Analysis of Motivations of Developing Underground Pedestrian Systems
- Decisive Effect of Weather Conditions

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Abstract:

Dominant modes of transport in city centres have a significant influence on urban morphology, land usage, the character of the urban environment and people's life style. Cities are currently faced with potentially severe environmental impacts from global warming and other detrimental side effects resulting from a high dependence on motor vehicles. Many metropolises are now beginning to realize the importance of planning and developing walking as a primary travel mode in the city. Improving accessibility, continuity, safety, availability and connectivity for pedestrians has crucial significance as a means of decreasing vehicle usage and increasing public transport usage. In some places, underground pedestrian networks have been used to integrate pedestrian traffic in transport systems, at the same time, as a strategy to provide additional space resources for multiple functions (such as commercial and public activities) for urban redevelopment. Underground pedestrian systems can contribute to building walkable cities, accelerating the harmonious development of pedestrian spaces on the street level and underground to provide convenience for pedestrians.

The research focuses on the interrelationship between underground pedestrian systems and urban environment. The research conducts a secondary data collection from 51 cases of underground pedestrian systems worldwide to generalize influences of environmental factor on developing underground pedestrian systems in city centres. Influencing factor, namely climate condition is considered for response to the hypothesis regarding its influence on deciding underground pedestrian systems utilization. The analysis is the basis for further research considering more influencing factors such as city scale and economic level. All of the outcomes from the secondary data will paves the way for primary data collection on the interaction between urban environment and underground pedestrian.

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Introduction

Underground pedestrian systems are unusual pedestrian facilities. The systems appear unbalanced distribution in the world with various scales and shapes. The reason for this phenomenon was that many influencing factors in urban environment interweaved with each other and composed a complicated context within which underground pedestrian systems were interacted with and developed (Belanger 2007).

Underground pedestrian systems are often regarded to locate on central areas of metropolises containing Central Business Districts (CBD), subcentres and regional centres. In those areas, natural environment and built environment compose the context that underground pedestrian systems exist. Previous research appeared to be descriptive with regard to how to build the systems and their characteristics, but hardly on assessing the facilities (Zacharias and Xu 2007). Regarding the motivations of developing underground pedestrian systems, weather conditions, topography, economic level, and development of underground transports and retails were considered and analyzed. But the limitation of previous research was general description of motivations of developing underground pedestrian systems, lacking systematic investigation: some of them focused on very famous cases of underground pedestrian systems, such as those in Toronto and Montreal (Belanger 2007; Baker 1986; Xu & Yan 2001); some conducted comparison between several selected underground pedestrian systems, such as Byer (1998b) with focus on comparison between the systems in Houston, Minneapolis and Toronto; and some research were conducted in a certain area such as cities of North America (Maitland 1992; Byers 1998a). From previous research, it is hard to conclude that whether or not a certain motivation such as weather condition is a main reason for developing underground pedestrian systems worldwide or at a certain area.

To make the question clear, it is necessary to understand the context within which underground pedestrian systems interacted with. This paper will firstly review the natural environment of underground pedestrian systems. After selecting cities with underground pedestrian systems, data collection will focus on weather conditions of each city. The data will build a basis for further analysis about effects of more influencing factors.

Natural Environment of Underground Pedestrian Systems

Natural environment is the collectivity of substance and energy that directly or indirectly affect people's life and production. The natural resources such as urban geology, topography, soil, air, climate, water and biological system compose natural environment of underground pedestrian systems. Those resources can be viewed as sub-factors of natural environment (Tong 2005; Xie & Deng 1996). Regarding major issues of natural environment, climate, geology and air are those that most benefits and drawbacks of underground systems related (Carmody and Sterling 1993).

In those environmental factors, climate commonly was mentioned as one of the most critical factors encouraging underground pedestrian systems (such as Byers 1998b; Sakakura, Shimizu and Itabashi 2007; Belanger 2007; Eady 1990). In the areas with severe weather conditions, underground pedestrian systems guaranteed pedestrian and commercial activities in daily life. It was severe weather conditions that greatly influence the usefulness and extensiveness of underground pedestrian systems. Tong (2005) indicated that geology, soil and water factors were related with underground space utilization. The lithosphere on the earth and soil layer on its top provided physical basis for underground spaces. Thus the geology condition decided the level of difficulties of developing underground spaces. In comparison, the effects of air conditions on underground pedestrian systems were not very obvious. Contrarily, improving urban air quality was one of the benefits underground pedestrian systems possibly brought. Air pollution in urban area resulted from people's concentration and activities. Utilization of underground spaces generally would not decrease air quality because development of underground spaces would decline the building density on the street level and thus increasing open and green spaces (Tong 2005; Chen & Wang 2005).

