviour using blown up diagrams of intersections, is included in the Analysis Chapter.

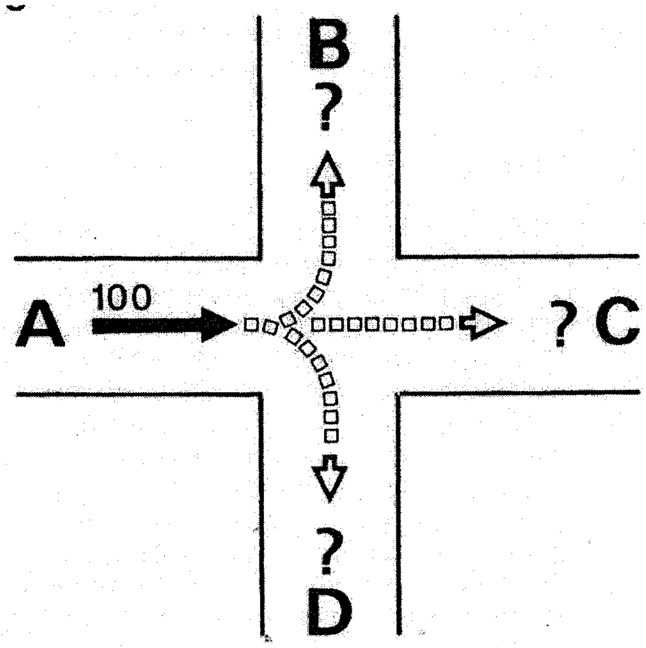


**Figure 3-2: Flow analysis diagram (Thornton et al., 1987)**

The main traffic generators were determined by analyzing the flows from the cordon count data. The generators and links with the largest flows were then considered the important ones to evaluate during further analysis of pedestrian dynamics at the site. The paths people use to travel between the main traffic generators required more in-depth analysis including tracking data to understand pedestrians' exact path choices. A map of the tracking results has been created in Adobe Illustrator and was cross-referenced with the cordon flow analysis. To get the fullest picture of where pedestrians are heading in the network, and how they get to those points, the cordon counts for the links that form these routes were compared to the number of tracked pedestrians that passed through these links.

**Analyzing pedestrian preference and spatial depth:** Questions three and four were as follows-- Do people have a preference for direct routes and ignore spatial depth of the route when moving through the network? Do people have a preference for the surface and bridge routes over the tunnel/underground routes when moving through the network?

To answer questions three and four, the secondary data (network and plan view maps) together with observations of the spatial layout of the site and the pathways, and the concept of spatial depth was employed. "Depth of one space from another can directly be measured by counting the intervening number of spaces between two spaces" (Bafna, 2003, pg. 21). An article on multilevel movement networks has provided me with another definition for spatial depth. "Regarding spatial depth, a space is said to be shallow when it is easily accessible with a relatively lower number of direction changes from all other spaces of the study areas. Conversely, a space is said to be deep when it is difficult to access, thus demanding frequent direction changes, from all other spaces of the area" (Chang, 2002, pg 583). This theory deals with particular spaces and their accessibility; for my study, that would be the spatial depth of each of the large generators at the intersection. An axial map of the network displaying cordon count results was used with network maps to conduct this analysis. In his article on space syntax, Bafna notes "if the focus of analysis is the understanding of behavioural characteristics of the spatial setting, axial maps are more useful" (Bafna, 2003, pg. 25).

What I did was analyze pathway segments along the heavily travelled routes in Xu Jia Hui to determine how spatially deep these routes were based on the factors found in Chang (1998). The level of depth was then compared with the volume of traffic for the segments in order to determine peoples' preferences for deep and shallow routes. Point depth, as determined by Chang, was used to help me calculate the spatial depth of a particular route. "Point depth from the major generator of movement breaks the line into segments which are the spaces between street intersections. These are points at which pedestrians must consider which is the most direct and simplest route when confronted with choices of direction." (Chang, 1998, pg. 525) Chang's equation puts more emphasis on horizontal depth than point depth. This relates to how many intersections must be passed while travelling on the selected route and uses that number as a factor in spatial depth. The point depth factor has to do with number of choices that lead to the destination that can be made along the way at the intersections. Since the point depth is not considered as important based on studies Chang looked at, the logarithm ($l_n$) of point depth (P) is used in the equation. H is the symbol for horizontal depth.

$$S_{HP} = \text{minimum}\,[\,H + \ln P\,]$$

For this equation the "minimum" is the lowest depth value possible for the particular route. This idea together with an analysis of level changes yields the estimate for spatial depth of a route.

To determine people's preference for a particular spatial depth, an equation or numerical way of determining the spatial depth of a route was created using a variation of what Chang (1998) did. This was then used with maps and observations to determine the spatial depth of the main paths travelled between the main traffic generators. The length of these routes was also measured as a factor to compare against the actual spatial depth of the routes. To determine people's preference for surface or underground routes, heavily travelled network segments between generators, where there was a choice of a surface and a tunnel route to arrive at the same destination, was studied. The cordon count ranking, and actual numbers at the cordon, together with tracking flow hits on the selected segments, determined if people moving between the generators were more likely to choose the surface or the underground route when both are available for use.

**Analyzing network and personal factors in path choice:** Questions five and six were as follows-- What are the network factors that cause people to choose the routes they do between traffic generators at Xu Jia Hui? What are the personal preference factors that cause people to choose the routes they do between traffic generators at Xu Jia Hui?

To answer questions five and six, information from the previous methodological questions came into play. Alongside spatial depth, the distances pedestrians travelled and the preference with regards to level changes was explored. Network factors in pedestrian choice were determined by cross-referencing information on the spatial depths of the paths, the level of use of the paths, and pedestrians' preferences in terms of length of trip and the number of level changes involved. Personal factors were determined by knowing the main origins of the pedestrians using heavily travelled routes, the destinations they were heading to, together with the above analyses.

### 3-6-Creation and Testing of an Equation:

**Creation of the equation:** Using results from the analysis of pedestrian behaviour and dynamics at Xu Jia Hui, a linear equation with distance (D), spatial depth (SD) and level change (LC) as the variables was created. This equation was created to be able to predict the level of use of pathways in a pedestrian environment based on the way the network is designed. It is a predictive model for how people behave in the environment based on pedestrians' preferences for trip distance, level changes, and spatial depth. The function of this equation is to predict numbers of pedestrians at specific locations within the network based on the variables stated above.

**Applying the Equation to the Proposed Network:** The model equation was tested using proposed changes to the layout of the Xu Jia Hui pedestrian and transportation network. This was a test of the accuracy of the equation and the usefulness of the model to make predictions about pedestrian behaviour. Using the maps and plans obtained while in Shanghai that display the potential layout of the metro stations proposed for the site, a new network map was created. Once created, the equation was used to generate numbers for traffic flows throughout the revised Xu Jia Hui network. Getting realistic and highly likely results from running the model would prove the equation is a valid one that may be applied to other existing pedestrian networks, as well as the design process for new networks.

A level-of-service test was also run on the network's underground tunnel system to determine how serious the crowding problem will be with the added stations, malls and pedestrians. Level-of-service, a concept created by Fruin (1971), is a measure of the freedom of movement of pedestrians on a pathway. It determines the degree of freedom of movement based on the ratio of pedestrians to square area of the pathway, and the average speed at which the pedestrian traffic is moving (Fruin, 1971). The equation is as follows:

$$P = \frac{S}{M}$$

Where P is the mean flow rate, or pedestrians per foot width per minute; S is horizontal mean speed; and M is the number of square feet per pedestrian based on area of the pathway and number of pedestrians on it (Fruin, 1971). For this study the units were converted to metres from feet (refer to the Level-of-Service Calculations appendix- pg. 97). The measure was carried out for the links in the new network that were found to have the highest flows and fit into the highest category of pedestrian traffic flow based on the predictive model's results.

To reach the point of creating an equation to be tested on the redeveloped Xu Jia Hui network, the pedestrian dynamics and route choice behaviour must be known. This is the function of the Analysis chapter which follows.

## 4-Analysis

In this chapter, a full analysis of pedestrian dynamics and route choice was conducted based on the methods described in the previous chapter which were used to conduct the Xu Jia Hui study and extract information from the results.

### 4.1-Pedestrian Dynamics at Xu Jia Hui:

**Traffic Generators:** The main traffic generators at the Xu Jia Hui intersection were the metro station, Grand Gateway mall, Oriental Plaza, Pacific Soho, Shanghai Lubai, and the Metro Center mall **(Figure 4-1).** Since the metro station is integral with the underground tunnels and has numerous entrances making analysis difficult with a small number of research assistants, the focus of the analysis was the movement between the commercial and retail traffic generators. These commercial and retail buildings and outlets were the main reason the people travelled to Xu Jia Hui each day.

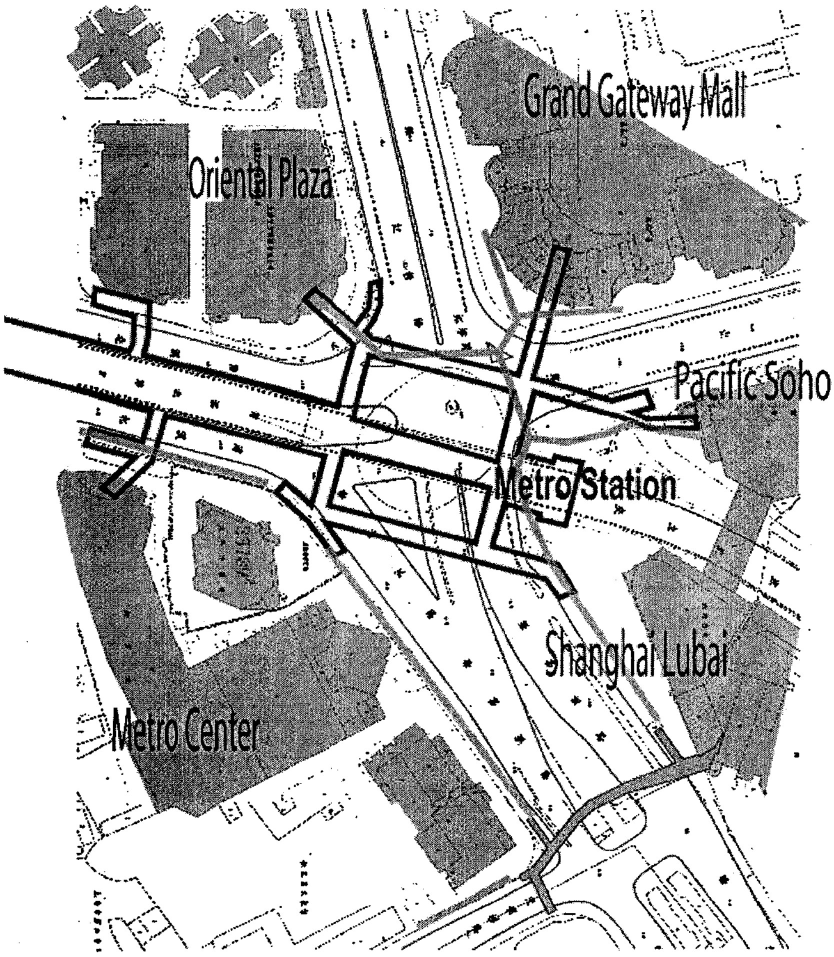


**Figure 4-1: Traffic generators**

**Levels of Flow:** When the cordon count data set was sorted and analyzed, three distinct levels of flow were discovered **(Figure 4-2)**. Also, in the third and highest level, one cordon covering the connection between the subway station and Grand Gateway mall had extremely high counts that could be considered its own fourth level. Overall, 41 of 57 cordons had values that fit within a distinct level set out on the chart; this was because of the overlap of the standard deviations into other levels for 15 of the cordon counts.

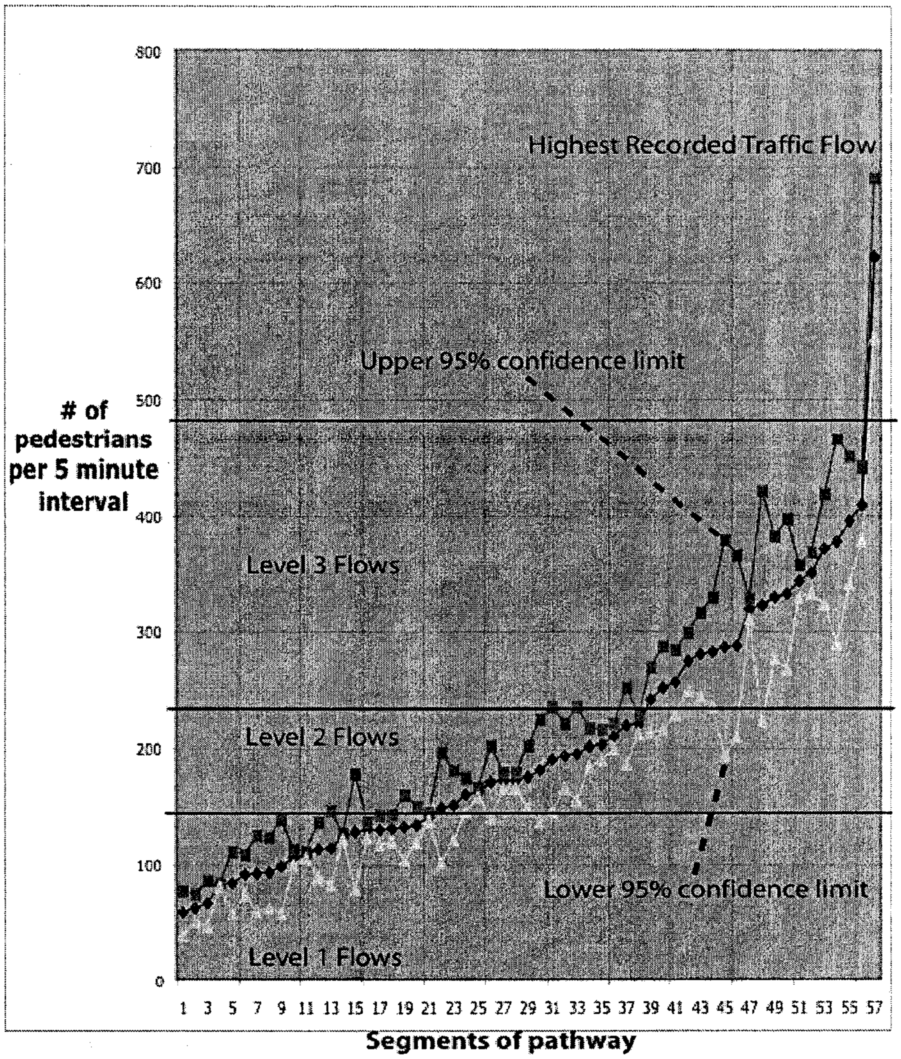


**Figure 4-2: Levels of flow on 57 segments of pathway with upper and lower confidence levels**

**Cordon Density Distribution:** The cordon counts were mapped in order to graphically display how pedestrians were distributed across the network at the times we collected cordon data **(Figure 4-3)**. The density map of pedestrian flows in the network shows the distribution of people according to the available cordon count information. The highest pedestrian traffic flows were within the metro station where the flow was as high as 131 pedestrians per minute and in the tunnel connecting the metro station to the Grand

Gateway mall where the flow reached 124 pedestrians per minute. On the surface, the street level crossing between Grand Gateway and the block Pacific Soho is located on had a flow of 45 pedestrians per minute. From that corner to the steps of Pacific Soho, the flow was 79 pedestrians per minute. From that same corner heading in the direction of Shanghai Lubai and the pedestrian bridge, the pedestrian flow was 66 pedestrians per minute. There are a number of links that do not have cordon count information on the sidewalks in front of Metro Center and along that entire block (indicated by the red lines). These flows along the street connecting to Metro Center by observation were very substantial and likely to match those between Grand Gateway and Pacific Soho.

