國立交通大學

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博 士 論 文

旅行者潛在構面之量測：車輛使用依賴性
之探索與老年人搭乘公車能力感認之衡量

**Measuring the Latent Traits of Travelers:
Exploring the Vehicle Dependence and Evaluating the
Perceived Physical Abilities of the Elderly Bus Passengers**

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摘要

本研究之主要目的是針對文獻上未有完整架構與常模之潛在構面進行探索並加以量測。包含兩個影響旅行者交通行為之潛在構面之探索。一為一般旅行者對於車輛使用之依賴性，另一則為老年人對於自己搭乘公車之行為能力感認。

關於車輛使用依賴性之探索，本研究認為該構面乃是一綜合經濟考量、心理偏好與習慣制約之潛在心理評價。由於旅行者少有察覺並能清楚表示自己之車輛使用依賴程度，故本研究採用項目反應理論之探討架構，由各種旅次目的設計負面剝奪性問項以刺激旅行者對於該車輛使用之依賴性。同時以 Rasch 模式將收集得資料進行對該依賴性構面之測量。為驗證本研究提出之測量方法之有效性，實證研究針對台北市機車騎士進行其對機車使用之依賴性。並將各人所量測得之機車依賴水準連結至其社經變數以作進一步探討。實證研究中發現台北市民在單人旅次、短程旅次與多停點旅次對機車之依賴行為較高，而年齡較輕者、收入較低者與無汽車可使用之機車騎士對機車依賴性顯著較高。由於此欲探討之車輛使用依賴性乃透過有效且可靠的施測方法加以收集並衡量，量測之結果亦建立在等距尺度上，可直接引入為傳統模型之解釋變數。本研究之探索相信將可提供傳統個體選擇模型引入心理層面考量為變數探討之借鏡，使模型解釋能力更高並進而提升其預測能力。

本研究第二個主題則針對老年人對自己搭乘公車之行為能力感認加以探討。由於高齡化社會慢慢形成，老人之外出行為需求亟需重視並加以安排。受限於身體機能退化，老人自己駕駛小客車或騎乘機車或自行車之危險性相較於年輕人高出甚多，搭乘公車不但能確保老人安全，同時亦是較有效率之社會經濟資源配置。本研究以老年人之觀點出發，藉由搭公車過程所需要完成之各種動作，由老人自行評估其完成各類動作之掌握程度。藉由測驗理論方法，測度各項動作之相對難度。實證研究結果發現老年人在公車運行過程中之平衡感之保持與閱讀車站資訊及辨識來車路線號碼上最感到困難。本研究更針對這些較為老年人感到困難之項目，對公車系統之設施與服務上提出具體之改善建議。希望能為老人建立一個更為安全且友善之公車搭乘環境，以吸引更多老人利用公車進行旅行活動。

關鍵詞：潛在構面、心理量測、羅許模型、車輛依賴性、行為能力感認

Measuring the Latent Traits of Travelers: Exploring the Vehicle Dependence and Evaluating the Perceived Physical Abilities of the Elderly Bus Passengers

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ABSTRACT

This study aims to demonstrate the exploration and measurement on two latent traits that underlie the travelers' considerations. One of these two latent traits is the vehicle dependence of the travelers on a given vehicle usage; the other is the physical ability perceived by elderly travelers when using buses. In the first topic, vehicle dependence is conceptualized as the subjective considerations of individual travelers, including their economic considerations, psychological preference, and habitual behavior. The Rasch model is reviewed, and suggested as an instrument to measure such a latent construct. An empirical analysis of motorcycle dependence was performed using self-rated information about eight items from 321 motorcyclists in Taipei. The empirical results showed that motorcyclists in Taipei depend on their motorcycles to achieve unaccompanied, short-distance, multistop trips; motorcyclists under the age of 25 who were inferior in economic terms and did not use an automobile showed relatively higher measures of motorcycle dependence. This paper robustly conceptualizes vehicle dependence in terms of both its socioeconomic and its psychological nature. The results of exploring vehicle dependence could benefit researchers in modifying their formulations of mode choice, and policy makers in enacting more effective policies.

In the second topic, it is proposed to measure the elderly bus passengers' abilities and to explore their difficulties in accomplishing the actions and motions required to patronize the bus service. A conceptual framework about the required actions and motions in bus taking was established and a questionnaire with 18 items was designed to test their ability to use buses. A face-to-face survey was conducted to collect the self-rated information from 304 elderly bus passengers in Taipei. The Rasch model was applied to estimate the difficulty of each item and the ability of each person to use buses. Results showed the relatively difficult items are mostly about keeping balance on the moving bus and reading the information or discerning the approaching buses at the stations, and the considered levels of physical ability showed negative associated with respondents' age. With relating the measures of person ability and item difficulty, the item-person map provides a straightforward and graphical illustration on the corresponding proportion of elderly bus passengers that can achieve in each given item with ease. Results from this study will help the traffic authorities or bus service providers in issuing instructions or enhancing the facilities and service to provide the elderly with a safer and friendlier environment for bus usage.

KeyWords: latent construct, psychometric measure, Rasch model, vehicle dependence, physical ability perception

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論文口試期間，承蒙台灣師大王國川教授、南台科技大學李治綱教授、中央大學陳惠國教授、本校馮正民教授、卓訓榮教授與任維廉教授的審閱與斧正，使得論文能更加充實與完備，在此致上最深的謝意。博士攻讀過程中，中興大學蔡明志老師、成功大學黃國平老師，以及本系吳宗修老師、郭秀貴老師都曾在我跌跌撞撞的時刻給予我扶持與關心。從就讀運管系大學部開始，本系所有老師對於我在交通專業的啟迪，亦是本篇論文得以完成之基石。求學過程於交大籃球隊受到本校盛育奎老師與宋濤教練之照顧，尤其宋教練給予我許多生涯觀念的啟發，亦讓我埋下心理計量研究的種子。此外本系王秀蔭、鄭幸榮助理，以及許許多多曾經協助過我的人，在此一併致上無盡感謝。

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吳舜丞　謹誌

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CHAPTER 1

Introduction

This study respectively measures two latent constructs behind travelers' considerations: the vehicle dependence of motorcyclists and the physical ability perceived by the elderly bus passengers. The first topic is aimed to identify and to measure the generalized latent construct of travelers' dependence on the given vehicles. It is aimed to conceptualize the vehicle dependence which can be applied in the researches of the mode choice behavior. The second topic is an explorative trial to realize how the senior bus passengers perceive their own physical abilities when using buses. Such a self-assessment of elderly passengers on their own physical abilities plays a critical role on their willingness of bus patronage. Both of these two concerned issues are seldom discussed on the literatures. Thus in the beginning of this thesis, we will start with the introduction of this research, including the motivations, objectives, and contributions of this study in the following parts.

