# Determinants of Bicycle Usage in Supporting of Daily Travels for a Densely Developed City: Trip Purpose Matters While Facing a Challenge from Motorcycle Competition

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**Abstract: Being a mode of green transport, bicycling is a highly efficient solution of zero-carbon transport for a sustainable living. Many European cities have built their cities cycling friendly via infrastructure improvements and policy supported. On the other hand, having an ownership ratio of 6 motorcycles per 10 people and with nearly 60 percent of motorcycle trips relating to working and schooling purposes in 2018, Taipei struggled to rearrange cycling rights of way along with major arterials for building its bikeway networks without success. Although researchers have found bicycle usage is affected by factors of physical environment, socio-economic features, and psychological preference, very few studies examine their linkages with various trip purposes. This research based on the consequence of government surveys on cycling and motorcycling further explores what determinants are considered by cyclists for their daily travels. Statistical evidence yields that work and school related cycling trips are strongly correlated with shorter travel times or distances. Cyclists for shopping and exercising related trips are less constrained by time and distance considerations. This study finds that determinants of bicycle usage considered by cyclists could be different according to cycling trip purposes.**

**Keywords: Green Transport, Bikeway Networks, Sustainable Transport, Bicycle-friendly Environment, Cyclist Preferences**

## I. INTRODUCTION

Bicycling as a non-motorized transport mode is a highly efficient zero-carbon sustainable transport in supporting a low-carbon living. Through reserving extensive cycling rights of way and sufficient bike parking, integrating bikeway network with public transport, educating cyclists and motorists, providing policies of compact and mixed-use developments facilitating shorter trips together with traffic calm in residential neighborhoods, nations such as Netherlands, Denmark, and Germany have made their cities cycling friendly [1].

Comparing with cities such as Berlin, Malmö, Antwerp, Utrecht, Copenhagen, and Amsterdam, Taipei city has the highest development density (9,818 persons per square kilometer in 2018) [2] together with 811,045 cars (about a ratio of 3 cars per 10 people) and 953,574 motorcycles registered in 2018 (about a ratio of 4 motorcycles per 10 people) [3]. Although Taipei is a compact city facilitated with easy accessible transit network and adopts a land use policy of well mixing residential houses with small retail shops within its neighborhoods where a typical of neighborhood street block is surrounded by major arterials together with lanes and alleys running through the block, 60% of motorcycle trips are for working and schooling purposes due to motorcycle's high mobility, less gas consumption (comparing with cars), time saving (motorcycling through lane and alley for avoiding traffic light), and easy parking [4].

In Taiwan, bicycles once were highly used in the 1940s and the 1950s before motorcycles being imported from Japan in 1968. 13,776,210 motorcycles were registered (about a ratio of 6 motorcycles per 10 people) in 2018 but only 948,783 cars registered (about a ratio of 3 cars per 10 people) in 2019 [3]. Regarding to modes used to workplaces and schools in 2009 and according to the 2009's Survey of the Condition of Bicycle Usage [5] allowing interviewees to select multiple-choice transport modes for daily commute, 56.9% of interviewees rode motorcycles. 34.3% of them drove automobiles and 13.7% of citizen cycled bikes. 11.5% of interviewees took buses and 8.7% took rapid transit, but only 8.6% of people walked from their homes to workplaces. Among these commuting trips, 33.7% of them transferred between different modes [5]. For motorcycle trips, 60% of motorcyclists rode motorcycles for 5.2 days a week in average to workplaces (56%) and spent about 50 minutes of motorcycling per day together with 21% of motorcycling trips for daily shopping [3]. Moreover, high mobility by riding motorcycles (79%), saving commuting time (53%), and inconvenience of transferring to public transit (37%) were reasons of choosing motorcycle for riding to workplaces and schools [3].

For cycling, only 24 cyclists per 100 people cycled bikes weekly in Taiwan in 2017 [6]. 42.2% of them rode bikes for 40 minutes in average for doing recreational activities; 36.6% of them cycled for shopping (13.4 minutes in average); and 21.1% of cyclists rode bikes for commuting to workplaces and schools (15.4 minutes in average) [7]. Among the trips of cycling to workplaces and schools, 35.3% of cyclists rode bike for connecting to public transit [7]. Moreover, nearly all cyclists chose lanes and alleys to ride their bikes regardless what types of cycling trip purposes; 55.8% of them cycled on bike lanes or tracks; and 26.0% of cyclists rode on pedestrian walkways [7]. For reasons of unwillingness to cycle, 56.4% of interviewees (through phone interviewing of 7911 people in 2017) had a habit by walking instead of by cycling and 31.7% of them had no need for cycling or unable to ride bikes [7]. Other reasons include spending too much time by cycling (12.6%), roadway unsafety (19.4%), bad weather condition (24.1%), and incomplete bikeway network (17%) [7]. Clearly, weather condition (rainy days), shorter distance and time, roadway safety (wider cycling rights of way), public transit transfer availability, and well connected built bikeway network are determinants in affecting bicycle usage.

Dill and Mohr together with Ma [8] stated that most cycling related researches have focused on improving infrastructure in the built environment for safety consideration, even though attitudes of cyclist were found to be strong associated with walking and cycling activities. Many previous researches have examined factors contributing to bicycle use for commuting, yet very few probe the bike usage according to non-commuting trips especially from cyclist perspective [9]. This study based on the findings derived from government surveys on cycling and motorcycling aims at further understanding what determinants and principles are underlying cyclist considerations for selecting the bicycle routes.