Methodology

The paper will firstly select cities with underground pedestrian systems. Journal article and books are reviewed to find cases of underground pedestrian systems. However, underground pedestrian systems are not the main field within transport research and urban planning, thus references are much limited. The researcher thus conducted personal observation of underground pedestrian systems in cities such as Sydney, Singapore, Nanjing and Shanghai. Internet resources finally are used and 51 cities are selected for this research. Mapping the cities, it is clear to find that underground pedestrian systems are concentrated in three main locations in the world, namely East Asia, Europe and North America (fig. 1). Underground pedestrian systems selected are listed on table 1.

The paper will then collect secondary data on weather condition for each city respectively. Cold weather and rainy conditions are selected for the research because they are common influencing sub-factors. Official website of each city, Official website of Census Bureau of some countries as well as additional information from the Internet resources (such as www.climate-charts.com, www.en.wikipedia.org and www.weatherbase.com) are compared and used.

Figure1 Locations of the 51 Underground Pedestrian Systems Worldwide

Table 1 Summarization of Underground Pedestrian Systems Worldwide

Cities	Underground Pedestrian Systems
North America	
Edmonton, Canada	Called Pedway, connecting buildings and LRT stations of the downtown core
Halifax, Canada	Called Downtown Halifax Link, within 10 minutes walking distance from one point to another
Montreal, Canada	Called RESO, 32 km, covering more than 41 city blocks (Besner 2007)
Toronto, Canada	Called PATH, 6 blocks wide, 10 blocks long, 27 km (Belanger 2007)
Vancouver, Canada	Over 3 city blocks, connecting 2 shopping malls, 200 stores and three stations
Winnipeg, Canada	Connecting commercial office, office towers and downtown traffic
Albany, New York, US	Called Empire State Plaza underground shopping mall, connecting theater, Museum, Library, tower and offces
Atlanta, Georgia	Called Underground, covering 6 city blocks
Chicago, Illinois	Called Pedway, covering 40 city blocks (8km^2), connecting 50 buildings (Wang & Liang 2010)
Dallas, Texas	Called Dallas Pedestrian Network (Zhu, Wang & Zhang 2007)
Duluth, Minnesota	Connecting several buildings
Houston, Texas	4.5 km (Tong 2005; Zhu, Wang & Zhang 2007)
New York City, New York	Locating at Rockefeller Centre in Manhattan, covering 10 city blocks (Tong 2005; Zhu, Wang & Zhang 2007)
Oklahoma City, Oklahoma	1.2 km, underground systems and skywalk systems covering 20 city blocks, connecting 30 buildings (Wang & Chen 2010)
Philadelphia, Pennsylvania	Several underground concourses in Centre City connecting subway stations
Richmond, Virginia	Connecting state government buildings
Rochester, Minnesota	The Mayo Clinic's buildings interconnecting with tunnels, containing hotels
Seattle, Washington	Locating in Westlake connecting with bus station; another connecting with squares, hotels, theatre and retail shops
Washington D.C.	Connecting all buildings in the United States Capitol Complex
Mexico City, Mexico	Underground pedestrian systems connecting subway system
East Asia	
Kawasaki City, Japan	Called Kawasaki Azelea, containing 5 squares, 154 shops, car park, police station and bank (Golany & Ojima, 1996)
Kyoto City, Japan	2km, connecting shops and subway stations (Zhu, Wang & Zhang 2007)
Nagoya City, Japan	Underground pedestrian systems connecting 9 underground shopping streets, 17 buildings and 3 subway stations (Geng 2005)
Osaka City, Japan	Umeda underground systems, the biggest in Japan (Zacharias 2007), connecting 3 subway stations and 24 buildings (Zhu, Wang & Zhang 2007)
Tokyo Metropolis, Japan	6km, containing 141 shops, connecting 51 buildings (Guan & Yang 2001)
Beijing, China	Locating at western area of Zhong Guan Cun (Liu 2009)
Harbin, China	250,000 m^2, several underground shopping streets interconnected (Zhu, Wang & Zhang 2007)
Nanjing, China	Locating in Xin Jie Kou, connecting department stores, subway stations and shops
Shanghai, China	Ren Ming Square containing 10,000 m^2 underground commercial spaces, connecting underground parking and subways (Geng 2005)