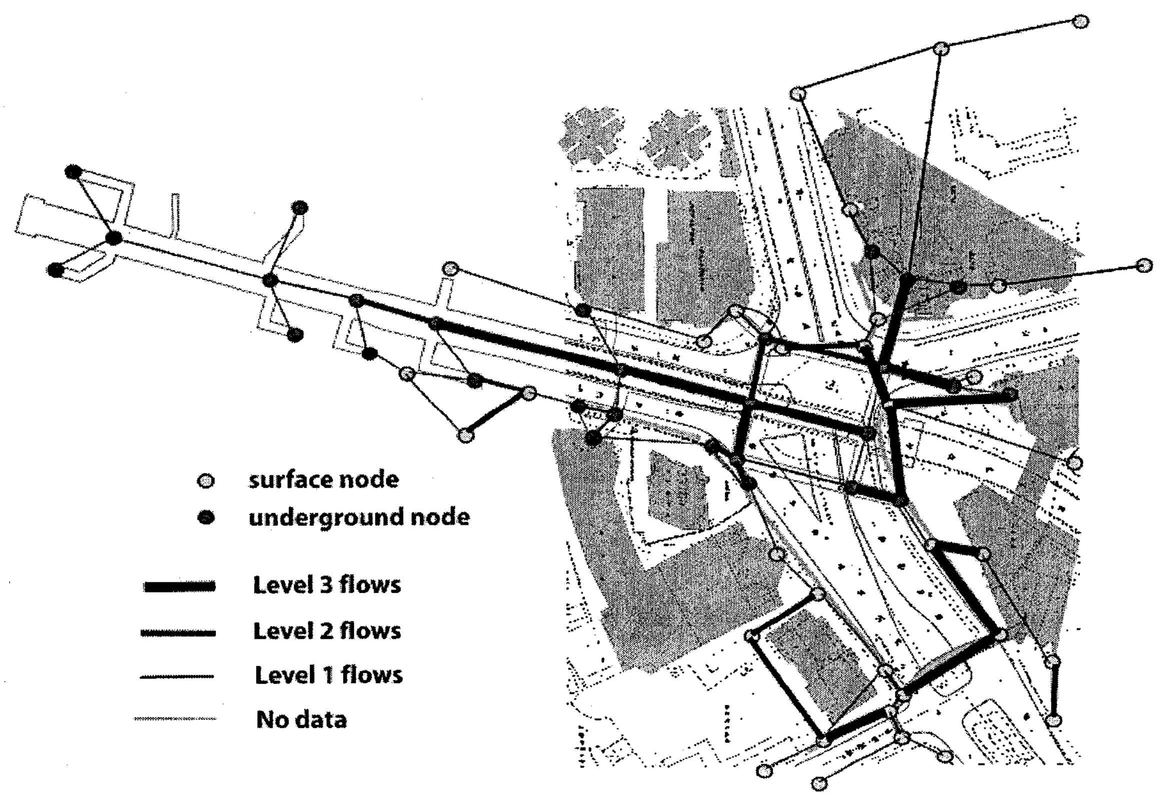


**Figure 4-3: Cordon density distribution**

**Tracking Density Distribution:** The density distribution diagram for tracking gives a similar, but not the same, picture of the distribution of pedestrians in the network **(Figure 4-4)**. The connection between the station and Grand Gateway is still shown to be strong, as is the connection between Grand Gateway, and Shanghai Lubai and Pacific Soho along the surface. There is also a strong connection between the station and Metro Center which follows the path from the metro station exit along the sidewalk on the surface to the mall. There is also a connection between Oriental Plaza and Grand Gateway that is significant due to the fact that the surface level trip is very simple and quick, and pedestrians appear to favour the surface routes at this point in the network.

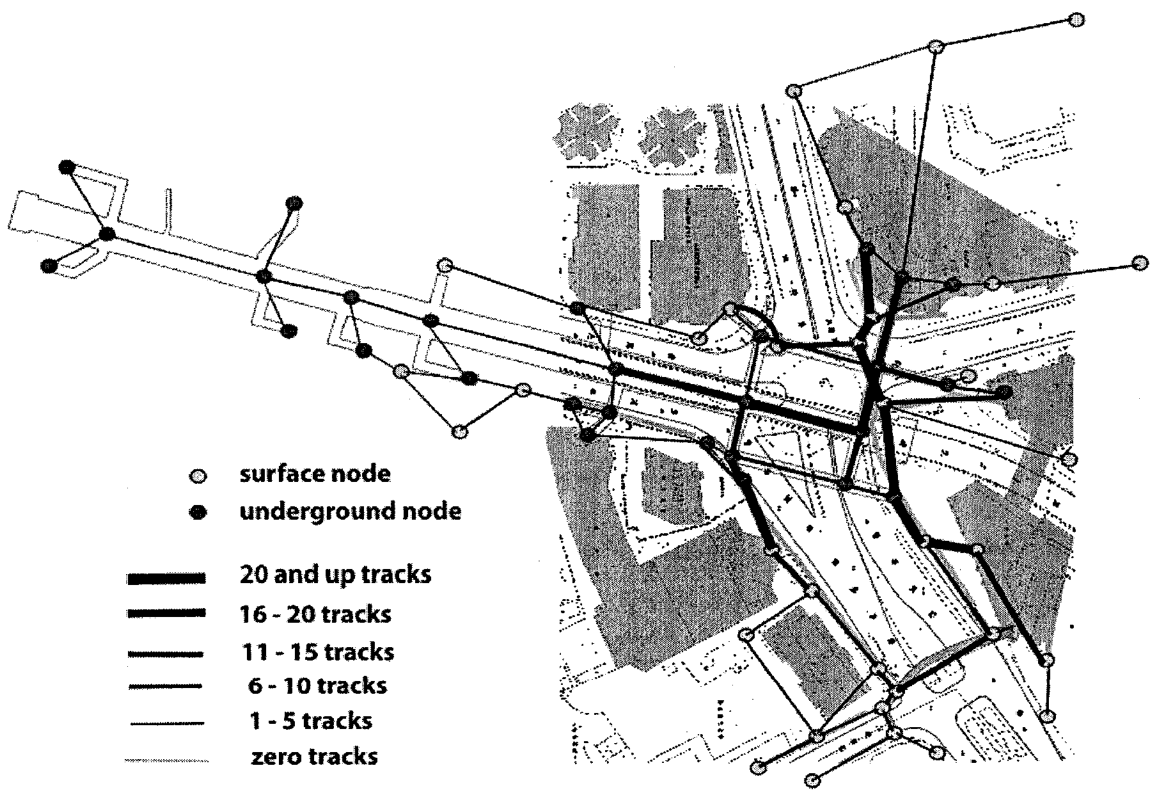


**Figure 4-4: Tracking density distribution**

**Flow Analysis:** Using the flow analysis techniques employed by Thornton et al. (1987), the routes people seemed most likely to use to navigate between the major traffic generators were similar to those indicated in the density distribution diagrams for the cordon counts and tracked trips. The directional flow of pedestrian traffic at intersections can be derived from cordon count data. The analysis that follows is a demonstration of this fact and shows that the flows through intersections were not evenly distributed, but were not too complex to be interpreted **(Figures 4-5 to 4-8)**. The following diagrams of nine analyzed intersections display the turning and flow behaviour of pedestrians at the specific locations in the network. The varying thicknesses of the arrows represent the volume of pedestrian flow in that particular direction relative to the other possible directions of flow at the given intersection. The location of these intersections within the network is indicated on each graphic display. On each link leading away from the intersection is the letter assigned to the link for calculation purposes, and the actual coded direction choice from the original node map (the number in brackets) which was used to turn the trackings into data usable for graphic displays of pedestrian distribution.

Intersections 18 and 20 are in the tunnel system that is integral with the metro station.

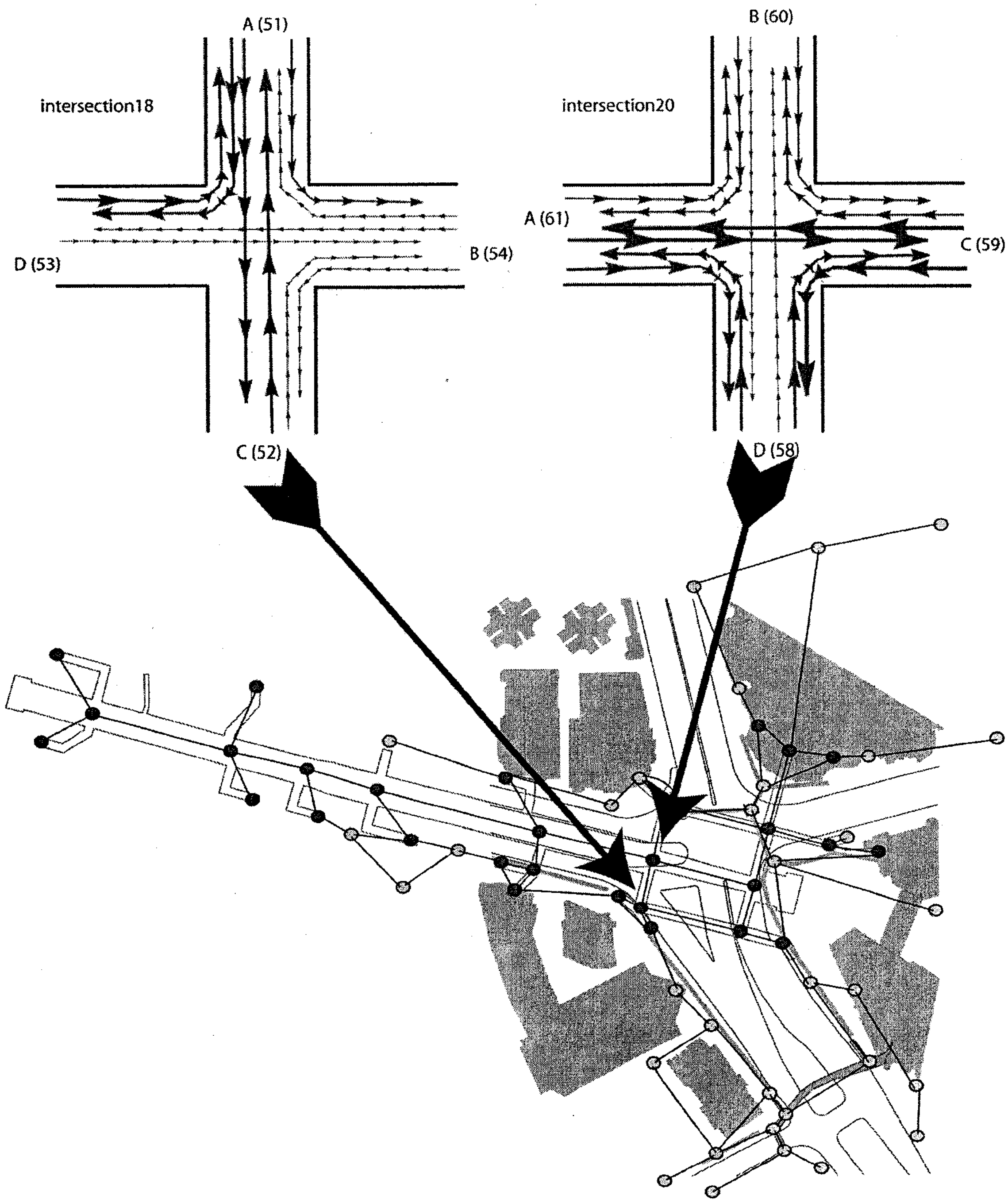


**Figure 4-5: Flow Analysis**

Intersections 43 and 59 are surface intersections handling traffic moving between various generators including Shanghai Lubai, the metro, Grand Gateway and Pacific Soho.