## II. PAST LITERATURE

In order to alleviate traffic congestion together with lessening air pollution and impacts of climate change, to prevent depletion of natural resources, and to enhance urban amenity and human health, a growing study of urban transport cycling has been conducted to overcome automobile dependence [10,11]. Generally, three types of urban cycling related researches are found and discussed. The first discussion based on traffic engineering perspective mainly refer to the shift of cycling rights of way for safety consideration, similar to cycling infrastructure improvement. The second type is about the determinants of bicycle use associated with physical environment and socio-economic features in relating to cycling and according to urban and transportation planning aspect. The examination of cyclist preferences for riding bikes in the built environment is the third one. The first two types are studies mainly based on a cross-sectional comparison between different cases. The third type of discussion is associated with cycling route choice.

### *2.1. Relationships between reassigning cycling rights of way, bicycle use, and safety*

To guide urban bikeway design and practice, transportation experts from the National Association of City Transportation Officials (NACTO) based on an extensive worldwide literature research including the United States, Europe, and Canada released an Urban Bikeway Design Guide in 2011 and a second edition in 2012 to provide cities to create safe and enjoyable bikeway network for cyclists. Bike lanes, cycle tracks, intersection treatments, bicycle signals, bikeway signing and marking, bicycle boulevards, and designing for all ages and abilities are seven elements included in the guideline.

According to the guideline, a bike lane is defined as a portion of the roadway that has been designated by striping, signage, and pavement markings for the preferential or exclusive use of bicyclists for providing them to ride at their preferred speed without interference from traffic condition. It is recommended that one way width is 1.5 meters (minimum is 1.2 meters) from the face of a curb or guardrail to the bike lane stripe [12]. For a cycle track, it is an exclusive bike facility physically separated from motor traffic and distinct from the sidewalk and combining the user experience of a separated path with on-street infrastructure of a conventional bike lane [12]. When a street has vehicle capacity of low motorized traffic volumes (fewer than 3,000 motor vehicles per day or 1,500 preferred) and car speed less than 25 mph or 20 mph preferred, bicycle boulevards are designated and designed to give bicycle travel priority by providing signs and pavement markings without rearranging additional cycling rights of way in order to discourage through trips by motor vehicles and to increase safety [12]. Bicycle boulevards are the supplement for providing connections between off-street paths, cycle tracks and bike lanes. Generally, bike lanes and cycle tracks are associated with adjustment of cycling rights of way, and bike paths separated from roadways are often located in parks or along waterfronts [13].

For exploring the safety issue on bicycle riding, Chen et al. [14] found that Installation of more bicycle lanes did not lead to an increase in crashes based on their comparing changes in police-reported crashes in a treatment group with another comparison group before and after installation of bicycle lanes and employing generalized estimating equation methodology, despite an increasing probability of traffic accident was likely to cause more cyclists on roadways due to the installation. Similarly, Jacobsen [15] found that motorists were unlikely to collide with pedestrians or cyclists based on a non-linear statistical examination, even if more people were walking or cycling on the streets. Ewing and Dumbaugh [16] found that denser urban area of the traffic environment seemed to be safer than the lower-volume of the suburbs. They also stated that design treatments such as narrow lanes, traffic-calming measures, and street trees close to the roadway were able to promote roadway's safety performance. Clearly, the number of road crash decreased is associated with more cyclists on bicycle lanes or tracks resulting in a rising awareness for car drivers to reduce their automobile speeds.

To evaluate changes in physical activity and active transportation associated with installation of new bicycle boulevards, Dill and McNeil together with Broach and Ma [17] did not find correlation between an increase of physical activity or active transportation among adults and children living near newly installed bicycle boulevards, after their using a longitudinal panel of 353 interviewees as case studies measured with Global Positioning System (GPS) and accelerometers in Portland, Oregon. Similarly, based on the survey through a random phone interview of three neighborhoods in Portland OR, Dill and Mohr together with Ma [7] found that relatively flat neighborhoods with well-connected, low-traffic streets and multiple destinations were correlated with the more frequent of bicycling but not with striped bike lanes.

By collecting national aggregate data and case studies based on large and small cities in Netherlands, Denmark, and Germany, Pucher and Buehler [3] stated that extensive cycling rights of way was one of important approaches in making famous cycling countries. Although NACTO has provided the dimension of bike infrastructures, Buehler and Dill [13] found that the width, design, coloring, location of the roadway, and the quality of bike lane can be different within and between cities and countries, after their reviewing a total of 84 studies on links, nodes, and bicycle networks constructed since 1990. Handy et al. [18] stated that many cycling related researches have emphasized mainly on transport engineering and on safety issue. Clearly, installation of more bicycle lanes and tracks together with bicycle boulevards facilitated by some design application might contribute to a safer riding environment for cyclists but may not promote more bicycle usages.

### *2.2. Determinants affecting bicycle use*

Rietveld and Daniel [19] found that altitude and size of a city, its population, road condition and safety, speed, parking cost, and numbers of stops on cycling routes are correlated with bicycle use, after their employing regression analyses to compare differences of cycling activities between cities in the Netherlands. By examining relationships between facilities and other factors of the built environment such as urban densities, land-use mixes, accessibility, and proximity to transit with walking and cycling behavior, Cervero et al. [20] found that road facility designs, street density, connectivity, and proximity to lanes are associated with physical activity of walking and cycling. Harms et al. [21] found that provision of sufficient cycling infrastructure with decrease of automobile dependence were likely to promote cycling and demographic trends might affect cycling policy outcomes, after their reviewing literature on the effectiveness of cycling policies. Through using a random phone interview for three neighborhoods in Portland OR and controlling interviewee attitudes and perceived behaviors, Dill and Mohr together with Ma [8] found that both the built environment and demographics influenced cycling and walking behaviors indirectly.