Hong Kong, China	Underground networks connecting buildings and shopping malls to Central Station (Yang, Wu & Liu 2008)
Taipei City, Taiwan	Taipei Metro Station connecting 4 underground shopping streets and several buildings (Liu 2009)
Europe	
Frankfurt, Germany	Underground networks around subway stations (Liu, Sun & Lu 2009)
Hamburg, Germany	Underground networks connecting subway stations, shops and underground shopping mall
Stuttgart, Germany	Underground network connecting subway stations, underground shopping mall and shopping street (Liu, Sun & Lu 2009)
Berlin, Germany	Underground network connecting several buildings, businesses on both side of the network
Munich, Germany	underground network around subway stations (Liu, Sun & Lu 2009)
Moscow, Russia	Underground network connecting underground shopping mall to subway station
London, United Kingdom	Underground network connecting subway stations to office towers and shopping malls
Paris, France	200,000 m^2 underground complex in Les Halles (Wang & Qian 2002)
Helsinki, Finland	Underground network connecting three subway stations and shopping malls
Athens, Greece	Underground network around Omonia square subway station
Amsterdam, Netherland	Underground network containing shops, restaurants and banks, connecting Amsterdam Central Stations to metro system
Barcelona, Spain	Underground network over one block
Geneva, Switzerland	Underground shopping centre connecting shops on the surface
St. Gallen, Switzerland Switzerland	Underground network connecting hospital to buildings, shops and storage facilities
Kiev, Ukraine	Underground network containing underground concourse connecting Metro and shopping mall around Maidan Nezalezhnosti
Other	
Bangkok, Thailand	Underground network connecting Metro and MRT malls
Singapore, Singapore	Locating at Raffles Place MRT Station, City Link Hall MRT Station area and Orchard Road respectively (Zhang 2004)
Sydney, Astralia	Locating at Town Hall, 3km
Buenos Aires, Argentina	Underground pedestrian systems connecting subway stations, shops, buildings and shopping centres
Santiago, Chile	Underground pedestrian systems connecting subway stations, shops, buildings and shopping centres

Note: According to www.en.wikipedia.org except references provided.

Figure 2 Toronto Underground Pedestrian System
http://www.toronto.ca/path/pdf/path_brochure.pdf

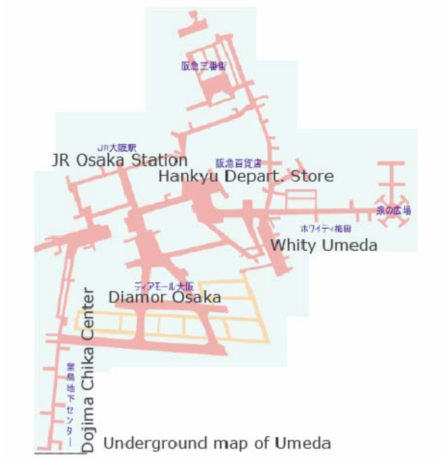

Figure 3 Underground pedestrian system in Umeda, Osaka
http://www.arch.usf.edu/arch-phenom2/_private/Osaka_Guide_S.pdf