1.1 Research Motivations

In the first topic, the motivation of exploring the vehicle dependence was originated from the mergence of econometric formulations and psychological viewpoints on the mode choice of travelers. The mode choice of travelers has commonly been analyzed in the framework of random utility theory since that theory was introduced (Domencich and McFadden, 1975). However, most mode choice studies have been formulated only in terms of observable economic variables, and this has resulted in a limitation of their predictive abilities. Kahneman et al. (1979) found that individuals facing decision-making tasks in carefully constructed experimental settings often exhibited behavior that was inconsistent with a

prediction based on economic variables, and indicated that some unexplored factors other than the observable economic factors might also influence one's choice. Gilbert and Foerster (1977) argued that attitudinal variables were important in decisions about mode choice and could significantly increase the explanatory power of mode choice models. Collins and Chambers (2005) tested the relative importance of and relationship between psychological and situational factors in predicting mode choice in commuter transport; they found that psychological beliefs played roles as important as situational conditions. Ben-Akiva et al. (1999) reviewed the literature and pointed out that choice behavior can be characterized as a decision process that is informed by perceptions and beliefs about the available information and is influenced by psychological factors such as affects, attitudes, motives, and preferences. The final choice could be regarded as an outcome of a complicated decision process.

In addition to economic concerns, travelers might be forced to make or willing to make particular mode choices, or could be habituated to those choices. Mode choice could be the combined result of travelers' economic concerns, psychological preference, and habitual behavior. That is to say, people might have some degree of reliance on the usage of one specific vehicle owing to both objective constraints and subjective considerations. Therefore, the term "vehicle dependence" was defined as people's reliance on the usage of a specific vehicle in the study described here, and it is expected to provide another auxiliary measure for exploring mode choice. Exploring the vehicle dependence provides valuable knowledge not only for understanding mode choice, but also for implementing transportation policy. This realization provides an insight into the needs of people for achieving their daily activities, and helps to identify the impact on travelers before a new transportation policy is implemented.

The second topic is concerned about the appropriate arrangement or assistance for the senior people in their daily transportation. Population aging commonly occurs in many

developed countries. In these aging societies, it was found that senior people (aged over 65) increasingly participate in some outdoor activities in order to maintain their social connections and receive emotional feedback (Unger & Wandersman, 1985). However, these demands for outdoor activity might not be accomplished because their travel options are somehow constrained. Golob (2000) found that elderly people's non-home activities and total time spent on traveling are negatively associated with their age. About 21% of Americans aged over 65 do not drive and more than half of these non-drivers aged over 65 (i.e. about 3.6 million Americans) stay at home all day partially due to lack of transportation options (Bailey, 2004). The limitations on elderly people's travel options might be mainly resulted from the decline in their physical ability. Increased age is associated with declines in some physical abilities such as perceptual mechanism (i.e. vision and hearing), cognitive performance (i.e. memory and attention), and physical strength (i.e. balancing and clutching). Decrease in physical ability deters the elderly from road using in some degree.

Limitations on physical abilities force the elderly to make some changes in their mode choices. Rosenbloom (1995) found that, as the age of the elderly traveler increased, traveling as a passenger increased significantly, while making trips as a driver decreased. Chang and Wu (2005) also showed that, as the elderly travelers become older, they tend to select some conservative ways to travel such as taking buses, taking taxies, or hitching the rides of their family members or friends (See Fig.1-1). Similar to the other two options, traveling by bus avoids tackling the traffic directly, which will reduce a large proportion of the potential risk of accidents for elderly travelers. Traveling by buses is more economical than by taxies in expense; it also enables the elderly to travel independently without bothering or matching somebody's trips. Traveling by buses therefore is quite appropriate for the elderly, especially for the younger elderly people (aged 65-75) who might have frequent participation in some outdoor activities.

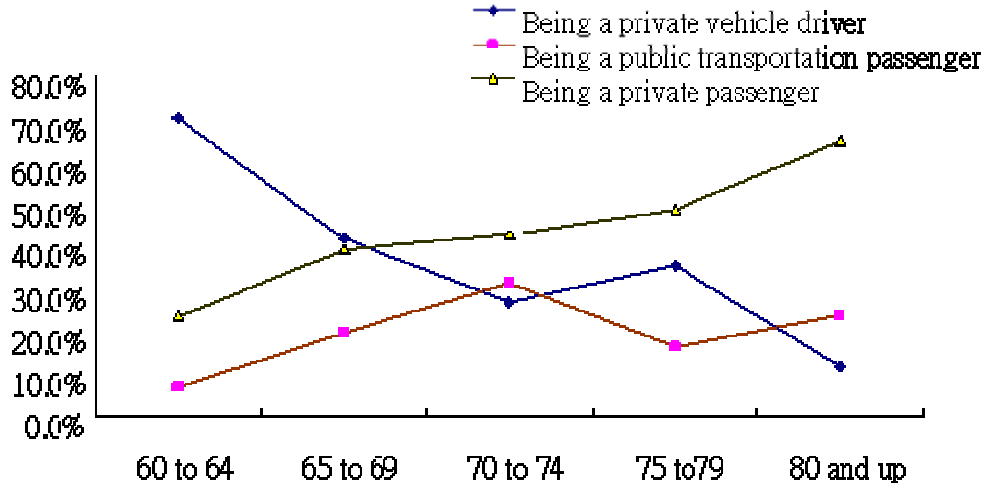


Fig. 1-1 Proportion of mode choice for the Taiwan elderly people at different range of age (Chang and Wu, 2005)

Encouraging younger elderly people to take buses is also regarded as an efficient management of social resource from the viewpoints of whole society. Elderly travelers are seldom peak-hour commuters; their patronage to bus service will effectively make use of the idled capacity of bus system during off-peak hours and bring about significant marginal benefit in saving the social cost of caring themselves. Most of traffic authorities in developed countries have enacted some fare-discount or free-taking acts for encouraging the elderly to patronize the bus service. However, using fare-discount incentives to encourage the elderly to travel by bus is just a naively unilateral willingness since the decrease of physical abilities might hinder the elderly from taking buses and make them select some ways of travel instead. Elderly people, constrained by some forms of physical disability, might also encounter some difficulties in necessary actions or motions when taking buses. If elderly people's concerns in these necessary actions or motions for bus taking can be explored, the traffic authorities or bus service providers can then issue instructions or enhance the facilities or service to provide the elderly with a safer and friendlier environment for bus usage.