Moreover, by using a structural equation model for studying the cycling usage and frequency in college campuses located in the Baltimore Metropolitan Area to promote cycling to college campus, Ketarestaghi et al. [22] found that female cyclists were more concerned with issues of theft together with road conditions and safety issues than male students. They also discovered that both types of students disliked environmentally-related obstacles, while comparing student cyclists with bicyclist of staff and faculty. To measure changes in physical activity and active transportation linking with new installation of bicycle boulevards, Dill and McNeil together with Broach and Ma [17] found that critical covariates included rain, being female, living close to downtown, and attitudes towards bicycling, walking and car safety. Lusk et al. [23] found that pedestrians and cyclists preferred vegetations such as trees and bushes located between the cycle track and on-street car parking area for giving perception of blocking traffic, after their conducting a visual preference survey on five existing cycle tracks in the Boston.

Lu et al. [24] compared cycling behavior with two types of urban greenness (overhead-view greenness and eye-level street greenness) based on participants in Hong Kong, after their using multilevel logistic regression models by controlling activity-influencing built environment and individual-level covariates. They found that cyclist behavior was positively correlated with eye-level street greenness and bike lane density, but negatively related to population density, number of bus stops, and terrain slope. They suggested that traditional green space measurements such as area and number of parks might not be considered by cyclists, while riding bikes. For exploring the linkage between cycling behavior with built urban environment, Miranda-Moreno and Nosal [25] found that temperature, humidity, and the presence of rain would affect bicycle volumes in a given hour based on their study including five automatic counting stations on primarily utilitarian bike facilities in the city of Montreal, Canada.

After employing factor analysis to underlie the linkage between urban design and land-use diversity dimensions of built environments, Cervero and Duncan [26] revealed that planning strategies of well-connected streets, small city blocks, mixed land uses, and close proximity to retail activities together with exogenous factors (topography, darkness, and rainfall) seemed to promote non-motorized transport especially for cycling and walking. They also stated that demographic characteristics of trip makers were likely to be associated with walking and bicycling choice than built-environment factors, and urban landscapes in the San Francisco Bay Area might be statistically insignificant effect on walking and bicycling [26]. By using GPS units for observing the behavior of 164 cyclists in Portland, Oregon, USA, Broach et al. [27] found that cyclists were sensitive to the effects of distance, turn frequency, slope, intersection control, and traffic volumes. Generally, determinants of bicycle usage can be classified into six areas listed as follows [1, 19, 28, 29, 30, 31].

1. Natural Environment Factors such as hilliness and landscape, slope, weather;
2. Built Environment Factors including urban form, facilities at work, land use pattern;
3. Socio-cultural Factors such as population, sex, age, development density, occupation, number of cars owned per capita, cultural background, ethnic origin, political preferences, socio-economic and household characteristics;
4. Psychological Factors and Individual Features including attitudes and social norms, perceived cycling behaviors, habits, reasons for (not) cycling;
5. Efforts of Implementing Bicycle-friendly Environment/Policies such as extensive systems of separate cycling facilities, intersection modifications and priority traffic signals, traffic calming, easy and sufficient bike parking, streetscape, coordination with public transport, traffic education and traffic laws training, local authority initiatives, parking costs, tax on fuel, tolls, supply of public transport services; and
6. Factors of Generalized Costs for Cycling including monetary cost, travel time, physical needs and energy, risk of injury, risk of theft, comfort, personal security, cycling safety.

By collecting a various academic literatures on bicycle commuting, Heinen et al. [28] found that many determinants may not be addressed by conventional mode choice of modeling studies especially in the areas of travel behavior, psychology, and health science. Rybarczyk and Wu [32] stated that policies of increasing bicycle mode share have to be integrated with human-scaled built form for addressing cyclist perception, after their constructing a sequence of binary logit choice models for examining the city of Madison, Wisconsin. By employing questionnaire surveys at bicycle parking facilities near Nanjing road and Shanghai central library to understand the underlying relationships between cyclist attitudes with public transport policies, Zacharias [33] found that both bicycle and car numbers decreased in the central area and cyclists were unlikely to shift to public transport even though various incentives were offered. Here, saving time while riding bicycles is the main consideration that cyclists keep on cycling, since cyclists know clearly about the routes and times needed to travel to a same destinations by bus in that district.

After employing a multivariate model for 36 cities and towns in Britain, Cervero and others [34] stated that existing literatures have highlighted the importance of built environments, urban amenities, and high quality bicycle networks in relating to cycling for work, yet few studies examined the respective connections and the collective causality of these influences together. Although most cycling relative studies have explored and defined some factors in association with bicycle usages, the underlying causalities between cyclist riding behaviors with those factors are still unclear and different on a case-by-case basis. Moreover, some determinants such as slope and weather condition should be treated as prerequisite conditions. When cyclists live in a geographic place with steep slopes and frequent rain area, they may have to ride bikes in such environment daily, if no other alternative transport mode could be chosen by them. Both factors (rain and slopes) seem to be unimportant to them in this case, unless cyclists are compared based on two different cross-sectional geographic places or regions.