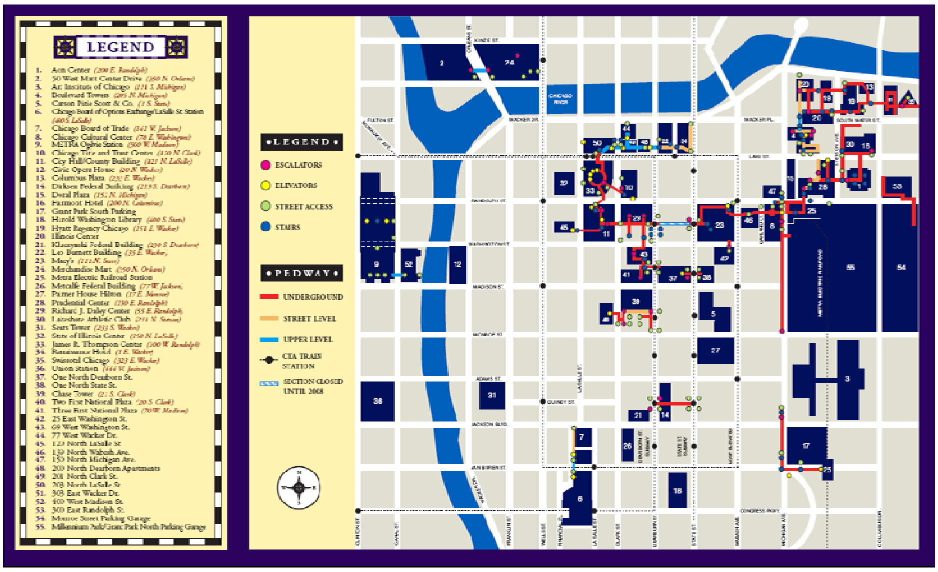

Figure 4 Chicago Underground Pedestrian System

http://www.spiegl.org/pedway/Pedwaymapandlegend.pdf

Data collection and Analysis

There are considerable sub-factors used to describe weather conditions such as temperature, rainfall, snowfall, windy and humanity. The selection of the sub-factors much affects the outcomes regarding the relationship between underground pedestrian systems and weather conditions. Previous research indicated that the most influencing sub-factors are hot and humid summer and cold winter, windy and wet streets (Belanger 2007), long snowing period, rainy weather, an average temperature below zero degrees Celsius in January (Tong 1998).

In this research, cold weather condition and rainfall will be considered to conduct some analysis. Before data collection, the measurement of cold weather needs to be clarified. The concept of Winter City is introduced for the measurement. In some cities, long winter with severe weather conditions disadvantages city life. In geography research, the earth was divided into different climate zones according to different latitudes. Cold Zone is above 60 degrees latitude and Temperate Zone is between 40 and 60 degrees latitudes. Generally, city within Cold Zone can be categorized to Winter City but those within Temperate Zone are not always excluded from Winter City. The reason for this phenomenon is that city weather is not only affected by latitude, but also sea-land shape and Gulf Stream. Thus cities with the same latitude can have totally different weather conditions. For example, with almost the same latitude in Harbin, China and Paris, France, the temperature mean value in Paris on January is 3.4 degrees Celsius and -20 degrees Celsius in Harbin (Len 2009).

Regarding the definitions of winter city, it is agreed that temperature under zero degrees Celsius can be utilized to measure whether or not a city belongs to winter cities. But there are disagreements with regard to the duration of temperature under zero degrees Celsius. Earlier researchers suggested that winter cities are those whose average temperature in January is under zero degrees Celsius (Rogers & Hanson 1980). Manty and Pressmen (1988) insisted that cities with at least two months' average maximum daytime temperature under zero degrees Celsius can be categorize to winter cities. Some academics also argued that if a city has three continuous months with average temperature under zero degrees Celsius, it can be viewed as winter cities (Liu 1998). 11th Mayors Conference 2004 (World Winter Cities Conference for Mayors) defined Winter City as those with 20 centimeters (cm) average snowfall a year or at least one month's temperature mean value under 0 degrees Celsius (Len 2009). According to the various definitions of Winter City, the number of months with temperature mean value under zero degrees Celsius a year of each city is collected as table 2. The average precipitation mean value of each city is also collected and considered as complementarities. And the statistics of the city number is as table 3.