1.2 Research Objectives

Traveler behavior is an important issue that has been widely discussed in the transportation research area. The related researchers have paid countless efforts to chase the key for explaining the revealed behavior of an individual. In the 80s, travelers' behavior was mostly discussed under the framework of the random utility theory. Since the 90s, many studies had recognized that some psychological factors, such as attitude, belief, motives, and perception, also play important roles in explaining the choice of a decision maker (Ben-Akiva et al., 1999). Many psychological factors were thus introduced and discussed as the explanatory variables in the discussion of travelers' behavior.

Since the psychological constructs have been recognized as significant factors that influence travelers' behavior, more and more researchers in transportation have put their attentions on the relationship between one's latent consideration and his/her revealed behavior. After plenty of related studies were conducted, one was left to question that: did we obtain convincible and comparable measures on the related latent constructs? Such a challenge on the measurement is critical, especially for those unexplored latent constructs which have no normalized scales (the norms) to serve as a reference of measurement. In practice, researchers usually measure such latent constructs by collecting the respondents' opinions, and these opinions are mostly presented by items with ordinal scales (e.g. the Likert scale) in some formed questionnaires. If these ordinal categories in the items were naively assigned with some incremental integers, such integers can only represent the rank among categories in a single item and has limitations in the statistical inference. For this sake, the whole study is aimed to demonstrate the approaches how to measure a new-specified latent construct, especially for ensuring the assessment on the trait level could serve as reasonable and effective factors for further statistical inference.

In the discussion with vehicle dependence, we would firstly review the development of

the concepts on vehicle dependence from the literatures, and then conceptualized our viewpoint on the vehicle dependence. An appropriate approach to measuring travelers' vehicle dependence was then suggested; we proposed a study based on this approach. For ensuring the idea and the findings would be convincing, an empirical study on the motorcycle dependence of motorcyclists would be then conducted. It was believed that he results of exploring vehicle dependence would benefit researchers in modifying their formulations of mode choice, and policy makers in enacting more effective policies.

In the exploration on perceived physical ability of elderly bus passengers, this study aims to develop an approach to measure the elderly passengers' ability of taking buses and explore the possible difficulties they will face along their bus-taking trips. A conceptualized framework for the actions and motions required for bus taking was first established, and a questionnaire was then designed to collect the required data to evaluate the relative difficulties of these required actions or motions. With an empirical exploration conducted on elderly bus passengers from Taipei, this study introduces a new approach to explore the elderly bus passengers' difficulties in bus taking and is expected to share the experience with other transportation authorities worldwide, who are making efforts to provide a safer and friendlier travel option for the elderly.

Consequently, the main objectives of this study are listed as follows:

(1) Developing a conceptual framework of the vehicle dependence.

(2) Designing an appropriate approach to collect and measure the vehicle dependence under the framework of the psychological exploration.

(3) Conducting an empirical study to verify our conceptual framework on vehicle

dependence.

(4) Interpreting and discussing the results from the empirical exploration on vehicle dependence.

(5) Conceptualizing the contents and measuring the physical abilities perceived by the elderly passengers by applying the Rasch measurement.

(6) Presenting the findings from exploring the elderly bus passengers' concerns on their physical abilities, and recommending the improvements on the facilities or service of the bus systems

1.3 Overview of Thesis

This thesis contains six chapters, which are organized as follows. Chapter 1 introduces our research motivations, objectives, and contributions. Chapter2 presents a brief literature review on both of these two concerned issues. Chapter 3 illustrates our methodology for measuring a latent construct. Chapter 4 demonstrates our exploration on the vehicle dependence. An empirical exploration on the motorcycle dependence in Taipei had been conducted to support our conceptual framework. Chapter 4 demonstrates our measurement of the perceived physical ability of elderly bus passengers. We also conducted an empirical study and interpreted the results into practical suggestions for caring such elderly travelers. At the end of the thesis, we conclude our findings and results from these two topic respectively and give some suggestions on the future study in the Chapter 6.

1.4 Research Contributions

The main contributions of this study could be summarized as follows:

(1) The concept of individual's vehicle dependence in terms of both its socioeconomic and its psychological nature can be conceptualized.

(2) The exploration of vehicle dependence can benefit the related researchers in modifying their formulations of mode choice, and policy makers in enacting more effective policies.

(3) Our concepts and approaches for assessing the level of a single latent construct can serve as a useful example for researchers who have to treat some latent constructs as the influencing variables in their statistical inference.

(4) The realization of the difficulties in the necessary actions or motions that an elderly passenger might encounter when using buses can help to suggest the necessary improvements of facilities and service of bus systems, which provide a safer and friendlier bus service for the elderly travelers.

CHAPTER 2

Literature Review

2.1 Development of the Concept on the Vehicle Dependence

In the Oxford Advanced Learner's Dictionary, there are two meanings for the word "dependence": one is "a state of needing the help and support of somebody/something in order to survive or be successful", and the other is "the state of being addicted to something" Economic considerations are the most common and convincing reasons for travelers' dependence upon specific vehicles (Koppelman, 1981). That is, some travelers are forced to depend on only a specific vehicle because their choice sets are constrained, i.e. they have no other alternative to choose from or their best alternative is out of their acceptable range. The limitations on their choice set may arise from their own abilities (e.g. their ability to operate other vehicles or their ability to afford the cost of using another vehicle) or from environmental conditions (e.g. the lack of a public transportation service). Such travelers are regarded as having structural dependences on a vehicle (Gray et al., 2001), and they are also called "captive riders" (Abe and Sinha, 1973) of that vehicle.

Psychological preferences or considerations also influence travelers' dependence on the usage of vehicles (Fujii and Garling, 2003; Vredin Johansson et al., 2006). Some people depend on a specific type of vehicle because they can receive direct feedback from the use of such a vehicle. For instance, travelers with an enthusiasm for driving automobiles would depend on automobile usage to achieve most of their daily trips. Special preferences or beliefs could also lead a traveler to depend on a specific type of vehicle. For example, travelers who emphasize the value of privacy and comfort during trips would tend to drive or ride in automobiles, and travelers with a strong awareness of environmental issues might tend to use

vehicles which produce little pollution.