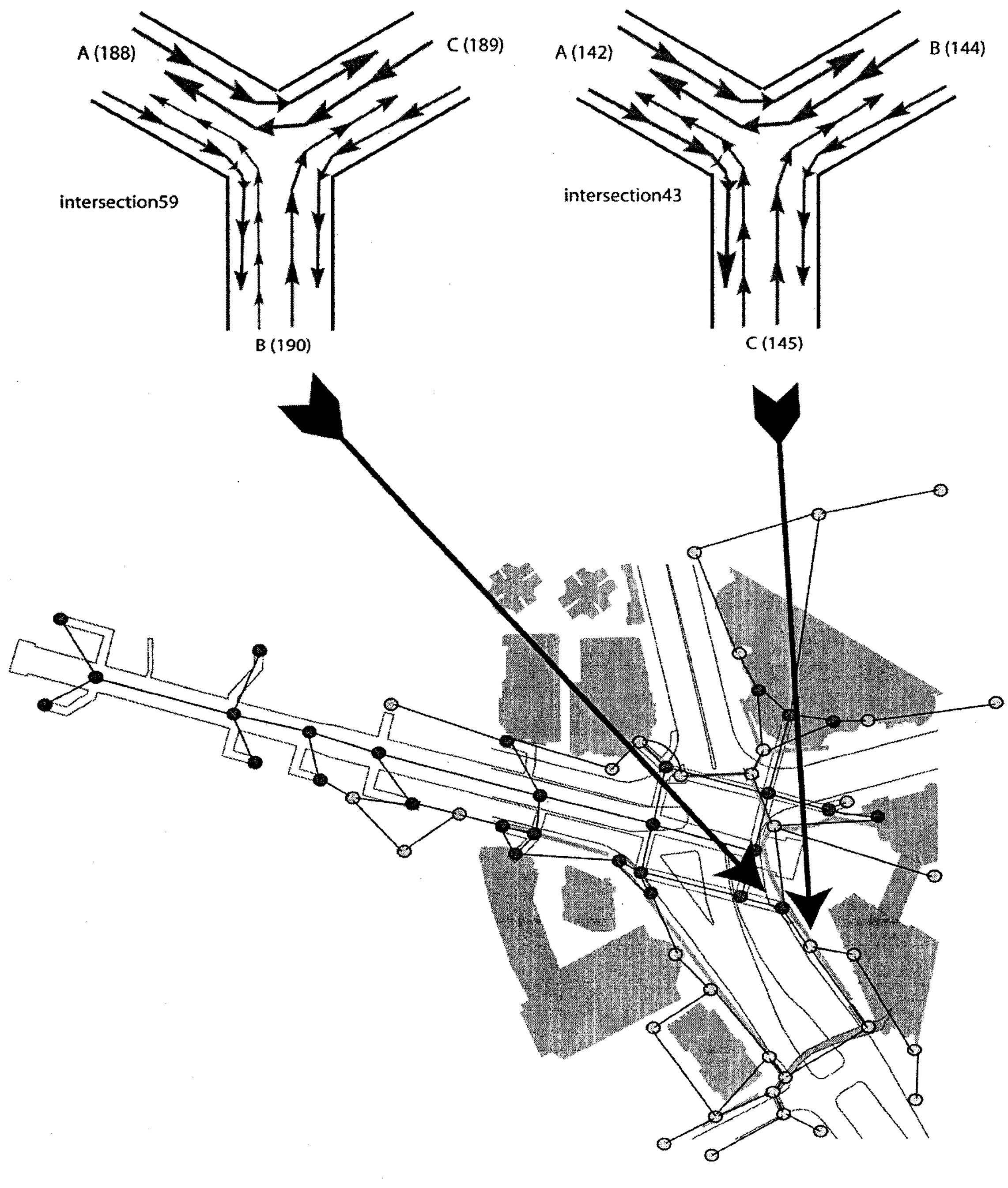


**Figure 4-6: Flow Analysis**

Intersections 45, 48 and 49 are all located on the bridge and handle all traffic crossing the network that does not flow through the underground tunnels but needs to cross the major road in front of Metro Center.

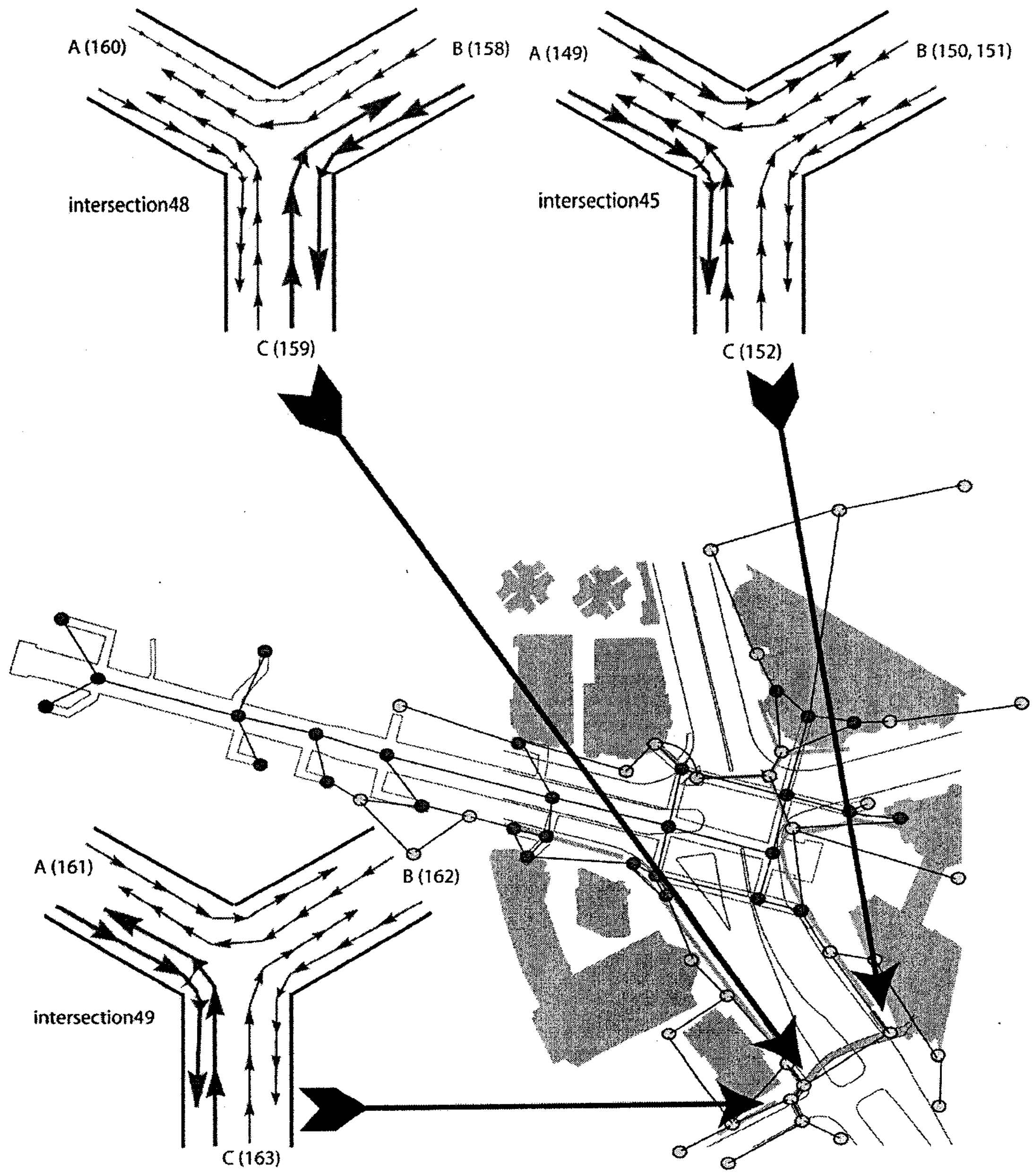


**Figure 4-7: Flow Analysis**

Intersection 40 is a major intersection handling traffic from many surface routes between the major generators. Intersection 36 is a peripheral, less important intersection.

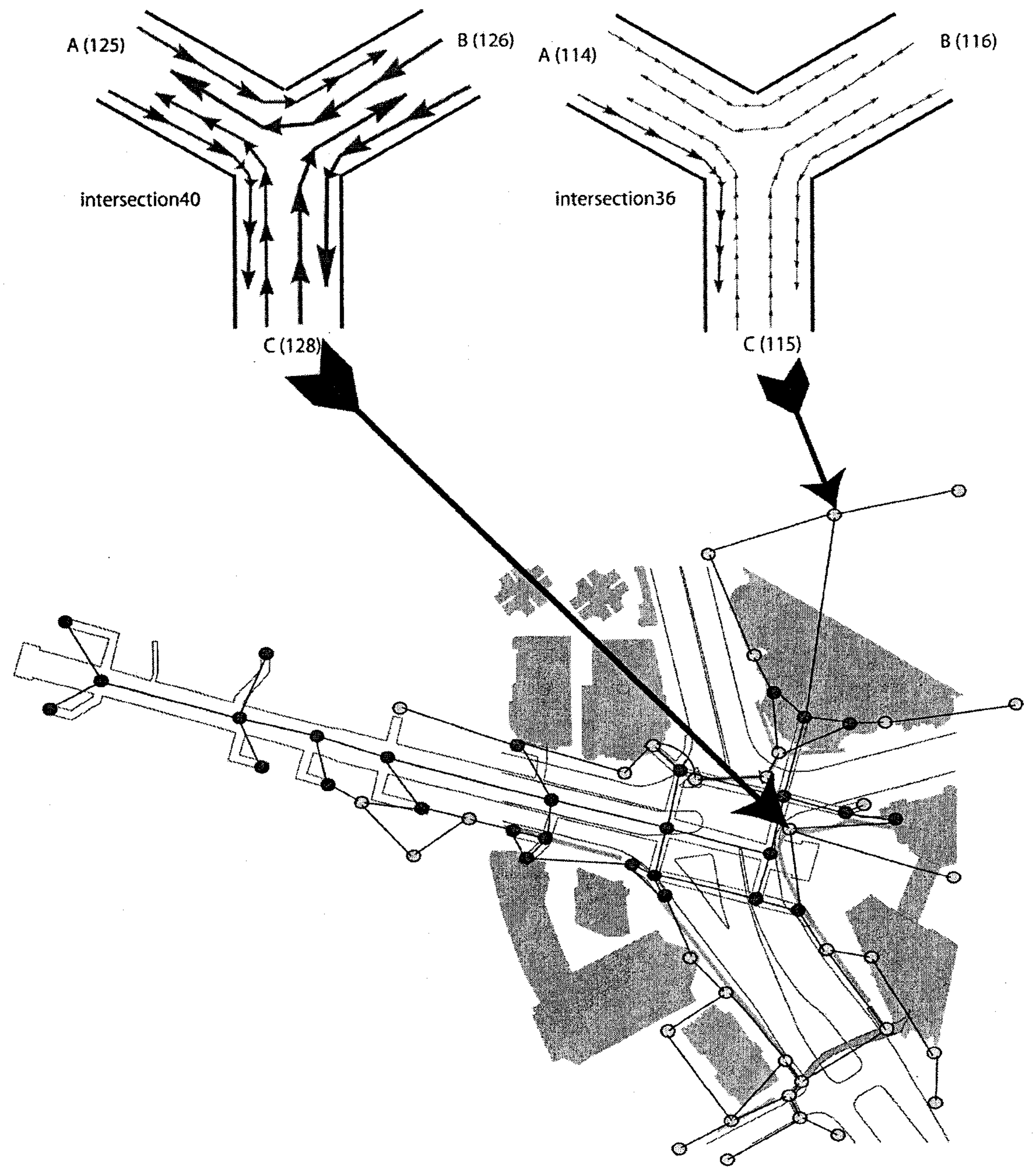


**Figure 4-8: Flow Analysis**

**Flow Analysis – Tracking Correlation:** This analysis comparing flows to tracking results was conducted in order to determine if the relatively small numbers of trackings conducted were an accurate representation of reality when it came to how pedestrians moved through the Xu Jia Hui network. The majority of trackings were conducted starting at one of six points. The six main generators that were the main starting points were the metro station (28), Grand Gateway mall (22), Shanghai Lubai (17), Metro Center (14), Oriental Plaza (10), and Pacific Soho (6). Pearson r tests the correlation between two sets of raw data. This is a descriptive statistic that measures if a positive or negative correlation exists and expresses the strength of the relationship as a sum of squares (Norman and Streiner, 2003). The significance of the correlation is calculated with $p < 0.05$ set for statistical significance. In this case the calculation was being used to test the relationship between the trackings and a number of available intersections analyzed using Thornton's flow analysis technique. A correlation between these sets of data means that cordon count information for this particular study and the trackings conducted in this study are significantly representative of each other. A positive correlation was found for this comparison of flow counts and tracking counts. The Pearson correlation (r) is 0.476 with a one-tailed significance of 0.005. These values mean that there is a significantly strong relationship between the two sets of data and therefore between the cordon counts and the tracking data. Therefore, even a small number of tracked trips can reveal the basic route patterns that pedestrians use to navigate around a pedestrian network.

### 4.2-Route Choice Analysis:

**The Wilcoxon Test:** The Wilcoxon signed rank test was used to evaluate pedestrians' preferences for route choice based on three factors—trip distance, spatial depth of the route, and number of level changes. In each case a one-tailed analysis was made since these studies followed those of Chang (2002, 1998), which hypothesized that pedestrians minimize for distance, depth and level changes.

The function of the Wilcoxon signed rank test is to compare two related samples of data. It checks the number of times that the values for the first set of data are larger than the corresponding values for the second set and ranks them. This determines the difference in rank and produces a "P" value (Norman and Streiner, 2003). If this value is a negative number, the values for the second set of data are generally larger than for the first set of data. For this study, the route actually taken by pedestrians was always the first set of data while the alternate routes not taken were represented in the second set of data. The last part of the calculations produces a "Z" value. This "Z-test" is common in statistical analysis and is used to show statistical significance and whether the data comes from a standard distribution. The test does this by comparing a sample mean to a known population (Norman and Streiner, 2003).

**Distance, Spatial Depth and Level Change:** The results of the three Wilcoxon tests show that the hypotheses for pedestrian behaviour in Xu Jia Hui in terms of minimizing distance, spatial depth and level changes, are all true. For the factor of trip length, the hypothesis was that pedestrians would choose the shorter trips over the longer ones. The calculation, having a sample size of 39 comparisons, produced results approaching significance that accepted this hypothesis. Pedestrians are generally choosing the shorter path when given a choice. ($Z= -1.532$, $P= 0.0625$) The results are not quite significant, but acceptable to make conclusions. For spatial depth, the hypothesis was that pedestrians minimize depth when choosing a route through a pedestrian network. Spatial depth calculations, with a sample size of 37 comparisons, had slightly less significant results but still accepted the hypothesis. ($Z= -1.427$, $P= 0.077$) People were taking routes with a lower spatial depth than the alternatives in general when given a choice. These results are also significant enough to make conclusions about the trend. The hypothesis for level change was that pedestrians wanted to minimize the number of level changes they made through selection of the proper route. The level change calculations, with a sample size of 39 comparisons, turned up absolute results. ($Z= -4.811$, $P= 0.0$) The P value is off the charts (the Z table of distributions). People are nearly always choosing to take routes with fewer level changes. This appears to be the number one consideration for people traveling through the Xu Jia Hui pedestrian network.