*2.3. Cyclist route choice and trip purposes*

Krizek et al. [35] stated that cycling related planning practice could be different between beginning cyclists, recreational cyclists, and serious cyclists, after their findings that elementary students may need programmatic interventions for increasing the perceived safety of their route to school by walking or cycling. Also, university students might be sensitive to parking pricing on campus, and therefore good sidewalk connections between cheaper peripheral parking spaces to the campus are likely to encourage walking and cycling [35]. For timid cyclists, a network of off-street bicycle trails seems to meet with their needs [35]. Chen et al. [14] stated that cycling in the United States was primarily for a recreational purpose rather than a means of daily travel. Harms and Kansen [36] found that the distribution of bicycle kilometers for Leisure trip purpose was about 37% in Netherland in 2016, followed by work trip (24%), school trip (20%), and shopping trip (13%). Pucher and Buehler [1] found that cyclists occasionally cycled for recreational purposes but seldom for daily practical travels in most of industrialized world. Clearly, cyclists are likely to have dissimilar considerations of riding bikes and attitudes according to different trip purposes.

To understand bicyclists' preferences for facility types, Broach et al. [27] found that route preferences differed between commuting with other utilitarian trips, and cyclists were more sensitive to distance and less sensitive to other infrastructure characteristics for commute trips. They also stated that cyclists preferred off-street bike paths, neighborhood bikeways with traffic calming features (bicycle boulevards), and bridge facilities [27]. Yehoah and Alvanides [9] found that shortest paths might not accurately match with observed bicycle routes of home-to-work commute but have a significant effect on the observed restricted bikeway networks based on their using OpenStreetMap (an online map) together with employing GPS tracks and travel diary data including 79 Utility Cyclists around Newcastle in North East England.

Meyer and Miller [37] defined a trip as one-way movement according to different purpose and classified five major trip purposes including home-based work (work, commute, or business trips), home-based shop (shopping trips), home-based school (schooling trips), home-based other (social or recreation trips), and non-home-based. They also found that people would like to minimize their travel time and cost together with maximize their comfort and convenience as possible as they could for travelling [37]. Among various trip purposes, cycling related studies have emphasized for commuting trip mainly, very few researches explore relationships of cyclist attitudes and behaviors for non-commuting trips. Moreover, whether a cycling-related research is analyzed based on GPS tools or not, different cycling trip purposes and relative considerations of route choices should be included as part of studies, when researchers explore determinants of bicycle usage.

## III. METHODS

By collecting and comparing various walking and cycling related studies to understand challenges and trade-offs that researchers have faced in evaluating the effectiveness of interventions designed for promoting walking and cycling resulting from strategies of infrastructure improvements to the built environment, Krizek et al. [35] believed that the difficulty of gathering sufficient large sample of cyclists had leaded to many previous studies with inconclusive outcomes. Instead of emphasizing on the increase of bicycle ridership through providing ample cycling rights of way as the intent, this research based on qualitative and quantitative methods examined the correlation between determinants and principles of cycling route choice that cyclists have considered while riding bikes with various travel purposes in order to unveil the causalities of bicycle use.

To understand the general linkages between cycling patterns with different trip purposes, the first study was conducted by interviewing cyclists who were intercepted randomly after their parking bikes at 11 locations of bicycle parking lots around Taipei city. These selected locations were either near schools, temples, night markets, department stores, libraries, and public commercial plazas. Cross-sectional quantitative analyses such as Chi-square test and cluster analysis were used for both studies to check the statistically importance between cycling trip purpose with the determinants of bike use and their considerations of route choice principles. The conceptual research framework is shown in **Figure 1**.