People's vehicle dependence is also thought to be a result of habitual behavior (Bamberg et al., 2003; Thogersen, 2006). Habitual behavior can be formulated into two processes: initiation and persistence (Ronis et al., 1989). During the stage of initiation, decisions are still made rationally. However, when the same behavior has been repeated for long enough, decisions that have been made become automatic and habitual as a result of a persistence process. Decision makers then make choices without evaluating any alternatives but just on the basis of their prior experience (Betsch et al., 1998). Chen et al. (2004) showed that travelers' activity rescheduling behavior is mostly habitual behavior. Travelers who habitually choose one vehicle for routine trips will keep choosing that vehicle until the stimuli (e.g. bad experiences) are strong enough. Travelers' dependence on such vehicles will thus generate a persistence process.

There have been similar formulations of vehicle dependence (mostly automobile/car dependence) in earlier studies. Dupuy (1999) indicated that the expression "automobile dependence" meant that an individual could not live without a car, just like a smoker who cannot live without cigarettes or a drug addict who is unable to live without drugs. His definition implied that automobile dependence could be an individual's subjective consideration, somehow beyond full rationality. Goodwin (1995) indicated that the generation of car dependence is a process influenced by travelers' subjective perception of their daily car usage: if the feedback from their car-driving experience is considered positive, people become more dependent on car usage unawares. His definition is consistent with the argument that vehicle dependence might arise from habitual behavior.

The Transport Studies Unit (1995) at Oxford University conducted research on car

dependence and indicated that car dependence may contain two elements: the absolute need for a car in order to maintain mobility without any other available option, and the perception of reliance on a car without actively considering the alternatives. This viewpoint is similar to our concept that the vehicle dependence of travelers arises from three types of reasons: economic considerations, psychological preferences, and habitual behavior. Overall, vehicle dependence could be interpreted as a level of reliance on a specific vehicle usage which is gradually developed as a consequence of travelers' economic concerns, psychological preference, and habitual behavior. Although vehicle dependence has been discussed in previous studies, however, no quantitative method to evaluate it among people with various personal characteristics has been tried. This might be the reason why the idea of vehicle dependence has not been applied to provide any useful information in the area of the description and prediction of mode choice.

2.2 Conceptual Framework of the Perceived Physical Ability of the Elderly Passengers When Using Buses

Even though the elderly bus passengers need not deal directly with the complicated traffic; they still have to maintain some physical abilities in order to travel by bus. In other words, if driving an automobile on the road is considered as a tough test for elderly travelers to coordinate the vehicle and traffic conditions with their human factors, then taking buses might be regarded as a relative easy test for them in terms of the necessary actions or motions in approaching the stations, traveling on the routes, and approaching the destination. Based on the required actions or motions on a bus trip, 18 items are conceptually collected and shown in Fig 2-1 for discussions as follows.

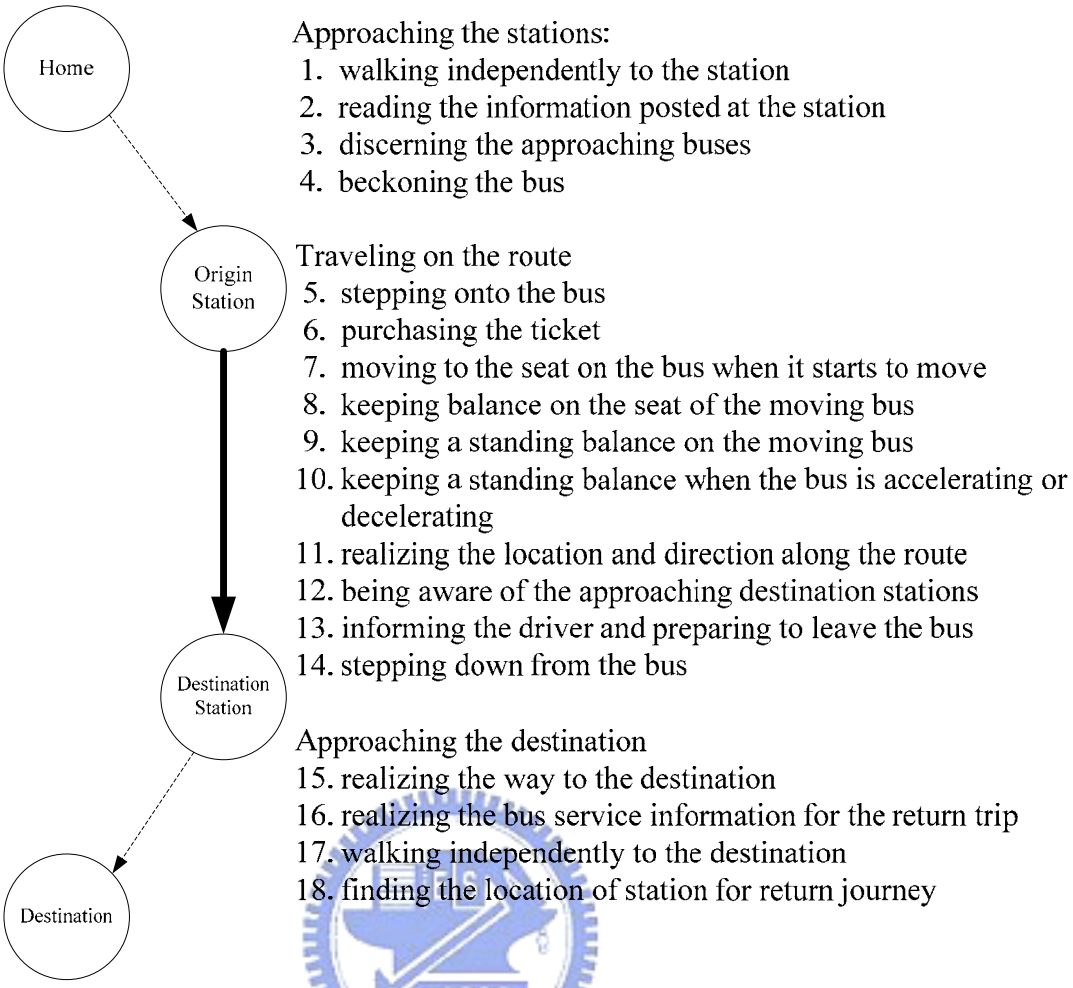


Fig 2-1. A conceptual framework for the required actions or motions when using buses

As shown in Fig 2-1, items in the process of bus taking can be simply divided into three stages. At the stage of approaching the station, four items need to be achieved: “walking independently to the station”, “reading the information posted at the station”, “discerning the approaching buses”, and “beckoning the bus”. Items at this stage would mainly demand elderly passengers’ physical strength and their visual abilities. Previous studies have shown that elderly people are proved to have about 12–15% less muscle strength than young people (Blocker, 1992). Arthritis also commonly occurs in the elderly population (Yee, 1985). The muscle strength will influence the elderly people’s ability to walk independently to the station. Older people also tend to have a smaller useful field of vision than younger people (Sekuler

and Ball, 1986), and the gradual degradation of eye muscle over time will influence their ability to focus on the objects at a distance or under a poor lighting condition. As a result, their poor visual ability is expected to worsen the elderly passengers' ability to read the information at the station and discern the approaching buses, more than that, it might deter them from signaling to the approaching bus drivers.