**Analyzing the Results:** These results give a picture of how people are moving around the pedestrian network support each other and converge on the same conclusions about pedestrian behaviour at Xu Ji Hui. The fact that there is a significant correlation between flow analysis and the tracked trips proves that it is possible to accurately determine the pedestrian flow behaviour using either method. Also, these methods can be used to check one another and help the researcher to be confident in his or her results. The results of the Wilcoxon tests all supported hypotheses made about the way people choose what route to take, which are the principles behind the pedestrian model developed in this study. Some conclusions can be drawn from these results about how people choose to move around Xu Jia Hui. Where there is a choice of a less complex route with a lower depth and fewer level changes, pedestrians will tend to take the less complex route. There also seems to be a strong preference for travelling on the surface. These partial conclusions will be revisited later. The route choice analysis results are now used to create an equation for the model in the next chapter. Spatial depth, distance and level changes are the factors involved.

## 5-Creating an Equation

This chapter outlines the creation of the equation that forms the pedestrian prediction model. This equation was designed as a linear equation that started with a given flow at the traffic generator, then subtracted from that flow based on three factors for the various links radiating outwards from the generator. Distance (D), spatial depth (SD) and level changes (LC) were the three factors of the equation that determined level of pedestrian traffic flow at any point in the network. This equation was made to apply to multiple traffic generators in a network, and the resulting numbers for flow on each link needed to be added where the coverage areas of each generator overlapped. That meant that links were influenced by their position with regards to more than one generator. For those reasons, the equation was kept simple to allow for accuracy on this non-computer generated model.

### 5.1-Formatting the Equation:

An assumption was made that only the three factors which were studied affected the flow of pedestrians on a link—distance from the generator, spatial depth of the link, and level changes on the link. If a link was free of distance, spatial depth and level change deterrents to pedestrian activity, then the flow leaving the link ($F_{final}$) should be equal to the amount entering the link (F). In the worst possible scenario for a link, $F_{final}$ should equal zero as no pedestrians would choose to use such a link. Thus the boundary conditions for the equation were that $F_{final}$ be greater than or equal to zero, and less than or equal to F. To ensure that these boundary conditions were upheld, the coefficients for distance, spatial depth and level change were normalized such that the sum of the coefficients was one. Also, the distance, depth and level change values were divided by the maximum possible distance, depth and level change values. This turned the distance, depth and level change values into proportions that determined the level of effect each of the three coefficients would have on each link in the network.

These measures ensured that it was impossible to end up with a negative $F_{final}$, or one that was larger than F. To normalize the coefficients, they were added up and then each coefficient was divided by the sum. Using this normalization process allows for inclusion of more factors affecting pedestrian flow, such as weather, time of day or day of the week, without sacrificing the validity of the equation. What follows is an explanation of how each of the three coefficients were derived and normalized.

**5.2-Distance Coefficient:**

The distance coefficient section of the equation determines the drop in pedestrian flow based on distance from the traffic generators in the pedestrian network. A comparison of categories of trip distance, and number of tracked trips in each category is displayed on the graph **(Figure 5-1)**. To create the coefficient, a sample of 40 trackings and their trip alternatives were analyzed to determine the drop in number of tracked trips due to an increase in trip distance. The actual coefficient is the drop in tracked trips divided by the increase in distance giving a proportional drop in trips per meter increase in trip distance. The coefficient was 0.0298 originally. After normalization, the coefficient was recalculated to be 0.0332.

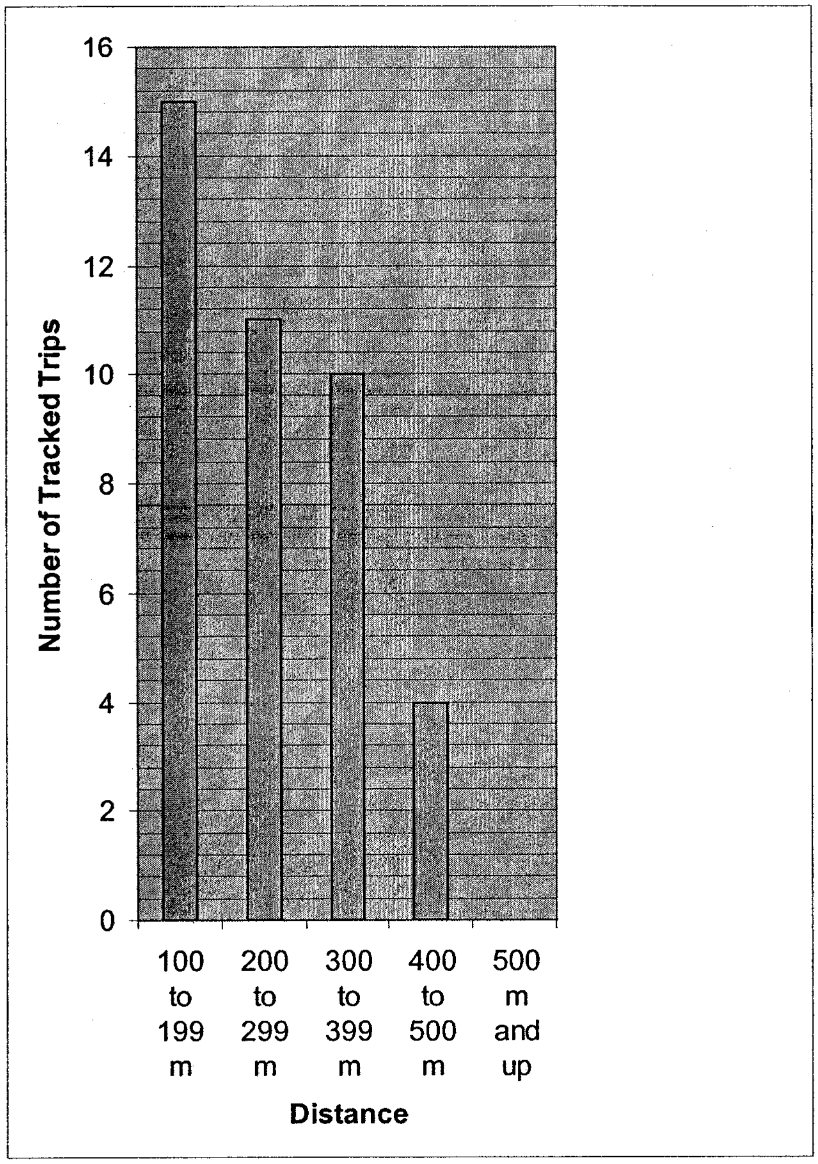


**Figure 5-1: Distance vs. tracked trips**

The $R^2$ value is the proportionate reduction in error, which is a measure of the worth of a regression equation. The closer the value is to 1, the greater the worth of the equation (Ryan, 1997, pg. 12). In this case the value ( $R^2 = 0.9641$) is exceptionally close to 1 which confirms a linear relationship between distance and pedestrian preference. Therefore the distance section of the equation is as follows:

$$- \left[ F \times \left( \frac{D}{D_{max}} \right) \times 0.0332 \right]$$

The minus sign in front of this term originated from the fact that the slope of the coefficient was negative. F is the flow entering the link and D is the distance from the generator placed in a fraction with respect to $D_{max}$, which is the maximum distance that pedestrians are willing to walk (i.e. where the slope crosses the x-axis). This term represents the amount of traffic flow subtracted off the number entering the link based on the effect of distance from the generator.

**5.3-Spatial Depth Coefficient:**

This section of the equation measures the drop in pedestrian flow on a given route based on how spatially deep it is from the major traffic generators in the network. Categories of spatial depth were compared to the number of tracked trips in each category below **(Figure 5-2)**. The spatial depth coefficient was created by analyzing a sample of 37 trackings and their trip alternatives to determine the drop in number of tracked trips based on level of spatial depth. The actual coefficient is the % drop in tracked trips divided by the increase in spatial depth (= 0.5517). After normalization the new value of the coefficient was 0.614.

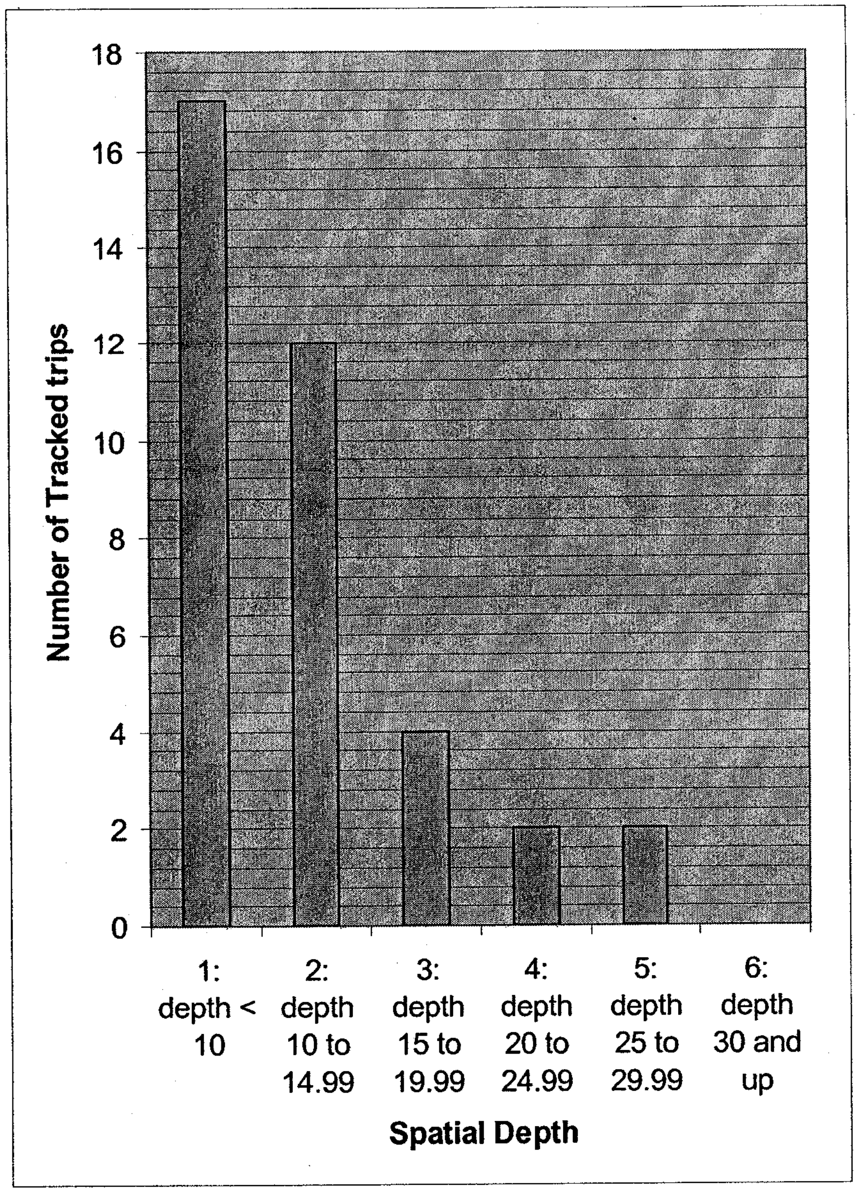


**Figure 5-2: Spatial Depth vs. tracked trips**

The $R^2$ value in this case ( $R^2 = 0.8546$) is approaching 1 meaning the correlation is strong and confirms a linear relationship between spatial depth and pedestrian preference. Therefore the spatial depth section of the equation is as follows:

$$-\left[F \times \left(\frac{SD}{SD_{max}}\right) \times 0.6140\right]$$

The minus sign in front of this term originated from the fact that the slope of the coefficient was negative. F is the flow entering the link and SD is the spatial depth and is in a fraction with respect to $SD_{max}$, which is the maximum depth that any point in the network is from a generator (i.e. where the slope crosses the x-axis). This term represents the amount of people subtracted from the number of pedestrians entering the link based on the effect of spatial depth.

**5.4-Level Change Coefficient:**

The level change section of the equation applied when the route being studied included a level change. At that particular link this coefficient was multiplied by the flow and level change factor (LC) to determine the drop in flow caused by the level change **(Figure 5-3)**. To get this coefficient, the percentage of tracked pedestrians from a sample of 41 trackings that chose to take a route with a level change was divided by the total pedestrians that had a choice of whether or not to take that route for their trip (=0.3171). After normalization the new coefficient was 0.3529.

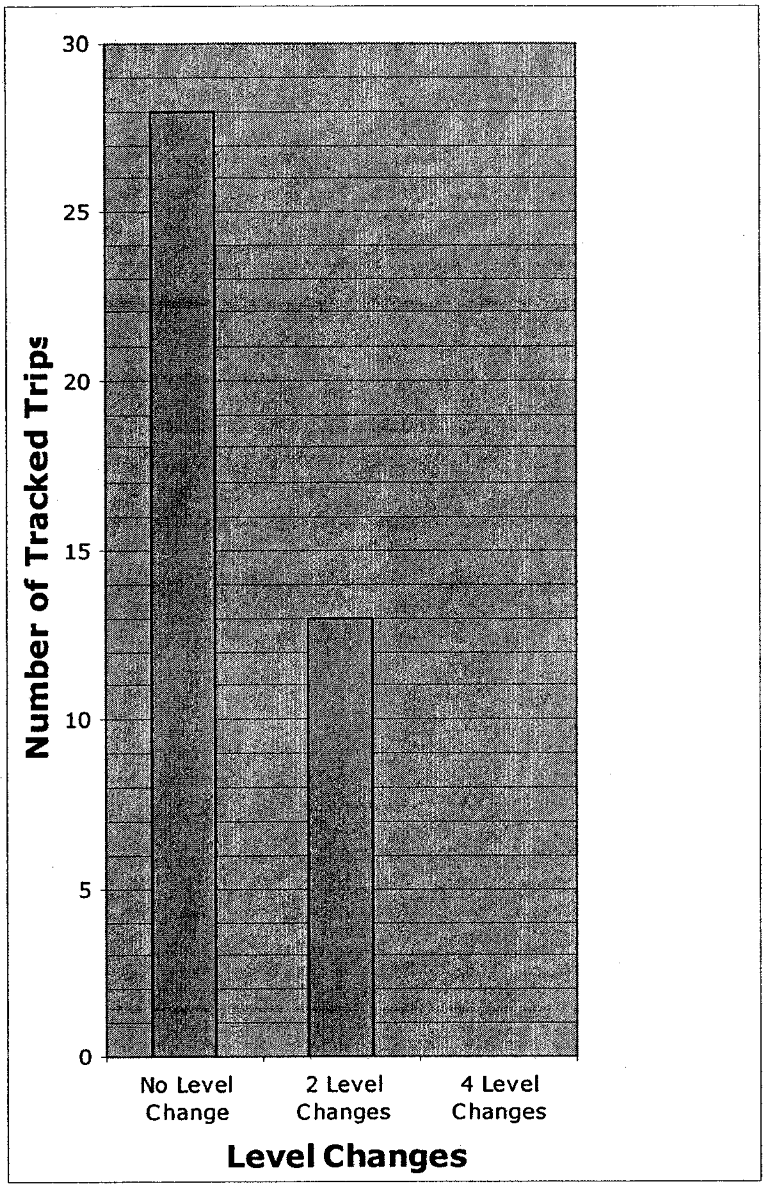


**Figure 5-3: Level Change vs. tracked trips**

The $R^2$ value in this case ($R^2 = 0.9983$) is exceptionally close to 1 which confirms a linear correlation between level change and pedestrian preference. Therefore the level change section of the equations is as follows:

$$-\left[F \times \left(\frac{LC}{LC_{max}}\right) \times 0.3529\right]$$

The minus sign in front of this term originated from the fact that the slope of the coefficient was negative. F is the flow entering the intersection and LC number of level changes on the link which is placed in a fraction with respect to $LC_{max}$, which is the largest number of level changes pedestrians will accept on a link. The fact that no person took a route with more than two level changes just re-enforces the validity of $LC_{max} = 4$ (i.e. where the slope crosses the x-axis). This term represents the amount of people to be subtracted from the flow for that link of the network due to level changes.