Table 2 Data of Weather Conditions of Each City

Cities	No. of Month	Precipitation (mm)	Cities	No. of Month	Precipitation (mm)
North America			Harbin, China	5	524
Edmonton, Canada	5	366	Nanjing, China	0	1,062
Halifax, Canada	4	1,356	Shanghai, China	0	1,165
Montreal, Canada	4	940	Hong Kong, China	0	2,383
Toronto, Canada	4	781	Taipei, Taiwan	0	2,325
Vancouver, Canada	0	1,167	Europe		
Winnipeg, Canada	5	416	Frankfurt, Germany	0	621
Albany, New York, US	3	918	Hamburg, Germany	0	773
Atlanta, Georgia, US	0	1,275	Stuttgart, Germany	0	734
Chicago, Illinois, US	3	974	Berlin, Germany	0	571
Dallas, Texas, US	0	856	Munich, Germany	3	967
Duluth, Minnesota, US	5	762	Moscow, Russia	5	705
Houston, Texas, US	0	1,170	London, United Kingdom	0	584
New York City, New York, US	1	1,200	Paris, France	0	650
Oklahoma City, Oklahoma, US	0	847	Helsinki, Finland	4	642
Philadelphia, Pennsylvania, US	1	1,052	Athens, Greece	0	141
Richmond, Virginia, US	0	1,115	Amsterdam, Netherland	0	780
Rochester, Minnesota, US	5	747	Barcelona, Spain	0	628
Seattle, Washington, US	0	945	Geneva, Switzerland	0	954
Washington D.C. , US	0	1,000	St. Gallen, Switzerland	3	1,248
Mexico City, Mexico	0	710	Kiev, Ukraine	3	649
East Asia			Other Areas		
Kawasaki, Japan	0	1,945	Bangkok, Tailand	0	1,497
Kyoto, Japan	0	1,581	Singapore, Singapore	0	2,150
Nagoya, Japan	0	1,535	Sydney, Australia	0	1,213
Osaka, Japan	0	1,318	Buenos Aires, Argentina	0	1,243
Tokyo, Japan	0	1,405	Santiago, Chile	0	313
Beijing, China	3	577			

It can be seen clearly from Table 3 that if winter cities defined as cities with at least one month's temperature mean value under zero degree Celsius, only 18 (35%) of them can be categorized to winter cities among the total 51 cities, and 31% according to other definitions. Cold weather may possibly is not a common motivation for underground pedestrian systems development worldwide. But more than half of the winter cities (61% and 56% according to different definitions) are located in North America, considering that total North American cities occupied 39% of the total world cities. In Other Areas, none of cities can be classified to winter city and the figure in Europe and East Asia are 33% and 22% respectively. It can be concluded that comparing to other areas, cold weather condition much affected developing underground pedestrian systems in North America.

Table 3 Number of Cities Statistics

Area		North America	East Asia	Europe	Other Areas	Total
No. of Cities with at Least One Month's Temperature Mean Value under 0 Degree Celsius		11	2	5	0	18
No. of Cities with at Least Two Months' Temperature Mean Value under 0 Degree Celsius		9	2	5	0	16
No. of Cities with at Least Three months' Temperature Mean Value under 0 Degree Celsius		9	2	5	0	16
No. of Cities with None Month's Temperature Mean Value under 0 Degree Celsius	Precipitation over 1,000 mm a year	5	9	0	4	18
	Precipitation under 1,000 mm a year	4	0	10	1	15

Among cities in Europe, East Asia and Other Areas, if weather temperature could not explain the motivation of developing underground pedestrian systems, precipitation possibly could relate weather condition with underground pedestrian systems from another perspective. In East Asian cities excluded from winter city, 9 cities (100%) have an average precipitation mean value over 1,000 mm a year. Similar situation can be found in Other Areas with 80% of cities. In contrast, European cities appear less relationship with precipitation, 100% of them with an average precipitation mean value under 1,000 mm a year. It can be concluded that in East Asia and Other Areas, precipitation much affected developing underground pedestrian systems. But both cold weather and precipitation do not much related to underground pedestrian systems in Europe.

Conclusion

Summarizing the analysis above, we can conclude that: first of all, East Asia, Europe and North America are three main locations in the world concentrated underground pedestrian systems; secondly, cold weather cannot be concluded as a common motivation for underground pedestrian systems development worldwide; thirdly, development of underground pedestrian systems in cities of North America has obvious consequence with cold weather temperatures. Utilization of underground pedestrian systems in cities of Asia and Pacific has obvious consequence with precipitation values. Weather temperatures and precipitation values did not show much relationship with underground pedestrian systems in Europe.

But the research also has some limitations: firstly, it is hard to include all underground pedestrian systems in the world, which possibly affect the exactness of the outcomes; secondly, regarding less obvious findings in the relationship between underground pedestrian systems and weather conditions in European cities, selecting more sub-factors such as hot weather conditions possibly will achieve direct results. Other improvements also can be utilized on dividing underground pedestrian systems into different categories to reach more specific outcomes.

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