At the stage of traveling on the route, the elderly travelers might encounter the following ten items to be dealt with: "stepping onto the bus", "purchasing the ticket", "moving to the seat on the bus when it starts to move", "keeping balance on the seat of the moving bus", "keeping a standing balance on the moving bus", "keeping a standing balance when the bus is accelerating or decelerating", "realizing the location and direction along the route", "being aware of the approaching destination stations", "informing the driver and preparing to leave the bus", and "stepping down from the bus". These ten items will demand the elderly passengers' physical strength, cognitive abilities, and sense of direction. It has been proved, that the speed of contraction and muscle coordination for elderly people are significantly slower than those of young people (Blocker, 1992), which may influence elderly people's motion in stepping up and down from the vehicles. Joint flexibility declines by nearly 25% in older adults (Smith and Sethi, 1975), which may decrease their ability to retain their balance on the moving buses. It was found that the general cognitive ability of an elderly person would worsen (Kelsey, 1989), reaction time would become longer (Retchin et al., 1988), and the ability to navigate would probably be reduced by the loss of cognitive abilities (Manton, 1989).

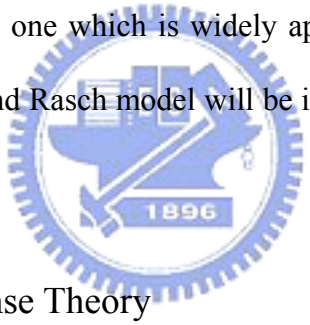
At the stage of approaching the destination, another four possible items need to be achieved: "realizing the way to the destination", "realizing the bus service information for the return trip", "walking independently to the destination", and "finding the location of the

station for the return journey". These four items will demand elderly passengers' physical abilities to achieve the final access to the destination and to prepare the necessary information for the return journey. Such physical abilities are also much related to the visual abilities, cognitive abilities, and physical strength that we have already discussed.

CHAPTER 3

Methods for Measuring a Latent Trait

From the illustration of conceptual frameworks, vehicle dependence and perceived physical ability of elderly bus passengers can be respectively conceptualized as two specific latent constructs of the related travelers. In this chapter, we would introduce the psychological viewpoints on measuring a latent construct. The item response theory (IRT), which is a model-based measurement in which trait level estimates depend on both persons' responses and on the properties of the item that were administered, has become the mainstream of the psychological measurement (Hambleton and Swaminathan, 1991). Among the various models of IRT, the Rasch model is the one which is widely applied for exploring the psychological construct. The review of IRT and Rasch model will be illustrated in the following parts of this chapter.



3.1 Review of Item Response Theory

Psychological constructs are usually conceptualized as latent variables that underlie behavior. Latent variables are assumed as unobservable entities that influence the manifest variables (e.g. test scores or item responses). Thus the observation on these manifest variables can only serve as indicators of a person's standing on the latent variable. As a result, measurements of psychological constructs are usually indirect, that is, latent variables are measured by observing behavior on relevant tasks or items. A measurement theory in psychology must provide a rationale that both persons and items on a psychological dimension should be inferred from behavior. Based on such a rationale, the item response theory has been elaborated to serve as a methodology in developing or executing a psychological test.

The item response theory is a measurement method which was developed to estimate the values of latent variables on an interval scale from item scores on an ordinal scale. In the original response data, the sum of scores across items for each person is referred to as the person raw score, and the sum of the scores across people for each item is called the item raw score. Discussions of item response theory are based on the Guttman scale (Guttman, 1950). A Guttman scale means that item raw scores are monotonic with item difficulties, and person's raw scores are monotonic with the person's abilities. If the raw scores form a unidimensional ordinal scale, then when the data are displayed with the items ordered according to item raw scores, and with the persons ordered according to person raw scores, such a data matrix will conform to a Guttman scale. For a data matrix which fits Guttman scale perfectly, the abilities of people are ranked by the person raw scores and the difficulty of the items are ranked by the item raw scores; the ranking of people will be the same for each item and the ranking of items will be the same for each person. In reality, however, such a rigid rule is hard to achieve because of some unexplored randomness. Thus, in applying item response theory, some violations of Guttman scales are allowed, but the overall statistical pattern of responses should agree with these expectations. The more closely the data fit a Guttman scale, the more likely that the raw scores represent an ordinal scale.

Item response theory begins with a definition of the latent variable, θ, which is supposed to be measured. This variable θ_n must be an attribute of the respondent and will have a unique value for each respondent n. In item response theory, each item is supposed to require a specific value (threshold) of θ to elicit a particular response from the respondent 50% of the time. Such a response threshold for item i, b_i, is assumed in the same unit as θ. The probability that respondent n will give a particular response to item i, $P(\theta_{ni})$, can be modeled in a logistic form as Eq (1):

$$P(\theta_{ni}) = c + \frac{d-c}{1+e^{-a_i(\theta_n - b_i)}} \quad (1)$$

where d is the upper performance asymptote ($0 < d \leq 1$), c is the lower performance asymptote ($0 \leq c < 1$), and a_i represents the slope of the item response function (Birnbaum, 1968). In earlier educational applications, the parameter c usually refers to the chance performance, d usually refers to a possible careless response error, and a_i is the discriminability of item i. In this study in our applications on self-rated responses, there is no "right" or "wrong" answer; thus we assume that c is equal to 0 and d is equal to 1 in Eq(1). In Birnbaum's formulations, the parameter of discriminability, a_i, is designed to absorb the variability and to create the illusion of precise estimation of person and item values. As previously illustrated, a perfect Guttman scale is hard to achieve, and minor violations are allowed in practice. Measurement noise can be due to instability in person abilities, in item difficulties, or in both. It can also be attributed to variables that are not being studied. In our case, we define $a = 1$ to keep an invariance across the items, which enables our items to be interpreted as measurements of a single variable.