**5.5-The Equation:**

This is the final equation with all the factors and normalized coefficients which will be used to predict the pedestrian flows in the new Xu Jia Hui network based on the three factors derived from flows at the three subway stations. $F_{final}$ is the final number of pedestrians staying on the link. F is the number of pedestrians entering the link that have potential to choose another path. D is distance in meters that the link is from the generator. SD is units of spatial depth measuring the depth of the link from the generator. LC is the number of level changes on the link. It must be noted that the relative magnitudes of the coefficients (i.e. slopes) are a direct measure of the importance that people place on the various factors involved in their decision on which path to take.

$$F_{final} = F - \left[F \times \left(\frac{D}{D_{max}}\right) \times 0.0332\right] - \left[F \times \left(\frac{SD}{SD_{max}}\right) \times 0.6140\right] - \left[F \times \left(\frac{LC}{LC_{max}}\right) \times 0.3529\right]$$

**5.6-Extending the Equation:**

This equation can be expanded on by allowing for the inclusion of positive factors that increase the number of pedestrians on a given link. This expanded equation with positive and negative terms would give a more complete picture of how pedestrians make route choices in a pedestrian network, and would improve the accuracy of the model. The same basic format is used in this equation and the basic term before normalization is as follows:

$$+F[1 + AP_1]$$

Where P is the pedestrian drawing factor (i.e. positive coefficient), A is the extent to which P is present (i.e. a fraction= 0.0 to 1.0) and F is the flow entering the link.

For the normalization process, the positive terms would be normalized the same way as was done in the original equation. If there is a mix of positive and negative coefficients then each term is normalized by dividing by the sum of the absolute values of all the coefficients (Z). Therefore the general version of the new final equation is as follows:

$$F_{final} = F\left[1 - \left(\frac{1}{Z}\right)(AN_1 + BN_2) + \left(\frac{1}{Z}\right)(CP_1 + DP_2)\right]$$

Where $\left(\frac{1}{Z}\right)$ is the normalization factor, $N_1$ and $N_2$ are negative factors affecting pedestrian flow, and $P_1$ and $P_2$ are positive factors affecting pedestrian flow. A, B, C, & D are the fractional amounts (i.e. between 0.0 to 1.0) to which the various factors are present. With this equation the values for $F_{final}$ will range between zero and two. While it is not possible to have an actual $F_{final}$ greater than one, what it indicates when the equation turns up such a number is that all pedestrians entering the link were retained and more positive incentive was applied than was needed to retain all pedestrians.

## 6-Applying the Equation

The equation created in the previous chapter is a pedestrian behaviour prediction model and is as follows:

$$F_{final} = F - \left[F \times \left(\frac{D}{D_{max}}\right) \times 0.0332\right] - \left[F \times \left(\frac{SD}{SD_{max}}\right) \times 0.6140\right] - \left[F \times \left(\frac{LC}{LC_{max}}\right) \times 0.3529\right]$$

It is designed to determine distribution of pedestrians across a pedestrian network based on the route choice preferences of the set of pedestrians being evaluated, and the volume of pedestrian traffic originating at the traffic generator. I applied this equation to each link in the proposed Xu Jia Hui network in order to determine the distribution of pedestrians in the pedestrian network, particularly the tunnel system.

### 6.1-The New Network:

A new network map was produced using plans of proposed stations for Xu Jia Hui. There are three metro stations integrated into one large transportation hub with an extensive tunnel system. The map below **(Figure 6-1)** shows the new layout at Xu Jia Hui and included are two blocks indicating where new malls are expected to be constructed in the next few years. The tunnel system is extended out to these malls from the second and third metro stations. Metro stations one and three are at the same depth below the street since those two metro lines merge into one. Metro station two is a level below since its tracks cross beneath those of the lines on which metro stations one and three are located. The level displayed on the map is where the concourse for metro Stations One and Three are located and is the level which was studied. This is the level to which all the surrounding malls and stores of the Xu Jia Hui commercial node connect to the metro stations and tunnel network. The area where metro Station Two is located has escalators down to the concourse level for that station where the turnstiles are, but since people would have to pass through the above level, that means the effects of Station Two were also taken into account in the study.

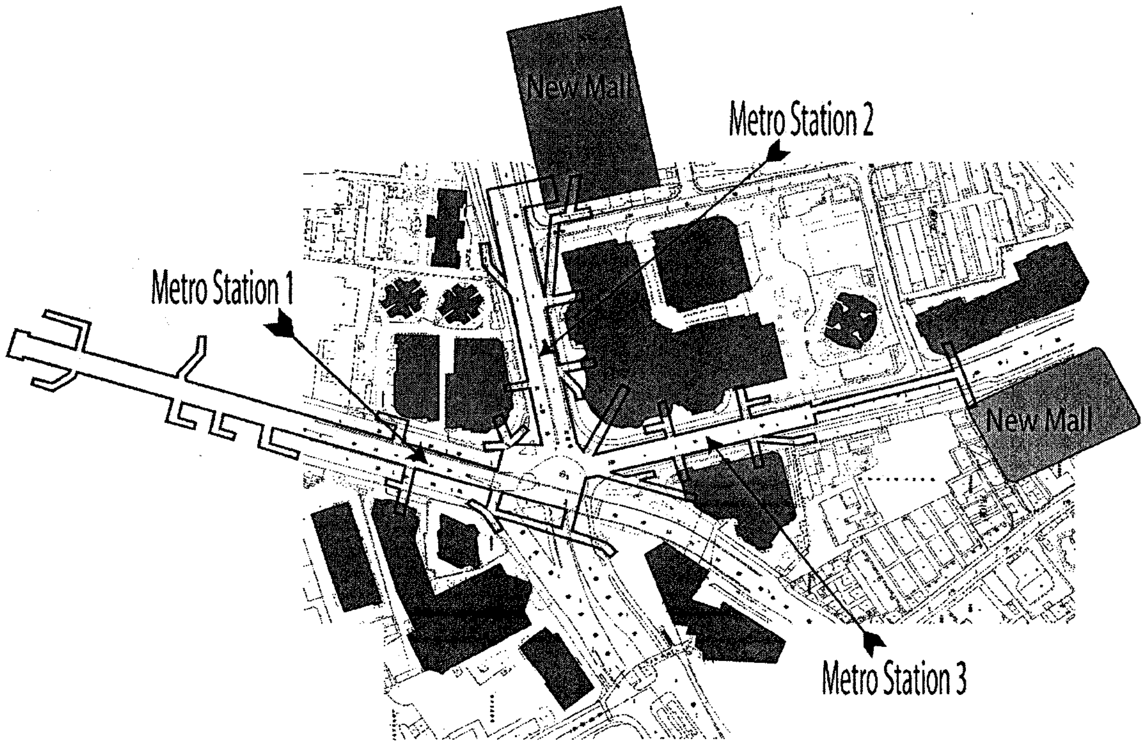


**Figure 6-1: New network**

### 6.2-Distribution of Pedestrians throughout the New Network:

The predictive model equation created in the previous chapter was run on a new nodal network created from the map of the new Xu Jia Hui layout **(Figure 6-2)**. The model was run by calculating the expected number of pedestrians on each link of the network based on their position relative to each station. For each station the initial number of pedestrians

(F) was set at 500 (per 5 minute period similar to cordon counts) and the number of pedestrians expected at the end of each link ($F_{final}$) was calculated using the results from the previous link. The calculations for the links radiated outward from each station. At the end the numbers for all 118 links, for each station, were added together to get a clear picture of how many people would be in the system at a given time. Below, **figure 6-2** displays the flows expected in the network based on the predictive model. It is a density of flow diagram that divides the flows into four levels. The central part of the network where the three stations connect, and the tunnel to the Grand Gateway center is located, is the busiest part of the network.

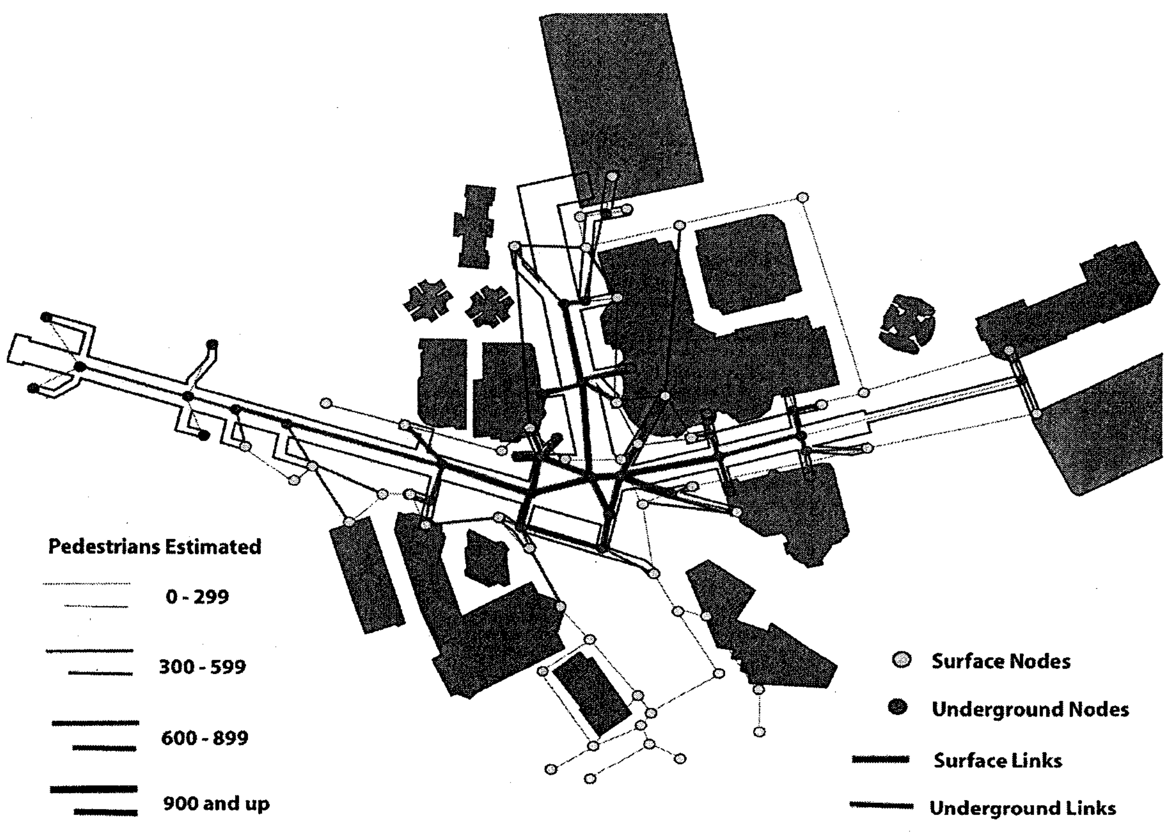


**Figure 6-2: Predicted flow density diagram**

### 6.3-Level-of-Service on Important Pathways:

To get an accurate idea of how congested the underground tunnels are projected to be by the model, a level-of-service study was conducted on the all the links that fell into the highest category of pedestrian traffic. The Fruin (1971) technique was used to determine how many pedestrians per minute per metre of width would be travelling on each of the pathways. The results were then classified using the levels (from A to F) that Fruin (1971) detailed in his study. All of the links that were analyzed for level-of-service were the D, E, or F ranges of service. According to Fruin, the D level-of-service is common for most crowded public spaces. It may sometimes include stoppage of flow or require the pedestrians to change pace as others get in their way due to congestion. The E level-of-service is a congested situation common for train stations, stadiums or other places where large masses of people periodically enter into the pathways. Pedestrian movements and speeds are quite restricted at this level. The F level is the worst conditions possible. Basically this is a traffic jam situation with stop-and-go movement (refer to the Level-of-Service Calculations appendix- pg. 97). It is not recommended to ever design a walkway to have this level-of-service (Fruin, 1971).

### 6.4-Evaluation of the Equation:

The elements of this equation were validated through the execution of this predictive model on the new Xu Jia Hui network. Spatial depth had a large effect on traffic flows. Level changes also decreased traffic flows where they existed. Distance is not a major factor at all with a small network such as this. The distance increase would have decreased the overall flows by more significant amounts if this network were spread over much larger area equivalent underground networks in downtown Toronto and Montreal. Given that the distance factor after normalization accounts for less than five percent of the pedestrian's decision making process, it technically could be dropped from the equation and replaced considering that many times accuracy for results are set at + or – 5%.