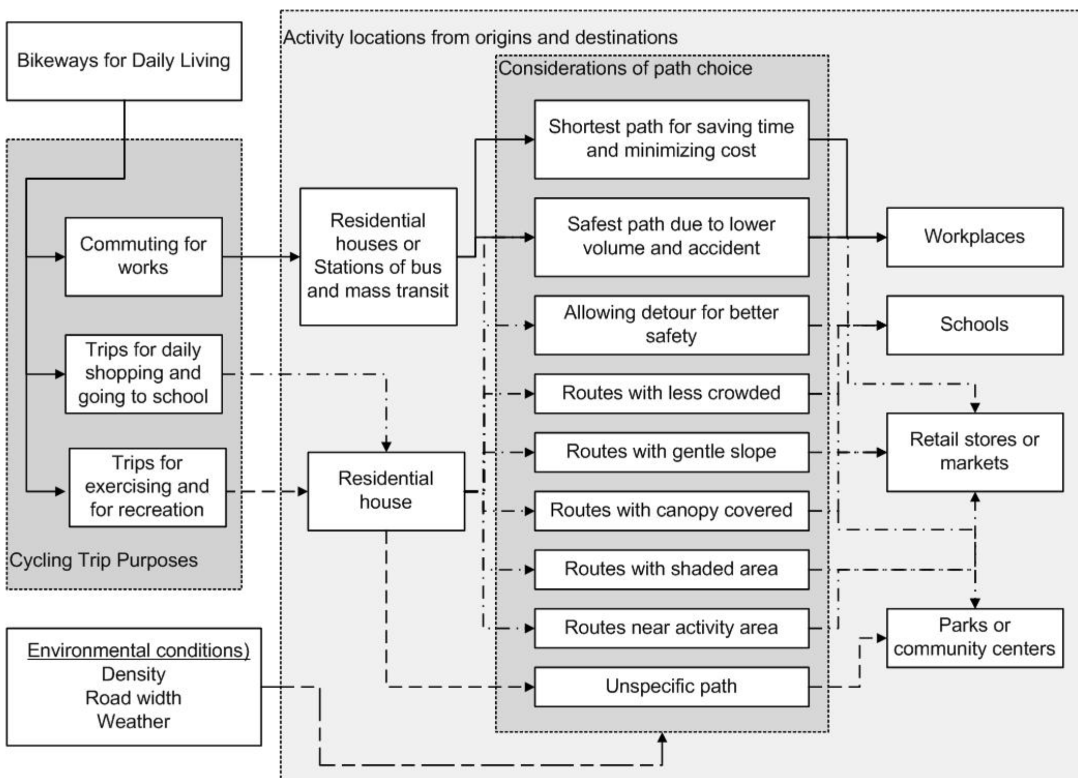


Figure 1. Causal Paths between Cycling Trip Purposes and Principles of Route Choice

### *3.1 Research Variables Associated with Determinants of Bicycle Usage*

Comparing the 2009's Survey of Taiwan's Bicycle Usage with the 2018's Survey of Taiwan's Motorcycle Usage, a determinant of "travel time" is an important connector for helping motorcyclists to shift to bike ridings, since “high mobility of riding motorcycles” (79%) and “saving commuting time” (53%) are two major reasons of keeping them riding their motorcycles. Although bicycle riding also has high mobility feature, it is slower than motorcycle riding. “Longer travel distance” and “spending too much time” are two main reasons of unwillingness to cycle. Therefore, shorter distance and time-saving are two critical considerations affecting cyclists for their commuting to workplaces and schools. The complete explanatory and dependent variables for this study are listed in Table 1.

Table 1 Questionnaire Items in this Study for Both Weekday and Weekend Cyclists

| Category | Item | Response Categories |
|---|---|---|
| Background of cyclists | Sex | 1. Male 2. Female |
| | Age | 1. <= 20 2. 21 – 30 3. 31 – 40 4. 41 – 50 5. 51 – 60 6. >= 61 |
| | Education status | 1. Elementary School<br>2. High School<br>3. College or University<br>4. Graduate School |
| | Location interviewed | 1. Bao-An Temple<br>2. Da-An City Park<br>2. Shui-Yuan Market<br>5. Rao-He Night Market<br>6. Lanya Junior High School<br>7. Taipei Medical University<br>2. Uni-President Dept. Store<br>3. Xin-Yi Plaza<br>9. Technology Office Bldg.<br>10. National Taipei University of Tech.<br>11. National Taiwan Normal University |
| Cycling trip purpose (single choice) | For works | 1. Frequency of cycling<br>2. Travel time in minutes<br>3. Considerations of route choice: 3.1 Routes with less traffic accident 3.2Detour for safety concern 3.3 Shortest distance or the most time-saving path 3.4 Less steep slope route 3.5 Less crowded route 3.6 Route next to activity node 3.7 Routes under tree canopy to avoid getting wet during rainy day 3.8 Route under shadow 3.9 Any route without preference (multiple choice) |
| | For shopping | 1. Frequency of cycling<br>2. Travel time in minutes<br>3. Considerations of route choice: 3.1 Routes with less traffic accident 3.2Detour for safety concern 3.3 Shortest distance or the most time-saving path 3.4 Less steep slope route 3.5 Less crowded route 3.6 Route next to activity node 3.7 Routes under tree canopy to avoid getting wet during rainy day 3.8 Route under shadow 3.9 Any route without preference (multiple choice) |
| | For leisure | 1. Frequency of cycling<br>2. Travel time in minutes<br>3. Considerations of route choice: 3.1 Routes with less traffic accident 3.2Detour for safety concern 3.3 Shortest distance or the most time-saving path 3.4 Less steep slope route 3.5 Less crowded route 3.6 Route next to activity node 3.7 Routes under tree canopy to avoid getting wet during rainy day 3.8 Route under shadow 3.9 Any route without preference (multiple choice) |
| | For school | 1. Frequency of cycling<br>2. Travel time in minutes<br>3. Consideration of route choice: 3.1 Routes with less traffic accident 3.2Detour for safety concern 3.3 Shortest distance or the most time-saving path 3.4 Less steep slope route 3.5 Less crowded route 3.6 Route next to activity |

| | |
|---|---|
| | node 3.7 Routes under tree canopy to avoid getting wet during rainy day 3.8 Route under shadow 3.9 Any route without preference (multiple choice) |
| For joining events | 1. Frequency of cycling<br>2. Travel time in minutes<br>3. Considerations of route choice: 3.1 Routes with less traffic accident 3.2Detour for safety concern 3.3 Shortest distance or the most time-saving path 3.4 Less steep slope route 3.5 Less crowded route 3.6 Route next to activity node 3.7 Routes under tree canopy to avoid getting wet during rainy day 3.8 Route under shadow 3.9 Any route without preference (multiple choice) |

### *3.2 Data Collection*

To obtain basic data for analysis, the first study randomly chose 30 interviewees of cyclists (15 during weekday and 15 in weekend) at each 11 different locations of bicycle parking lots around Taipei city for ensuring that samples collected were based on experienced cyclists who were willing to respond to and answer questions without any interruption after their parking bicycles. Totally, 330 cyclists were collected in 2015 for this research and their characters were shown in **Table 2**. The age of most interviewees was from 21 to 40 years old (64%) and 66% of them graduated from colleges or universities. The number of female cyclists is more than the male's number in the study.