The simplified item response model ($d = 1$, $c = 0$, and $a_i = 1$) in our case is identical to the probabilistic measurement model developed by Georg Rasch (Rasch, 1960). He deduced his model from the item response theory (Andersen, 1995), and proved that the person and item parameters (θ_n and b_i) are separable, and that item and person raw scores are sufficient statistics to estimate the values of the item and person parameters. Since the 1980s, Rasch models have been intensively used to estimate values on an interval scale from raw scores in psychometric studies.

3.2 Brief Introduction of the Rasch Model

3.2.1 Formulation of the Rasch model

The Rasch model has been intensively used to estimate values on an interval scale from raw ordinal responses in psychometric studies (Fisher et al., 1995; Massof and Fletcher, 2001). To simplify our introduction of the Rasch model, we shall consider only the dichotomous responses to begin with.

Taking the elderly bus passengers' ability as an example, the questions are assumed to be the type of "Can you easily achieve the following necessary action or motion?" The response is either "yes" or "no". A score of 1 is assigned to an item to which the traveler responds "yes, I can"; otherwise, a score of 0 is assigned. The probability that an elderly passenger n will respond with "yes, I can" for item i is expressed as

$$P(1|\theta_n, b_i) = \frac{e^{\theta_n - b_i}}{1 + e^{\theta_n - b_i}} \tag{2}$$

and the probability that an elderly passenger n will respond with "no, I can't" for item i is then expressed as

$$P(0|\theta_n, b_i) = 1 - P(1|\theta_n, b_i) = \frac{1}{1 + e^{\theta_n - b_i}} \tag{3}$$

therefore, the odds ratio that an elderly passenger n can achieve item i is

$$\frac{P(1|\theta_n, b_i)}{P(0|\theta_n, b_i)} = e^{\theta_n - b_i} \tag{4}$$

and the logarithm of the odds ratio, known as the "logit", is

$$\ln \frac{P(1|\theta_n, b_i)}{P(0|\theta_n, b_i)} = \theta_n - b_i \tag{5}$$

which isolates the parameters of interest.

The person and item parameters in the case of dichotomous responses can be estimated from the response odds ratios in the data set using the formulation of Eq. (5). In addition to dichotomous responses, the Rasch model has been modified to be applicable to polytomous rating-scale instruments, such as the five-point Likert scale (Andrich, 1978; Masters, 1982). The modified Rasch model decomposes a polytomous response into several dichotomous responses and formulates one multinomial-choice problem into several binary-choice problems. That is, it assigns b_{ik} as the value of the item parameter for the rating category k to item i, and assumes that Eq. (2) refers to the probability of subject n responding with rating category k rather than $k-1$ to item i. In other words, we can model the log odds of the probability that a person responds in category k for item i, compared with category $k-1$, as a linear function of the person parameter θ_n and the relative parameter of category k, namely b_{ik}, for item i

$$\ln\left(\frac{P_{nik}}{P_{ni(k-1)}}\right) = \theta_n - b_{ik} \tag{6}$$

Following Andrich's modification of the Rasch model for a polytomous response, two types of formulation are widely applied in assessing the values of item and person parameters, namely the "rating scale model" and the "partial-credit model". The rating scale model is used only for instruments in which the definition of the rating scale is the same for all items, while the partial-credit model is used when the definition of the rating scale differs from one item to

another. Specifically, the partial-credit model is similar to the rating scale model except that each item i has its own threshold parameters F_{ik} for each category k (Wright, 1977). This is achieved by a reparameterization of Eq. (6)

$$b_{ik} = b_i + F_{ik} \tag{7}$$

and the partial-credit model becomes

$$\ln\left(\frac{P_{nik}}{P_{ni(k-1)}}\right) = \theta_n - b_i - F_{ik} \tag{8}$$

The partial-credit model (Masters, 1982) is used for items where: (1) credits are given for partially correct answers, (2) there is a hierarchy of cognitive demand on the respondents for each item, (3) each item requires a sequence of tasks to be completed, or (4) there is a batch of ordered response items with individual thresholds for each item. In exploring the latent constructs, it is not necessary to assume that the rating scales of the items are the same, and thus the partial-credit model would be suggested for the proposed empirical studies.

3.2.2 Parameter estimation of the Rasch model

Based on different statistical assumptions, there are several approaches for estimating the parameters of Rasch model. Among them, the joint maximum likelihood (JML) estimation is a relative simple and effective way, which is also the core technique of the related computer programs: the WINSTEPS and FACETS (Linacre and Wright, 1997). A simple introduction of the JML estimation is given as follows.

In JML estimation, unknown construct levels are handled by using provisional trait level estimates as known values. The provisional trait level estimates themselves are

improved by using subsequently estimated item parameters, which are successively improved. In other words, JML estimation is an iterative procedure which typically involves sequential estimates of person and item parameters. In the initial stage, person parameters are estimated. The first iteration of the two-stage procedure involves specifying starting values for the item parameters so that the maximum likelihood estimates of person parameters can be obtained. Then the item parameters are estimated using the first person-parameter estimates. In the following iterations, person and item parameters are iteratively estimated using the improved person or item parameters respectively. The iterations continue until the item parameters change very little between the successive iterations (the convergence status).

JML has been extensively applied in the estimation of many IRT models. It has several advantages in applications. First, this algorithm is easily programmable. Second, JML is applicable to many IRT model. Both the 1PL IRT (e.g. the Rasch model) and 2PL IRT (e.g. the Multi-Facet Rasch Model) can be estimated with JML. Third, JML is efficient on computation. One thing has to be noted in applying the JML estimation that there is a strong limitation of in applying JML algorithm. In JML estimation, the items or persons with perfect scores (all passed or all failed) provides no information about the parameters because there are no constraints are placed on the solution (Holland, 1990). Therefore, estimates of such items or persons with perfect scores are not available in the JML estimation. In fact, such measures of items or persons with perfect scores mostly occur on the data of the educational tests but rarely in the psychological exploration. In the psychological exploration, items with perfect scores are regarded as inappropriate items because they provide no information on evaluating construct levels of the respondents; person with perfect scores can be also considered as a ineffective observation for their construct level are not comparable. It is generally suggested to exclude these items or persons from the original data, or to withdraw the data and redesign the whole investigation program.

3.2.3 Reliability and validity statistics in the Rasch model

In latent construct measurement, reliability indices help us to examine whether or not the model is convincing and the material is replicable, and validity indices help us to examine whether or not the properties of our material are consistent with the assumption of the measurement. In Rasch model, indices of reliability and validity are calibrated respectively via person and item aspects (Wright and Master, 1982) to provide the critical proofs on the quality control of data. We would give a brief introduction of these two indices of Rasch measurement in the following paragraphs.