## 7-Error Analysis

### 7.1-Design Flaws and Data Collection Errors:

Both through human error during data collection, and data collection design flaws, there turned out to be missing values for cordon counts in this study. No cordons were set up on the sidewalks in front of Metro Center leaving a number of holes in the cordon distribution map. For the cordon counts that were designed into the study, human errors led to some of this data being lost or not counted. Those cordons that were not counted were filled out with dummy numbers and in one case (links 13 and 15 on the original network map), cordon numbers were created based on the flows entering and leaving the intersection via the other two links of this four way intersection (links 16 and 17). The generated numbers for 13 and 15 ended up the same based on the calculation, but this is not a very accurate depiction of the situation as was clearly observed while studying the intersection since a lot more pedestrians exited the metro through link 15 than link 13. For those cordons that were counted, the method used of counting pedestrians in five minute intervals can lead to an error in estimating average flows on a pathway. Pedestrian counts cannot be generalized from short counts as easily as motor vehicles can because pedestrians sometimes are grouped together tightly, or they change direction frequently, and also they are not limited to any one path and can move around freely (Hocherman et al., 1986). According to Haynes (1977), these types of pedestrian counts are subject to error because of the fact that pedestrian flows can fluctuate and are irregular over periods of time. This can lead to falsely high or low counts that end up being generalized to the pathway as an average flow rate. This study did not use 15 minute counts that were found by Hocherman et al. (1986) to be inadequate to calculate hourly rates of flow, and therefore the 5 minute counts may not have a high level of accuracy (Hocherman et al., 1986).

Also, another design flaw was that the cordons that were set up were not coordinated with the nodal map used to analyze tracking. This is because the trackings were not collected before the cordon counts. That led to guessing as to where it was important to set up cordons rather than knowing the places to set cordons in order to easily compare the results to the tracking results. Another problem caused by the mismatch between cordons and the trackings was that when the correlation between flow analysis and the tracking data was made, not enough points of comparison could be found. A sparse and small number of intersections, relative to the total number of intersections in the pedestrian network, were able to be analyzed for flow patterns. If a larger number of these intersections could have been analyzed, the results of the comparison between tracking and flow would have been more complete with more accurate results.

**7.2-Construct Validity:**

The idea of construct validity relates to the strength of the connection between the theory behind a study and the actual carrying out of the methodology of the study (Trochim, 2002). A study that is not valid in terms of construct will not have a strong connection between the theory the researcher originally based the study on, and the results once the study has been carried out. The model equation is an additive linear equation as opposed to a linear regression equation. This means it has been assumed that the factors of the equation can simply be added up and the effect they have on each other is not accounted for. Overall, in terms of construct validity, this study is valid. The goals were to determine how people moved around the Xu Jia Hui commercial node and to evaluate plans for expansion of the tunnel system with the addition of the two new metro stations; those goals were achieved.

### 7.3-Internal Validity:

The concept of internal validity is important to any study that tries to find a causal relationship. Internal validity means that the study is constructed in such a way that the causes studied are the main, if not entire, reason for the effects seen. A study with errors in the area of internal validity will fail to prove that the defined causes are the reason for the effects determined in the results (Trochim, 2002). The only part of this study where internal validity comes into question is that of the number of trackings conducted. Given the large number of pedestrians that move through the Xu Jia Hui network on a daily basis, 124 trackings is a small number to conduct. Had more trackings been conducted, more solid and non-disputable results for how people choose to move around the network could have been yielded.

### 7.4-External Validity:

The idea of external validity is that a particular study on a specific case can be generalized to other cases. A study that is not externally valid has limitations and conditions that apply, that do not exist in similar situations elsewhere, making it impossible to say that the results of the study can be generalized for use in other situations (Trochim, 2002). This study took place in China. While it will definitely apply in a general way to East Asian cities, it may or may not apply to North American cities. The model itself is simple enough that it can be re-calibrated to the environment it is being used in. The conclusions about how people choose to move around multi-level pedestrian environments are the elements of this study that will not be generalized to other situations so easily because of different network designs.

Another very important factor that limits the ability of the results of any study of pedestrian behaviour in an environment to be generalized to other environments is the fact that layout is a major determinant of pedestrian behaviour. Considering the great influence the layout of a pedestrian network has on the behaviour and route choice of pedestrians, it is not easy to generalize from one network to many others simply due to the fact that no two pedestrian environments are designed exactly the same. However, in this study the tracking evidence was corroborated by the cordons showing that the technique used was a valid one. This method was created using approaches that have been proven in other pedestrian behaviour studies and in other pedestrian environments. This further validates the study. In general, the approach used here, due to its design, is applicable to all the other situations which used the analytical approaches that were incorporated into the development of the equation derived in this study.

## 8-Conclusions

### 8.1-Results:

The results of the initial study of Xu Jia Hui that were used to create the prediction model revealed some potential problems at the commercial node. During peak periods when cordon counts were being conducted, and also at other periods when trackings were being conducted, some of the tunnels in the system were filled to capacity. Particularly where people exited the metro platforms through the turnstiles, and where the metro station connected to the Grand Gateway mall. These hallways had flowing traffic, but clearly were at capacity and any increase in pedestrians passing at a given time would lead to stoppage of flow. Pedestrians prefer the street level crossings to those tunnels below that allow travel in the same directions. Spatial depth and level changes are strong factors in pedestrian route choice while distance travelled is a minor factor in the equation.

The predictive model was applied to test its ability to predict flows and to evaluate how well the design of the new Xu Jia Hui tunnel system will handle the increased levels of pedestrian flow generated by the addition of more metro stations. The level-of-service study indicated that three of the 11 most travelled links on the new network had a D level-of-service; three had an E level-of-service; and five had an F level-of-service. This shows that given the extensions to the underground network and two new metro stations proposed the pedestrian crowding problem at the Xu Jia Hui commercial node will only get worse. The 3rd Railway Survey and Design Institute was contracted by Shanghai city government to over see the project of incorporating two new subway stations into the transportation hub. The plans that they laid out for this project are insufficient to handle the levels of pedestrian traffic predicted by the model. Too much pedestrian activity will be concentrated in the centre of the underground tunnel network where the three stations interconnect to each other and the entrance to Grand Gateway mall. The tunnels are too narrow and will cause levels of congestion that will hold up traffic and deter people from entering the tunnel system. Also there are concerns about security and emergency evacuations that need to be considered. In an environment with such intense pedestrian activity and crowding, it may be difficult for security guards, emergency service workers and other public safety officials to do their job in ensuring that people are safe in the tunnels. Also, in the event that the metro stations and tunnels must be evacuated, there are not enough exits to ensure that pedestrians quickly and safely can exit to street level. Another problem to be addressed is that there are retail outlets located in some of those tunnels and the levels of crowding may negatively affect their sales in spite of the fact that large numbers of people will have access to the stores.

**8.2-Policy Implications:**

Clearly the tunnel system proposed for Xu Jia Hui would be inadequate to handle the levels of pedestrian traffic expected to flow through them. The tunnels will need to be widened, but also more tunnels may need to be incorporated into the design if possible to relieve some of the pressure. Also, there had been talk of closing street level crossings; this is not at all feasible. In the current situation a high number of pedestrians are crossing between Oriental Plaza and Grand Gateway, and on the other side, between Pacific Soho and Grand Gateway. It has been shown that pedestrians prefer the street level crossing to underground tunnels and with the added congestion and more shoppers in the area, those street level crossings will be used by a much larger number of pedestrians than at the current time. To close these street level crossings with the assumption that the tunnels can pick up the slack is not good planning. The government of the Xu Hui district of Shanghai, where Xu Jia Hui is located, received a proposal from consultants to solve the crowding problem by connecting all the sides of the intersection by pedestrian bridges. In order to use these bridges, pedestrians would have to exit the tunnels, and then climb up the stairs to cross the bridge to another point in the intersection. Provided that they want to enter their destination at street level, the pedestrians would be making three level changes to make such a trip. It was determined during the calibration of the predictive model that the presence level changes significantly dropped the number of pedestrians on a link. It would be likely that if these bridges opened and street level crossings were to close, as was part of the proposal, that pedestrians would crowd the tunnels until the congestion becomes unbearable, then they would use the bridges. The result would be wasted money on the bridges which would go under-used, and extreme crowding and safety problems in the tunnels, restricting activities at Xu Jia Hui since the metro system is the life-blood of the node.

These types of studies are very important to the planning process. The information on pedestrian behaviour should be required before architects and engineers lay out initial plans for connecting transportation hubs to commercial buildings. Once the initial plans are created, and before the process moves forwards, a pedestrian behaviour model must be applied to the design for the new network in order to determine where the major problems are so that modifications can be made to the design before the plan becomes official and construction is started. The information provided by running a prediction model can be compared against city rules, regulations and standards regarding pedestrian facilities and their level-of-service.

### 8.3-My Contribution to the Study of Pedestrian Behaviour:

My contribution relates to the fact that I was able to take elements of various pedestrian behaviour research studies and combine them to form a predictive model. This model equation I created is simple enough to be generalized and used in other situations provided that the user calibrates the coefficients for local pedestrian movement patterns. Also this thesis shows what can be learned about a pedestrian network when both time, and resources such as research assistants, are severely restricted. This area of pedestrian modelling has not yet found its place in the planning process but this study is a showcase of how such behaviour prediction models can be a vital part of the urban planning process. This study has taken a real life example of development and applied this pedestrian behaviour prediction model which allowed me to critique the plans created by the firm hired to deal with metro expansion at Xu Jia Hui. It can now be used as an example of the power of pedestrian behaviour prediction modelling within the context of planning expansions to current networks, and developing new ones.

### 8.4-Recommendations:

There are numerous improvements that could be made to this study. First of all, better coordination between the cordons and the overall layout of the network would ensure that flow analyses could be conducted for every major intersection that tracked trips were recorded as passing through. Cordon counts could also be set up to determine how many people enter the commercial node by bus, and how many come out of the turnstiles at the metro stations. Between cordon counts and statistics collected by the owners of the large malls, it could be determined how many pedestrians the malls generate per minute and from that the equation could be calculated using each of those malls as a generator. This would give a more complete picture of the levels of congestion at the site than this study, which was only able to use the three metro stations as generators for the calculations.

This model can be extended by the addition of factors affecting pedestrian flow. With the normalization technique used, the equation can accommodate a large number of added factors such as weather, time of day, day of the week, and any other factor that a research can derive empirical results for. The factors do not all have to be negative factors that decrease the number of pedestrians on each link. Incentives can be studied such as the addition of public bathrooms, the addition of restaurants and the addition of information kiosks to a link. A coefficient could be created to determine the level of positive effect on pedestrian flow each factor has, then the factor could be calculated in the same way as the negative factors but with a plus sign in front of the term of the equation representing it.

This kind of study is applicable to the extension of the Spadina subway line in Toronto from its current terminus to York University. The placement and design of the new stations on that line could be facilitated by a study like this. Also the continuation of the Sheppard subway line and development around its current stations would benefit from a study such as this. It helps the urban planners and engineers to design connecting tunnels and surface level pathways or bridges that will adequately serve the number of pedestrians generated by the station. There is a need for adequate understanding of the dynamics of a site, and the dynamics of the pedestrians using the site, among planners, engineers and architects when physical changes are being planned at that location. This type of study is essential to that understanding and should be a required part of the planning process for these developments.

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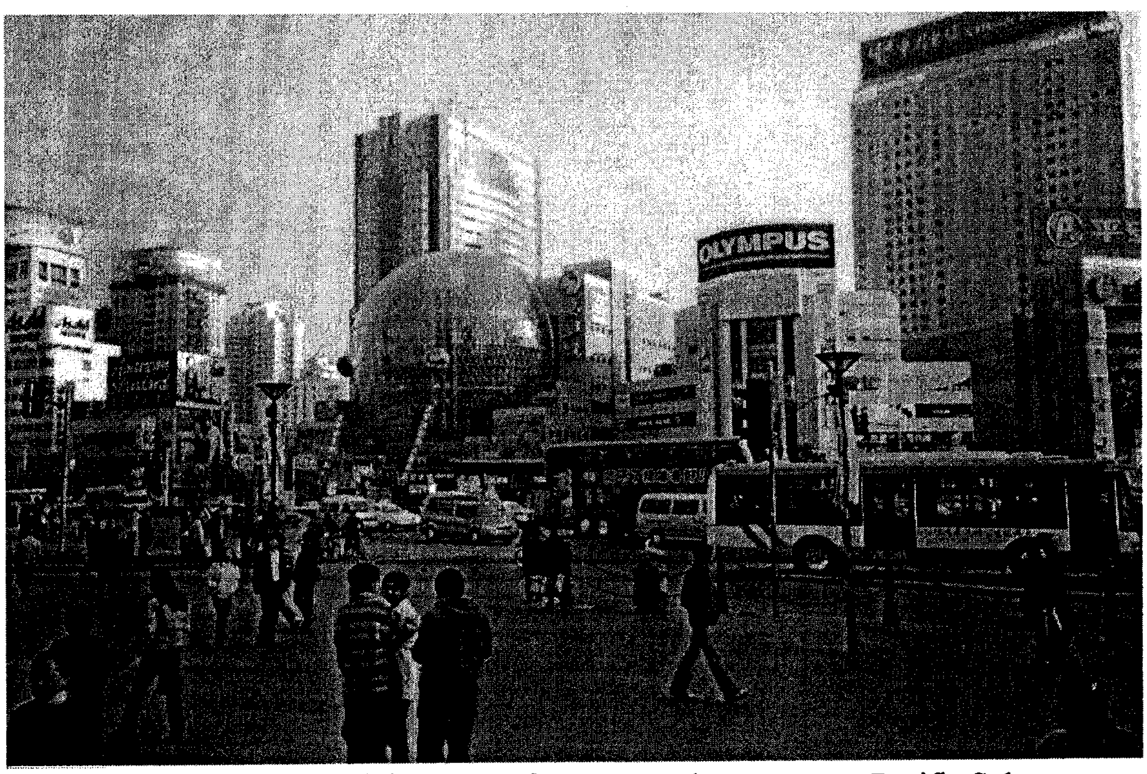
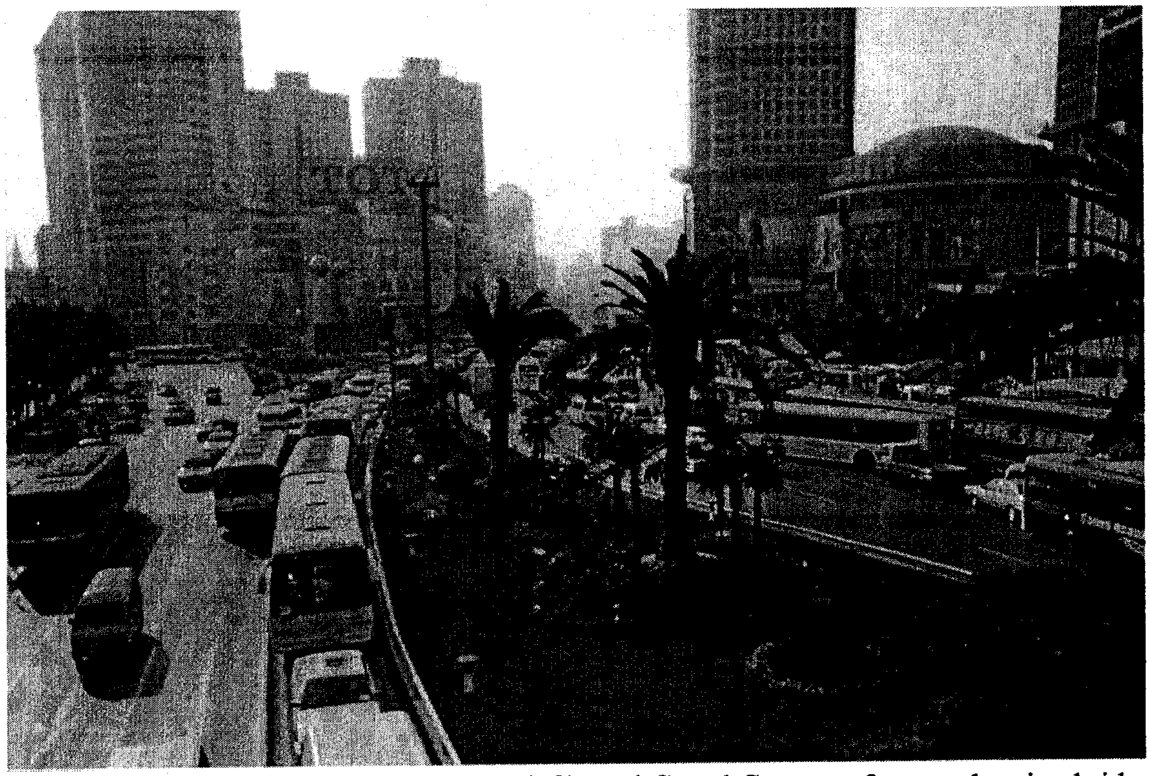
**10-Appendicies**