Table 2. The Background of 330 Cyclists (Unit: Person)

| Locations | Time of Survey | Sex | | Age of Interviewee | | | | | | Educational Status | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Male | Female | Under 20 | 21-31 | 31-40 | 41-50 | 51-60 | 61 Above | Elemen-tary School /Under | High School | College or University | Graduate School |
| Bao-An Temple | Wkday | 3 | 12 | | 9 | 3 | | | 3 | 3 | | 9 | 3 |
| | Wkend | 9 | 6 | | 3 | 3 | 3 | 3 | 3 | | 6 | 9 | |
| Da-An City Park | Wkday | 3 | 12 | 1 | 8 | 6 | | | | | | 12 | 3 |
| | Wkend | 5 | 10 | 4 | 7 | | 4 | | | | 7 | 8 | |
| Shui-Yuan Market | Wkday | 3 | 12 | | 15 | | | | | | | 12 | 3 |
| | Wkend | 1 | 14 | 6 | 9 | | | | | | 6 | 6 | 3 |
| Rao-He Night Market | Wkday | 8 | 7 | 6 | | 3 | 3 | | 3 | 3 | 6 | 3 | 3 |
| | Wkend | 4 | 11 | | 9 | 6 | | | | | | 15 | |
| Lanya Junior High School | Wkday | 3 | 12 | | | 6 | 3 | 6 | | | | 15 | |
| | Wkend | 12 | 3 | | 3 | 9 | | 3 | | | 3 | 3 | 9 |
| Taipei Medical University | Wkday | 3 | 12 | 3 | 6 | 6 | | | | | | 12 | 3 |
| | Wkend | 12 | 3 | 3 | 6 | 4 | 2 | | | 3 | | 9 | 3 |
| Uni-President Dept. Store | Wkday | 14 | 1 | 6 | | 9 | | | | | 6 | 9 | |
| | Wkend | 7 | 8 | 3 | 9 | | 3 | | | 3 | | 12 | |
| Xin-Yi Plaza | Wkday | 11 | 4 | 6 | 3 | 3 | 3 | | | 3 | | 12 | |
| | Wkend | 3 | 12 | | 6 | 6 | 3 | | | | | 9 | 6 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology Office Bldg. | Wkday | 9 | 6 | 4 | 11 | | | | | | 3 | 9 | 3 |
| | Wkend | 3 | 12 | 3 | | 6 | 3 | 3 | | | 3 | 6 | 6 |
| National Tpe University of Tech.. | Wkday | 3 | 12 | 5 | 10 | | | | | | | 15 | |
| | Wkend | 7 | 8 | 3 | | 6 | 3 | 3 | | | 3 | 9 | 3 |
| National Tai-wan Normal University | Wkday | 6 | 9 | 6 | 6 | | | 3 | | | | 12 | 3 |
| | Wkend | 9 | 6 | | 12 | 3 | | | | | | 12 | 3 |
| Total | | 138 | 192 | 59 | 132 | 79 | 30 | 21 | 9 | 15 | 43 | 218 | 54 |
| % | | 42 | 58 | 18 | **40** | **24** | 9 | 6 | 3 | 5 | 13 | **66** | 16 |

## IV. CYCLING PATTERNS IN TAIWAN

Based on the survey of 330 cyclists in Taipei, the study examines relationships and determinants of bicycle usages according to different cycling trip purposes and considerations of route choice. Statistical examinations are discussed as follows.

### *4.1 More Cyclists Riding for Leisure Purpose during Weekend than Weekday in Taipei*

Among 330 cyclists in the first study, 78% of them rode bikes more than half an hour in average for recreational purpose during weekend and 24% of interviewees during weekday. 36% of cyclists commuted for works about 15 minutes in average and 31% of them cycled to school during weekday. The result of interviews unveiled that most of commuters did not ride bicycles directly from homes to workplaces. Instead, they either rode bikes from homes to transit stations/bus stops or from transit stations/bus stops to workplaces, after comparing the travel times with the 2009 data that residents of urbanized neighborhoods spent about 40 minutes in average commuting to workplaces by motorcycles or by transits [38]. A detail of 330 cyclists in relating to different cycling trip purposes at 11 locations is shown in **Table 3**.

Table 3. A List of Cycling Difference at 11 Bicycle Parking Lots during Weekday and Weekend