Reliability in latent construct measurement is commonly defined as the consistency of the responses to a set of items or the consistency of scores from the same instrument. Following such concept, reliability index R in the Rasch model is defined as the degree to which scores are free from measurement errors (Andrich, 1988). As a result, the reliability estimate for persons (R_p) is shown (Bond &Fox, 2001) as follows:

$$R_p = \frac{SA_p{}^2}{SD_p{}^2} \tag{9}$$

the total person variability ($SD_p{}^2$) represents how much respondents differ on the measure of interest. The adjusted person variability ($SA_p{}^2$) represents the reproducible part of this variability (i.e. the amount of variance that can be reproduced by Rasch model). This reproducible variability is divided by the total person variability to obtain the person reliability estimate (R_p) with values ranging between 0 and 1, which is consistent to the concept as Cronbach's α (Wright, 1996).

On the other hand, reliability for items (R_I) is estimated in the same manner as for persons, with item variance being substituted for person variance:

$$R_I = \frac{SA_I^{\,2}}{SD_I^{\,2}} \tag{10}$$

where the total item variability ($SD_I^{\,2}$) represents how much items differ on the measure of interest. The adjusted item variability ($SA_I^{\,2}$) also represents the proportion of total item variability that can be reproduced by the Rasch model.

The Rasch model is regarded as a prescriptive rather than a descriptive approach (Bond, 2001). That is, the data must fit the model, or the assumptions of the model must be rejected for a particular data set, i.e., the degree to which the previously described properties hold depends on how closely the data fit the model. With the comparison between the observed and expected patterns, two fit statistics, namely information-weighted fit ("infit") and outlier-sensitive fit ("outfit") (Smith, 1991), are generated to evaluate the validity in the Rasch model. An overview of the derivation of fit statistics is summarized in following paragraphs.

Based on the estimated parameters, each observation for person n on item i with K categories (denoted as X_{ni}, X_{ni} = k if the kth category is chosen), has its expected response value E_{ni}:

$$E_{ni} = \sum_{k=1}^{K} k(P_{nik}) \tag{11}$$

where k (k =1,2,…,K) represents the category k of item i and P_{nik} is the probability of person n being observed in category k on item i. The variance W_{ni} and the standardized

residual Z_{ni} of each observation X_{ni} are then obtained:

$$W_{ni} = \sum_{k=1}^{K} (k - E_{ni})^2 P_{nik} \tag{12}$$

$$Z_{ni} = \frac{X_{ni} - E_{ni}}{\sqrt{W_{ni}}} \tag{13}$$

These standard residuals are squared and summed to form a chi-square statistic. With divided by total observation number N , the Mean-square Outfit statistic is then obtained.

$$\sum_{n=1}^{N} Z_{ni}^{\ 2} \sim \chi_{(N)}^{\ 2} \tag{14}$$

$$\text{Mean-square Outfit} = \frac{\sum_{n=1}^{N} Z_{ni}^{\ 2}}{N} \tag{15}$$

In addition to the Outfit statistic, the Infit statistic weighs the squatted standardized residual Z_{ni} by their individual variance W_{ni}. It can be calculated as:

$$\text{Mean-square Infit} = \frac{\sum_{n=1}^{N} W_{ni} \times Z_{ni}^{\ 2}}{\sum_{n=1}^{N} W_{ni}} \tag{16}$$

The main difference of these two fit-statistics is the outfit statistic place more emphasis on unexpected responses far from a person's or item's measure, while infit place more emphasis on unexpected responses near a person or item's measure (Bonds, 2001). The expected values

of these two Mean-square fit statistics are 1, and the guideline for determining unacceptable departures from expectation remains many discussions (Smith et. al, 1995). To achieve a more generalized standards, both the outfit and infit can be further expressed as normalized residuals (Zstd) via a transformation into a t-statistic with an approximate unit normal distribution (Wright & Stone, 1979). Such a Zstd (Z-standardized fit) statistic has an expected value at 0 and a variance as 1, which has previously been used to select items at the 0.05 significance level and according to the ± 2 criteria.

CHAPTER 4

Exploring the Vehicle Dependence behind Mode Choice: Empirical Evidence of Motorcycle Dependence in Taipei

According to the prior discussion, vehicle dependence could be thought of as a latent construct of a traveler that represents the traveler's reliance on a specific vehicle as a consequence of economic concerns, psychological preference, and habitual behavior. How to gather the necessary information and design a measuring tool to evaluate travelers' vehicle dependence to make our idea operational is another issue, which we consider below.

4.1 Questionnaire Design for Gathering Vehicle Dependence

Latent constructs are commonly explored by means of questionnaires that include appropriate items that respondents can answer on the basis of their daily life experience. Since there was no available questionnaire to follow, we had to design our own questionnaire for our study. Essentially, people use and depend on vehicles to meet the needs of their daily activities, and the significant relations between travelers' mode usage and their participation in activities have been widely investigated and discussed (Kitamura, 1988; Pas, 1996). As a result, the need to have a specific vehicle to participate in various possible activities was thought to define the appropriate items in the questionnaire to explore a traveler's dependence on that vehicle. Because the travelers' answers to the items would be given on the basis of their daily travel experience, and depend on subjective judgment and objective constraints, the responses could then be used to reflect the travelers' latent trait of dependence on that specific vehicle.

In psychometric questionnaires, the questions should motivate and guide respondents to

express their real considerations and judgments. Therefore, our questionnaire on vehicle dependence would need to be designed to let the respondents express precisely their reliance on a specific vehicle for performing their daily activities. According to our observations, travelers might find it hard to express how they depend on a specific vehicle for their daily trip purposes because they are unaware of their vehicle dependence. However, it might be easier for them to answer how bothersome it would feel if they were not allowed to use a specific vehicle to undertake specific activities. This provided us with a better measuring tool to gather the information from travelers to capture their dependence on specific vehicles.

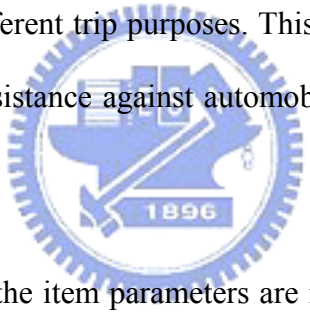
Furthermore, respondents' answers to the questions in our design did not usually have to be simply "yes" or "no". A well-designed questionnaire should provide an opportunity for respondents to express the degree of their feeling or judgment about the items referred to. Therefore, the questions designed to measure the latent construct of vehicle dependence included suggested answers on an ordinal scale, with several categories that represented the respondent's possible level of judgment.