**10.1-IMAGES OF XU JIA HUI:**

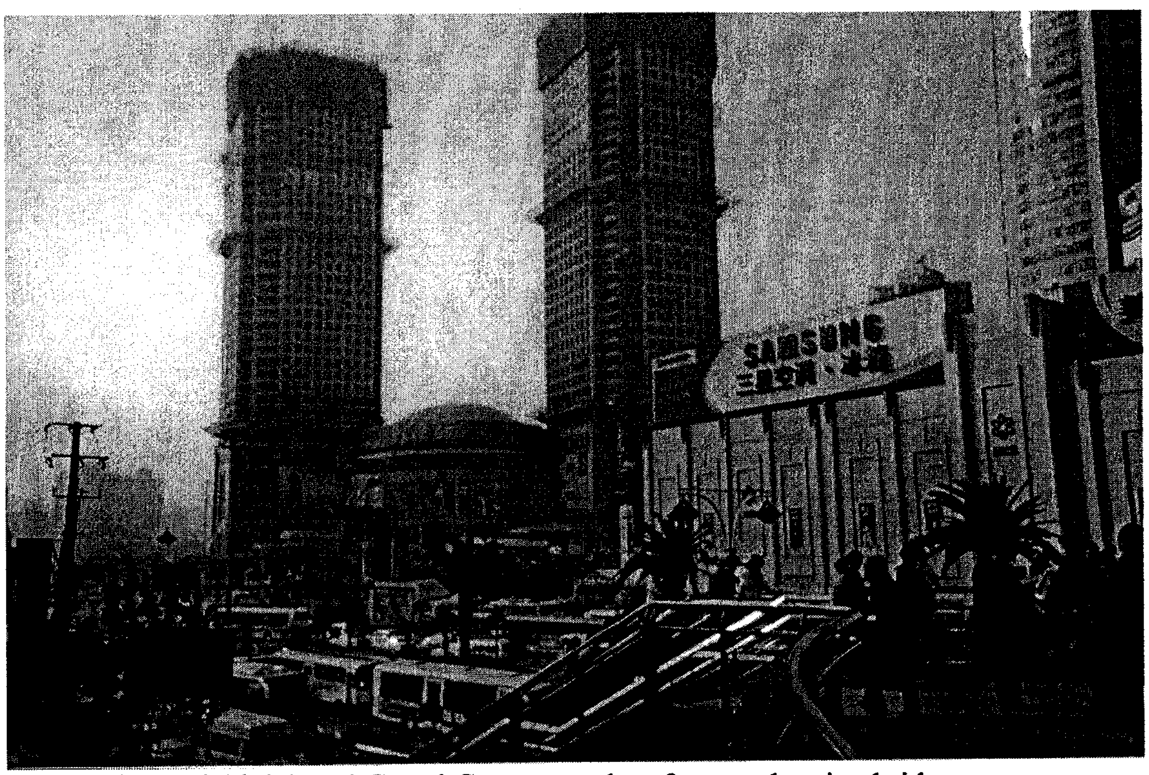
Metro station exit near Metro Center




Metro Center and Pacific Digital, taken from across the street near Pacific Soho



The intersection, Oriental Plaza (centre-left), and Grand Gateway from pedestrian bridge.




Shanghai Lubai (right) and Grand Gateway, taken from pedestrian bridge.

## 10.2-Tracking Analysis by Node and Coded Direction Choice

This is a condensed summary of tracking results that was used for analytical purposes in the thesis. The original data was filled out into an Excel spreadsheet with the nodes (bold #'s from 1 to 60) across the top, and each coded direction choice (#'s from 1 to 193) filling one column, grouped under the node they are part of. The rows in the spreadsheet were the 124 tracked trips. Where a trip entered a node a "1" was placed under the coded direction choice involved. Where a trip left a node a "0" was placed in the coded direction choice involved. The following is the accumulated entries and exits for each node, by the coded direction choice.

DATA SHEET FOR THE DISTRIBUTION OF TRACKED PEDESTRIANS IN THE NETWORK

**(Totals)** (sum for 1's, sum for 0's) 1= entry 0= exit

| | | | | | | |
|---|---|---|---|---|---|---|
| **1** | | **2** | | | **3** | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 2, 1 |
| | | **4** | | **5** | | |
| 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1, 0 | 1, 3 | 0, 1 | 1, 0 | 3, 1 | 1, 3 | 0, 0 |
| **6** | | | **7** | | | **8** |
| 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 0, 0 | 0, 0 | 0, 0 | 0, 0 | 0, 0 | 0, 0 | 3, 1 |
| | | **9** | | | **10** | |
| 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 1, 3 | 0, 0 | 0, 0 | 0, 0 | 0, 0 | 4, 0 | 0, 4 |
| **11** | | | **12** | | | **13** |
| 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| 0, 0 | 0, 3 | 3, 0 | 0, 3 | 3, 0 | 0, 0 | 3, 0 |
| | | | **14** | | | **15** |
| 36 | 37 | 38 | 39 | 40 | 41 | 42 |
| 0, 1 | 0, 1 | 1, 1 | 1, 3 | 2, 1 | 1, 0 | 1, 0 |
| | | | **16** | | | |
| 43 | 44 | 45 | 46 | 47 | 48 | 49 |
| 4, 2 | 0, 1 | 1, 2 | 3, 10 | 3, 0 | 4, 1 | 3, 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **17** | | | | **18** | | |
| 50 | 51 | 52 | 53 | 54 | 55 | 56 |
| 2, 2 | 1, 0 | 2, 2 | 5, 4 | 2, 2 | 9, 5 | 2, 5 |
| | **19** | | | | **20** | |
| 57 | 58 | 59 | 60 | 61 | 62 | 63 |
| 8, 9 | 3, 5 | 3, 1 | 9, 8 | 12, 13 | 3, 5 | 9, 5 |
| | | **21** | | | **22** | |
| 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| 5, 9 | 5, 9 | 5, 3 | 5, 3 | 1, 0 | 0, 2 | 0, 2 |
| | **23** | | | **24** | | |
| 71 | 72 | 73 | 74 | 75 | 76 | 77 |
| 4, 0 | 2, 0 | 2, 1 | 8, 3 | 2, 8 | 2, 0 | 8, 4 |
| **25** | | | | **26** | | |
| 78 | 79 | 80 | 81 | 82 | 83 | 84 |
| 11, 4 | 8, 17 | 3, 5 | 13, 5 | 7, 19 | 6, 5 | 17, 7 |
| **27** | | | **28** | | | |
| 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| 6, 2 | 2, 4 | 5, 6 | 6, 13 | 0, 1 | 1, 1 | 10, 3 |
| | | **29** | | | **30** | |
| 92 | 93 | 94 | 95 | 96 | 97 | 98 |
| 2, 0 | 1, 2 | 3, 0 | 0, 0 | 4, 6 | 1, 0 | 1, 1 |
| | **31** | | | | | **32** |
| 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| 0, 0 | 14, 15 | 2, 1 | 2, 2 | 6, 5 | 9, 4 | 15, 13 |
| | | **33** | | | | **34** |
| 106 | 107 | 108 | 109 | 110 | 111 | 112 |
| 15, 13 | 4, 8 | 2, 2 | 2, 8 | 5, 0 | 0, 0 | 1, 0 |
| | | | **35** | | | **36** |
| 113 | 114 | 115 | 116 | 117 | 118 | 119 |
| 1, 0 | 0, 0 | 1, 2 | 0, 4 | 1, 0 | 3, 0 | 0, 0 |
| | | **37** | | | **38** | |
| 120 | 121 | 122 | 123 | 124 | 125 | 126 |
| 1, 0 | 0, 1 | 0, 0 | 1, 0 | 0, 1 | 4, 11 | 1, 3 |
| | **39** | | **40** | | | |
| 127 | 128 | 129 | 130 | 131 | 132 | 133 |
| 10, 1 | 3, 1 | 1, 3 | 13, 15 | 12, 6 | 0, 0 | 7, 11 |
| | **41** | | | | **42** | |
| 134 | 135 | 136 | 137 | 138 | 139 | 140 |
| 3, 0 | 1, 9 | 11, 1 | 7, 0 | 4, 12 | 0, 6 | 5, 0 |
| | **43** | | | | **44** | |
| 141 | 142 | 143 | 144 | 145 | 146 | 147 |
| 0, 0 | 4, 4 | 11, 7 | 9, 16 | 7, 4 | 15, 8 | 4, 0 |
| | **45** | | | | **46** | |
| 148 | 149 | 150 | 151 | 152 | 153 | 154 |
| 6, 9 | 3, 6 | 1, 0 | 0, 0 | 7, 4 | 4, 5 | 2, 1 |
| | **47** | | **48** | | | **49** |

| | | | | | | |
|---|---|---|---|---|---|---|
| 155 | 156 | 157 | 158 | 159 | 160 | 161 |
| 3, 1 | 1, 2 | 2, 0 | 4, 7 | 6, 2 | 3, 4 | 2, 6 |
| | | **50** | | | **51** | |
| 162 | 163 | 164 | 165 | 166 | 167 | 168 |
| 4, 1 | 2, 1 | 1, 4 | 1, 0 | 3, 0 | 0, 3 | 3, 0 |
| **52** | | **53** | | | | **54** |
| 169 | 170 | 171 | 172 | 173 | 174 | 175 |
| 0, 1 | 1, 0 | 0, 3 | 0, 2 | 1, 2 | 6, 1 | 1, 5 |
| | **55** | | | **56** | | **57** |
| 176 | 177 | 178 | 179 | 180 | 181 | 182 |
| 4, 0 | 2, 0 | 4, 3 | 2, 5 | 2, 1 | 1, 2 | 3, 1 |
| | | **58** | | | **59** | |
| 183 | 184 | 185 | 186 | 187 | 188 | 189 |
| 3, 8 | 5, 2 | 8, 3 | 11, 12 | 3, 0 | 0, 3 | 4, 3 |
| | **60** | | | | | |
| 190 | 191 | 192 | 193 | | | |
| 4, 2 | 0, 3 | 1, 3 | 5, 0 | | | |