| Locations | Time of Survey | Cycling Trip Purpose | | | | |
|---|---|---|---|---|---|---|
| | | For Works | For Shopping | For Leisure | For School | For Joining Events |
| Bao-An Temple | Wkday | 39% (7.5) | | 61% (40) | | |
| | Wkend | | | 100% (30) | | |
| Da-An City Park | Wkday | 40% (20) | | 42% (17.5) | 18% (8) | |
| | Wkend | | | 80% (33.33) | | 20% (20) |
| Shui-Yuan Market | Wkday | 40% (10) | 21% (25) | 39% (20) | | |
| | Wkend | 20% (20) | | 80% (26) | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Rao-He Night Market | Wkday | | 20% (15) | 61% (40) | 19% (10) | |
| | Wkend | | | 100% (44) | | |
| Lanya Junior High School | Wkday | 79% (10.8) | | | 21% (10) | |
| | Wkend | | | 100% (21.3) | | |
| Taipei Medical University | Wkday | 60% (16.7) | | | 40% (22.5) | |
| | Wkend | | | 100% (28.8) | | |
| Uni-President Department Store | Wkday | 20% (5) | 22% (5) | 40% (22.5) | 18% (10) | |
| | Wkend | 19% (5) | | 81% (81.3) | | |
| Xin-Yi Plaza | Wkday | | | 42% (10) | 40% (22.5) | 18% (15) |
| | Wkend | | 59% (10) | 41% (20) | | |
| Technology Office Building. | Wkday | 61% (13.3) | | | 38% (10) | |
| | Wkend | | 40% (15) | 60% (13.3) | | |
| National Taipei University of Technology | Wkday | 19% (15) | | | 81% (13.3) | |
| | Wkend | 20% (15) | 18% (18.8) | 42% (17.5) | | |
| National Taiwan Normal University | Wkday | 39% (17.5) | | | 61% (15) | |
| | Wkend | | | 80% (18.8) | 20% (20) | |
| Total | Wkday | 36% (12.8) | 5% (15) | 25% (24) | 31% (13.5) | 3% (15) |
| | Wkend | 5% (13.3) | 11% (14.6) | **78%** (32.6) | 4% (20) | 2% (20) |

Note: Numbers in parentheses are average travel time in minutes by cycling

*4.2 Correlations between Route Choice Considerations and Different Cycling Trip Purposes*

A Chi-square test is employed to identify any significant difference between principles of cycling route choice. Based on a 95 percent confidence level and *p*-value less than 0.05 together with Chi-square value higher than the Chi-square distribution with 4 degrees of freedom ($X^2_{.05}$= 9.48773), the following statistical examination shows some evidences as follows (see **Table 4**).

1. Regardless cycling in weekends or during weekdays, nearly 52% of cyclists ride bikes for leisure purpose and 21% of them ride for commuting purpose. Only 16% of them were students cycling to schools.

2. Exclusive cycling for doing recreation, cyclists generally spend less than 20 minutes of bike riding for going to school, for commuting to work, for heading to stores, and for participating events. However, cyclists could ride nearly half an hour in average for leisure purpose.

3. Although cyclists may detour to avoid unsafe routes for working (57%), for schooling (67%) and for doing recreation (54%), they are more likely to avoid being late while they ride to workplace and to school. They therefore tend to choose the most time-saving paths or shortest distance routes for commuting (74%) and schooling (83%) without considering safety issue (traffic accident) as their top priority.

4. The consideration of traffic accident seems to be insignificant due to rare traffic accident caused by cycling or being reported. Cyclists thereby seem to be careless about issues relating to traffic safety.

5. When cyclists ride bikes for shopping, they are likely to ride in or around the neighborhood and stop by several shops and stores for buying their needs. They thereby tend to choose routes close to activity nodes (33%) and less slope path (11%)) for avoiding riding hard, while carrying heavy loads (shopping goods).

6. To join events by riding bikes, cyclists may have enough time for riding bike easily. They thereby might choose routes with shade and with canopy cover for avoiding getting hot and wet.

7. When cyclists ride for doing recreation, they would like to relax without suffering from time constrains. They therefore may choose any routes for sightseeing or exercising. Similarly for riding to shops, cyclists are likely to bike any paths around or in the neighborhood easily.

Table 4. A Comparison of Route Choice Principles with Different Cycling Trip Purposes

| | **Cycling Trip Purposes** | | | | | **Chi-square *p*-value** |
|---|---|---|---|---|---|---|
| | **For Works** | **For Shopping** | **For Leisure** | **For School** | **For Joining Events** | |
| Percentage of Cycling | **20.91%** | 8.18% | **51.82%** | **16.36%** | 2.73% | N/A |
| Mean Travel Time in Minutes | **13.17** | 16.11 | **28.83** | **15.00** | 18.33 | N/A |
| **Principles of Route Choice** | | | | | | |
| Routes with Less Traffic Accident (*LTA*) | 21.74% | 44.44% | 29.82% | 38.89% | 33.33% | 4.50823 p=.341580 >0.05 |
| Detour for Safety Consideration (*DSC*) | **56.52%** | 44.44% | **54.39%** | **66.67%** | 33.33% | 7.38370 p=.11.6958 >0.05 |
| Shortest Distance (The Most Time-saving path) (*SD*) | **73.91%** | 11.11% | 12.28% | **83.33%** | 30.33% | **94.8453 p=.00000 <0.001[a]** |
| Less Steep Slope Route (*LSS*) | 0% | 11.11% | 0% | 5.56% | 0% | **14.5988 p=.005612 <0.05[b]** |
| Less Crowded Route (*LC*) | 52.17% | 11.11% | 40.35% | 38.89% | 32.33% | 9.23532 p=.055487 >0.05 |
| Route Next to Activity Node (*AN*) | 0% | **33.33%** | 7.02% | 0% | 0% | **28.0346 p=.000012 <0.001[c]** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Routes with Canopy Cover to Avoid Getting Wet during Rainy Day (*Cvr*) | 8.70% | 11.11% | 3.51% | 11.11% | **23.33%** | **9.75524 p=.044766 <0.05[d]** |
| Route with Shadow (*Shd*) | 13.04% | 11.11% | 12.28% | 5.56% | 0% | 2.234261 p=.692931 >0.05 |
| Any Route without Preference (*NS*) | 4.35% | **22.22%** | **78.95%** | 5.56% | 13.33% | **27.3491 p=.000017 <0.001[e]** |

Note: [a] Highly significant difference between work and schooling trips, while comparing with other cycling trips.
[b] Significant difference between shopping and schooling trips, while comparing with other cycling trips.
[c] Highly significant difference between shopping trip, while comparing with other cycling trips.
[d] Significant difference between the trip for joining events, while comparing with other cycling trips.
[e] Highly significant difference between shopping and leisure trip purposes, while comparing with other cycling trips.