## 10.3-Pro Rating of Cordon Count Trials

UCC= underground cordon count
SCC= surface cordon count
IAGCC= indoor above ground cordon count

| Cordon | Type | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | UCC | 98 | 102 | 94 | 172 | 170 | 192 |
| 2 | UCC | 130 | 136 | 125 | 221 | 227 | 282 |
| 3 | UCC | 173 | 250 | 271 | 307 | 422 | 443 |
| 4 | UCC | 368 | 330 | 330 | 347 | 486 | 440 |
| 5 | UCC | 254 | 231 | 264 | 277 | 550 | 517 |
| 6 | UCC | 388 | 300 | 279 | 428 | 571 | 431 |
| 7 | UCC | 106 | 111 | 102 | 119 | 185 | 160 |
| 8 | UCC | 183 | 142 | 158 | 114 | **172** | 165 |
| 9 | SCC | 195 | 236 | 169 | 157 | **237** | 226 |
| 10 | SCC | 263 | 249 | 200 | 157 | **237** | 226 |
| 11 | UCC | 434 | 454 | 417 | 356 | 756 | 615 |
| 12 | UCC | 205 | 214 | 197 | 236 | **357** | 342 |
| 16 | UCC | 348 | 363 | 334 | 356 | 605 | 526 |
| 17 | UCC | 82 | 58 | 87 | 94 | 168 | 213 |
| 18 | UCC | 209 | 218 | 201 | 122 | 364 | 339 |
| 19 | UCC | 220 | 243 | 105 | 122 | 351 | 329 |
| 20 | UCC | 331 | 365 | 479 | 537 | 526 | 419 |
| 21 | UCC | 233 | 279 | 284 | 362 | 445 | 448 |
| 22 | SCC | 226 | 237 | 217 | 232 | 394 | 525 |
| 23 | SCC | 162 | 169 | 156 | 166 | 282 | 270 |
| 24 | SCC | 161 | 169 | 155 | 243 | 281 | 269 |
| 25 | SCC | 259 | 270 | 248 | 401 | 450 | 431 |
| 26 | SCC | 126 | 132 | 121 | 174 | 220 | 211 |
| 27 | SCC | 125 | 131 | 120 | 159 | 218 | 209 |
| 28 | SCC | 365 | 372 | 350 | 310 | 635 | 570 |
| 29 | SCC | 134 | 148 | 136 | 145 | 246 | 235 |
| 30 | SCC | 134 | 140 | 129 | 113 | 233 | 223 |
| 31 | SCC | 103 | 176 | 342 | 386 | 620 | 593 |
| 33 | SCC | 210 | 219 | 201 | 172 | 365 | 349 |
| 34 | SCC | 224 | 234 | 215 | 204 | 389 | 372 |
| 35 | SCC | 322 | 336 | 309 | 306 | 560 | 536 |
| 36 | IAGCC | 82 | 85 | 78 | 84 | 142 | 136 |
| 37 | IAGCC | 124 | 129 | 119 | 127 | 215 | 206 |
| 38 | SCC | 363 | 379 | 348 | 72 | 631 | 689 |
| 39 | UCC | 219 | 205 | 276 | 286 | 490 | 453 |
| 41 | UCC | 322 | 296 | 342 | 396 | 788 | 704 |
| 42 | SCC | 419 | 438 | 403 | 259 | 730 | 737 |
| 43 | SCC | 127 | 112 | 66 | 238 | 309 | 290 |
| 44 | SCC | 213 | 222 | 204 | 95 | 370 | 381 |
| 45 | SCC | 209 | 218 | 200 | 161 | 363 | 349 |
| 46 | SCC | 99 | 130 | 53 | 109 | 96 | 92 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 47 | SCC | 68 | 71 | 65 | 32 | 118 | 113 |
| 48 | SCC | 155 | 118 | 87 | 57 | 157 | 88 |
| 49 | SCC | 81 | 102 | 76 | 197 | 137 | 89 |
| 50 | SCC | 121 | 235 | 83 | 166 | 150 | 130 |
| 51 | SCC | 107 | 112 | 103 | 110 | 187 | 180 |
| 52 | SCC | 162 | 126 | 118 | 131 | 214 | 205 |
| 53 | SCC | 49 | 51 | 47 | 107 | 85 | 81 |
| 54 | SCC | 143 | 152 | 76 | 157 | 137 | 131 |
| 55 | SCC | 114 | 147 | 55 | 121 | 99 | 95 |
| 56 | SCC | 45 | 102 | 50 | 93 | 91 | 87 |
| 57 | SCC | 262 | 228 | 335 | 321 | 747 | 711 |
| 58 | SCC | 152 | 159 | 146 | 156 | 265 | 330 |
| 59 | UCC | 656 | 686 | 448 | 636 | **1142** | 1093 |
| 60 | SCC | 197 | 253 | 246 | 210 | 676 | 724 |
| | original total | 4840 | 5065 | 4339 | 10440 | | 12304 |
| | new total | 11528 | 12043 | 11070 | 11816 | 20061 | 19201 |
| | Final total | 11260 | 11770 | 10819 | 11816 | | 19200 |

Mean of totals for first 4 counts = 11416
Pro rating numbers for last 2 counts = (each link) x (mean / total for that count)

| 5 | 5.1 Pro rated # | 6 | 6.1 Pro rated # |
|---|---|---|---|
| 170 | 96.74094 | 192 | 114.16 |
| 227 | 129.17761 | 282 | 167.6725 |
| 422 | 240.14516 | 443 | 263.40042 |
| 486 | 276.56528 | 440 | 261.61667 |
| 550 | 312.98539 | 517 | 307.39958 |
| 571 | 324.93575 | 431 | 256.26542 |
| 185 | 105.27691 | 160 | 95.133333 |
| **172** | 97.879069 | 165 | 98.10625 |
| **237** | 134.86825 | 226 | 134.37583 |
| **237** | 134.86825 | 226 | 134.37583 |
| 756 | 430.21265 | 615 | 365.66875 |
| **357** | 203.15597 | 342 | 203.3475 |
| 605 | 344.28393 | 526 | 312.75083 |
| 168 | 95.602811 | 213 | 126.64625 |
| 364 | 207.13942 | 339 | 201.56375 |
| 351 | 199.74159 | 329 | 195.61792 |
| 526 | 299.32785 | 419 | 249.13042 |
| 445 | 253.23364 | 448 | 266.37333 |
| 394 | 224.21136 | 525 | 312.15625 |
| 282 | 160.47615 | 270 | 160.5375 |
| 281 | 159.90708 | 269 | 159.94292 |
| 450 | 256.07896 | 431 | 256.26542 |
| 220 | 125.19416 | 211 | 125.45708 |
| 218 | 124.05603 | 209 | 124.26792 |

| 5 rounded | 6 rounded |
|---|---|
| 97 | 114 |
| 129 | 167 |
| 240 | 263 |
| 277 | 262 |
| 313 | 307 |
| 325 | 256 |
| 105 | 95 |
| 98 | 98 |
| 135 | 134 |
| 135 | 134 |
| 430 | 365 |
| 203 | 203 |
| 344 | 312 |
| 96 | 127 |
| 207 | 201 |
| 200 | 196 |
| 299 | 249 |
| 253 | 266 |
| 224 | 312 |
| 160 | 160 |
| 160 | 160 |
| 256 | 256 |
| 125 | 125 |
| 124 | 124 |

| | | | | | |
|---|---|---|---|---|---|
| 635 | 361.35586 | 570 | 338.9125 | 361 | 339 |
| 246 | 139.98983 | 235 | 139.72708 | 140 | 140 |
| 233 | 132.59199 | 223 | 132.59208 | 133 | 133 |
| 620 | 352.8199 | 593 | 352.58792 | 353 | 353 |
| 365 | 207.70849 | 349 | 207.50958 | 208 | 208 |
| 389 | 221.36603 | 372 | 221.185 | 221 | 221 |
| 560 | 318.67604 | 536 | 318.69667 | 319 | 319 |
| 142 | 80.807138 | 136 | 80.863333 | 81 | 81 |
| 215 | 122.34884 | 206 | 122.48417 | 122 | 122 |
| 631 | 359.07961 | 689 | 409.66792 | 359 | 410 |
| 490 | 278.84153 | 453 | 269.34625 | 279 | 269 |
| 788 | 448.42271 | 704 | 418.58667 | 448 | 419 |
| 730 | 415.41698 | 737 | 438.20792 | 415 | 438 |
| 309 | 175.84089 | 290 | 172.42917 | 176 | 172 |
| 370 | 210.55381 | 381 | 226.53625 | 211 | 227 |
| 363 | 206.57036 | 349 | 207.50958 | 207 | 208 |
| 96 | 54.630178 | 92 | 54.701667 | 55 | 55 |
| 118 | 67.149594 | 113 | 67.187917 | 67 | 67 |
| 157 | 89.343104 | 88 | 52.323333 | 89 | 52 |
| 137 | 77.961816 | 89 | 52.917917 | 78 | 53 |
| 150 | 85.359653 | 130 | 77.295833 | 85 | 77 |
| 187 | 106.41503 | 180 | 107.025 | 106 | 107 |
| 214 | 121.77977 | 205 | 121.88958 | 122 | 122 |
| 85 | 48.37047 | 81 | 48.16125 | 48 | 48 |
| 137 | 77.961816 | 131 | 77.890417 | 78 | 78 |
| 99 | 56.337371 | 95 | 56.485417 | 56 | 56 |
| 91 | 51.784856 | 87 | 51.72875 | 52 | 52 |
| 747 | 425.09107 | 711 | 422.74875 | 425 | 423 |
| 265 | 150.80205 | 330 | 196.2125 | 150 | 196 |
| **1142** | 649.87149 | 1093 | 649.87958 | 650 | 650 |
| 676 | 384.6875 | 724 | 430.47833 | 385 | 430 |

## 10.4-Completed Set of Cordon Count Data

**Final set of altered numbers to work with:**

(including generated data for cordons 13 and 15)

Xu Jia Hui Cordon Count Trials

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| link # | | | | | pro rated numbers | pro rated numbers |
| 1 | 98 | 102 | 94 | 172 | 97 | 114 |
| 2 | 130 | 136 | 125 | 221 | 129 | 167 |
| 3 | 173 | 250 | 271 | 307 | 240 | 263 |
| 4 | 368 | 330 | 330 | 347 | 277 | 262 |
| 5 | 254 | 231 | 264 | 277 | 313 | 307 |
| 6 | 388 | 300 | 279 | 428 | 325 | 256 |
| 7 | 106 | 111 | 102 | 119 | 105 | 95 |
| 8 | 183 | 142 | 158 | 114 | 98 | 98 |
| 9 | 195 | 236 | 169 | 157 | 135 | 134 |
| 10 | 263 | 249 | 200 | 157 | 135 | 134 |
| 11 | 434 | 454 | 417 | 356 | 430 | 365 |
| 12 | 205 | 214 | 197 | 236 | 203 | 203 |
| 13 | 174 | 182 | 167 | 178 | 172 | 156 |
| 15 | 174 | 182 | 167 | 178 | 172 | 156 |
| 16 | 348 | 363 | 334 | 356 | 344 | 312 |
| 17 | 82 | 58 | 87 | 94 | 96 | 127 |
| 18 | 209 | 218 | 201 | 122 | 207 | 201 |
| 19 | 220 | 243 | 105 | 122 | 200 | 196 |
| 20 | 331 | 365 | 479 | 537 | 299 | 249 |
| 21 | 233 | 279 | 284 | 362 | 253 | 266 |
| 22 | 226 | 237 | 217 | 232 | 224 | 312 |
| 23 | 162 | 169 | 156 | 166 | 160 | 160 |
| 24 | 161 | 169 | 155 | 243 | 160 | 160 |
| 25 | 259 | 270 | 248 | 401 | 256 | 256 |
| 26 | 126 | 132 | 121 | 174 | 125 | 125 |
| 27 | 125 | 131 | 120 | 159 | 124 | 124 |
| 28 | 365 | 372 | 350 | 310 | 361 | 339 |
| 29 | 134 | 148 | 136 | 145 | 140 | 140 |
| 30 | 134 | 140 | 129 | 113 | 133 | 133 |
| 31 | 103 | 176 | 342 | 386 | 353 | 353 |
| 33 | 210 | 219 | 201 | 172 | 208 | 208 |
| 34 | 224 | 234 | 215 | 204 | 221 | 221 |
| 35 | 322 | 336 | 309 | 306 | 319 | 319 |
| 36 | 82 | 85 | 78 | 84 | 81 | 81 |
| 37 | 124 | 129 | 119 | 127 | 122 | 122 |
| 38 | 363 | 379 | 348 | 72 | 359 | 410 |
| 39 | 219 | 205 | 276 | 286 | 279 | 269 |
| 41 | 322 | 296 | 342 | 396 | 448 | 419 |
| 42 | 419 | 438 | 403 | 259 | 415 | 438 |
| 43 | 127 | 112 | 66 | 238 | 176 | 172 |
| 44 | 213 | 222 | 204 | 95 | 211 | 227 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 45 | 209 | 218 | 200 | 161 | 207 | 208 |
| 46 | 99 | 130 | 53 | 109 | 55 | 55 |
| 47 | 68 | 71 | 65 | 32 | 67 | 67 |
| 48 | 155 | 118 | 87 | 57 | 89 | 52 |
| 49 | 81 | 102 | 76 | 197 | 78 | 53 |
| 50 | 121 | 235 | 83 | 166 | 85 | 77 |
| 51 | 107 | 112 | 103 | 110 | 106 | 107 |
| 52 | 162 | 126 | 118 | 131 | 122 | 122 |
| 53 | 49 | 51 | 47 | 107 | 48 | 48 |
| 54 | 143 | 152 | 76 | 157 | 78 | 78 |
| 55 | 114 | 147 | 55 | 121 | 56 | 56 |
| 56 | 45 | 102 | 50 | 93 | 52 | 52 |
| 57 | 262 | 228 | 335 | 321 | 425 | 423 |
| 58 | 152 | 159 | 146 | 156 | 150 | 196 |
| 59 | 656 | 686 | 448 | 636 | 650 | 650 |
| 60 | 197 | 253 | 246 | 210 | 385 | 430 |

## 10.5 Level-Of-Service Calculations

| Pedestrians | Link | Area of link | M | S | P |
|---|---|---|---|---|---|
| 1040 | 25 | 916.8 | 0.881538462 | 3.1 | 3.516579407 |
| 917 | 28 | 192.3 | 0.209705562 | 3.1 | 14.78263131 |
| 900 | 52 | 192.3 | 0.213666667 | 3.1 | 14.50858034 |
| 1162 | 53 | 2106.5 | 0.47647591 | 3.1 | 6.506100166 |
| 1028 | 54 | | | | |
| 1087 | 55 | | | | |
| 1144 | 57 | | | | |
| 909 | 56 | 223.1 | 0.245434543 | 3.1 | 12.6306589 |
| 1111 | 58 | 1174.5 | 1.057155716 | 3.1 | 2.932396765 |
| 954 | 59 | 192.3 | 0.201572327 | 3.1 | 15.37909516 |
| 908 | 68 | 446.9 | 0.492180617 | 3.1 | 6.298500783 |
| 1055 | 78 | 1000.5 | 0.948341232 | 3.1 | 3.268865567 |
| 1041 | 109 | 1150.5 | 1.10518732 | 3.1 | 2.804954368 |
| 909 | 110 | 279.4 | 0.307370737 | 3.1 | 10.08554044 |

M = pedestrian module
P = pedestrian level-of-service
S = meters/second

*Levels-of-Service (P) by the pedestrian module (M)*

**A** **> 3.25** **square meters per pedestrian**
Sparsely populated pathway.

**B** **2.32-3.25** **square meters per pedestrian**
Low flow with total freedom of movement.

**C** **1.39-2.32** **square meters per pedestrian**
Pedestrians can move at normal pace occasionally interrupted by slower pedestrians.

**0.93-**
**D 1.39 square meters per pedestrian**
Typical of crowded public places like stadiums....interruption of speed and movement.

**0.46-**
**E 0.93 square meters per pedestrian**
Speed and movement of all pedestrians interrupted...this is not an acceptable L-O-S

**F < 0.46 square meters per pedestrian**
Traffic jam. This is a situation with movement only in the form of shuffling.

(Fruin, 1971)