A Cluster analysis is further used for ensuring the consequence of previous Chi-square examination. Based on the criteria of linkage distance under 1.0 (see Figure 2), a cluster analysis unveils that work and school related cycling trips are strongly correlated with a consideration of the most time-saving paths or shortest distance routes. Also, cyclists ride for shopping and for exercising may select any path. Cyclists riding bikes for cycling trip purposes such as joining events, are more likely to select any route rather than specific path, since they may not necessarily need to arrive at destinations in a hurry.

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Figure 2. A Tree Diagram of Cycling Trip Purposes Underlying Route Choice Considerations

## V. CONCLUSION AND DISCUSSION

Researchers have identified that bicycle usage could be affected by at least six types of determinants including **Natural Environment** Factors (slope, weather), **Built Environment Factors** (urban form, facilities at work, land use pattern), **Socio-cultural Factors** (population, sex, age, development density, occupation, number of cars owned per capita, cultural background, ethnic origin, political preferences, socio-economic and household characteristics), **Psychological Factors and Individual Features** (attitudes and social norms, perceived behavioral control, habits), **Efforts of Implementing Bicycle-friendly Environment/Policies** (cycling facilities, intersection modifications and priority traffic signals, traffic calming, sufficient bike parking, streetscape, coordination with public transport, traffic education and training traffic laws, local authority initiatives, parking costs, tax on fuel, tolls, supply of public transport services), and **Factors of Generalized Costs for Cycling** (monetary cost, travel time, physical needs and energy, risk of injury, risk of theft, comfort, cycling safety). Among these determinants, this study has found that cycling trip purpose is associated with bicycle usage critically, especially for cycling to work and to school.

Based on the ratio of 2016's registered motorcycles and the 2019's ratio, the motorcycling trips for working and schooling increases 2.6% (from 57.4% to 60%) [39, 3]. The travel time decreases 3.8 minutes in average daily (from 53.8 to 50 minutes) and the frequency of motorcycle riding also reduces 0.3 days per week in average slightly (from 5.5 to 5.2 days). Moreover, "high mobility" as a reason to ride motorcycle increases 24.8% (from 54.2% to 79%) and "saving commuting time" also increases 34% (from 19% to 53%). On the other hand, this 2015's cycling study based on focus group survey shows that 51.82% of cyclists ride bikes for spending nearly 30 minutes in average to participate in leisure activities (40 minutes surveyed by MOTC in 2017) and this ratio of cycling for doing recreation activities falls between 60.5% in 2009 and 42.2% in 2017 [40, 7]. For cycling trips of going to workplaces for at least 5 days per week, this study finds that 20.91% of cycling trips surveyed in the study are for working. This ratio also falls between the ratio of 12.5% in 2009 and 21.1% in 2017 [40, 7]. In spite of facing an issue of a small size sampling in this research, the consequence unveiled from this study by employing a focus group survey are acceptable and meaningful.

For cycling to work and to school trip purposes, commuters and students tend to choose the most time-saving paths or shortest distance paths for avoiding arriving late, regardless thinking about safety issues as their main concern. Students generally choose to walk or cycle to school through neighborhood lanes and alleys. Although many lanes and alleys are possible to be chosen by students, only a few routes with shortest possible time or distance feature in the school district are heavily used. When riding for shopping or leisure trip purposes, cyclists are likely to choose routes more freely. Since shops are not necessarily located along main streets, shoppers tend to cycle mainly on neighborhood lanes and alleys but not so much along main streets. Sometimes, they may choose less steep routes next to activity nodes for lessening their loading and the average cycling travel time is less than 20 minutes. On the other hand, leisure cyclists are concerned about relaxation and interesting scene, and they thereby may choose routes (riverside cycle paths, neighborhood lanes and alleys) even more freely and randomly. They prefer cycling routes with canopy cover.

Unlike the study by Miranda-Moreno and Nosal [25], this research found that many cyclists in Taiwan may not consider temperature and humidity seriously, especially for student cyclists and commuters. While comparing cycling with walking, cyclists prefer to ride bikes rather than walk, since they could feel moving air and breeze keeping them cold, but not by foot. Therefore, a bicycle route with building shadow or tree shade and roof covered seems to be less important for cyclists. Generally, determinants of bicycle usage are considered differently by cyclists depending on their cycling trip purposes. However, some determinants such as slope and weather condition could be identified as prerequisite factors, if cyclists have limitation of route choice.

Although various determinants of bicycle usage are identified by researchers, this study based on questionnaire survey finds that determinants of bicycle usage are closely associated with cycling trip purposes meaningfully. Moreover, since bicycle usage related studies have to rely on assembling a large enough sample of people who cycle, or of cycling trips [35], the relationships between some determinants such as population density, built environment, and weather condition with bicycle ridership need to be further studied, once a sufficiently large consistent cross-sectional data of cyclist survey is available.

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