4.2 Concept for Applying the Rasch Model for Measuring the Vehicle Dependence

Presumably, every traveler n has a unique value of his/her dependence on a specific vehicle θ_n, which is the person parameter to be measured. Such a latent trait can be revealed by the person's answers. That is, travelers who have higher dependence on a vehicle will respond with high scores (i.e. a high level of vehicle dependence) on a greater number of items than will those with lower dependence. In addition, travelers' dependence on a specific vehicle could be different for various activities (i.e. trip purposes). Some trip purposes might be more suitable than others for a specific vehicle usage. Thus, travelers' vehicle dependence for two types of trip purposes could be different (e.g. bicycle riding might be depended on for

achieving in-town travel but not for intercity travel). Such properties for each trip purpose (i.e. the item parameters) can be regarded as an inherent resistance against travelers' vehicle dependence. It can be assumed that each item (trip purpose) i has a unique resistance parameter b_i. The items with lower resistance parameters b_i are those trip purposes which are inherently suitable for a specific vehicle usage. Therefore, there would be more responses indicating high dependence for those items.

Taking automobile usage as an example, a simplified diagram illustrating this concept is shown in Fig. 4-1. The right-hand side of Fig.4-1 presents the relative levels of automobile dependence of three travelers. Joe has the highest automobile dependence, and Tom has the lowest. The left-hand side of Fig. 4-1 shows the relative inherent resistance against automobile driving for two different trip purposes. This example indicates that commuting in congested traffic has higher resistance against automobile driving than has weekend outdoor travel.



Under the assumption that the item parameters are independent of the person parameters, some conclusions could then be drawn from the information provided in Fig. 4-1. Namely, all three travelers are more likely to drive an automobile for weekend outdoor travel than for commuting in congested traffic, because the former has lower inherent resistance against dependence on automobile driving. On the other hand, the tendencies to drive an automobile are in the order Joe, Mary, and Tom, from high to low, no matter whether for commuting in congested traffic or for weekend outdoor travel, on the basis of the magnitudes of their dependence on an automobile. If we consider the above characteristics, it is apparent that the difference between the person parameter θ_n and the item parameter b_i will determine the tendency of traveler n to depend on a given vehicle for achieving trip purpose i. This tendency could then be formulated as a function of a probability and determined by the value of

$\theta_n - b_i$.

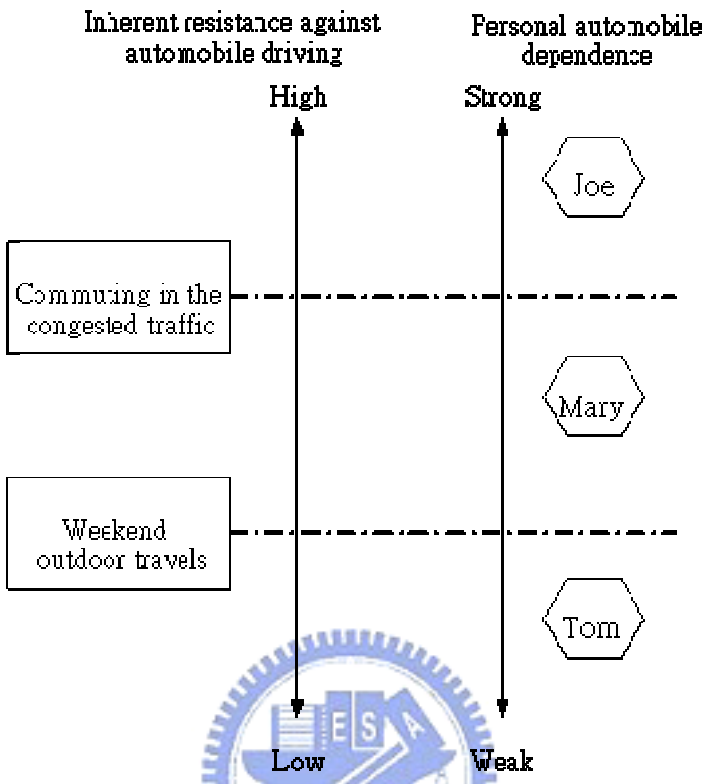


Fig. 4-1 Conceptual example of travelers' automobile dependence, and inherent resistance against automobile driving for various trip purposes.

In order for us to provide a theoretical basis for comparisons, the person parameters (vehicle dependence) and item parameters (inherent resistance against vehicle dependence) must be measured on a consistent interval scale. However, all of the responses of travelers to the questionnaire were collected on an ordinal scale in order to provide room for respondents to describe their judgments more precisely. Therefore, the Rasch model to convert the ordinal raw data into data on an interval scale was applied in the following analysis.

4.3 Design of the Empirical Exploration on Motorcycle Dependence

To demonstrate our conceptual framework and measurement approach for vehicle dependence, an empirical study was performed to explore motorcyclists' dependence on

motorcycle usage in Taipei, Taiwan. Motorcycles are used intensively as a mode of daily road transportation in Taiwan and some other Asian countries. In addition to identifying and measuring the motorcycle dependence of motorcyclists, we also expect that our findings for Taipei could serve as reference information for traffic authorities in other areas where motorcycles are intensively used.

4.3.1 Background on transportation in Taipei

Taipei, the political and commercial center of Taiwan, has an area of 272.80 square kilometers, in which nearly 4.5 million people (Official Statistics, 2005) live or travel every day. To provide residents and visitors with efficient travel inside this intensively occupied city, Taipei offers a high-density public transportation service, including mass rapid transit (MRT), commuter rail, buses, and taxis. However, it still encounters daily traffic congestion in rush hours, just like many other metropolises around the world. According to official statistics, households in Taipei possess 1.17 motorcycles and 0.49 automobiles on average; 28.72% of people in Taipei travel by automobile, 32.34% of people travel by motorcycle, 30.58% of people travel by public transportation, and the remainder travel by taxi, bicycle, or walking. The common use of motorcycles results in many problems in traffic engineering, management, and safety (Chang, 2002); worst of all, it reduces the effectiveness of investment in public transportation.

The Taipei traffic authorities have enacted many policies to encourage motorcyclists to travel by public transportation instead of by motorcycle (e.g. exclusive bus lanes, discounts on public transportation fares, and motorcycle parking charges around the commercial area). However, the usage of motorcycles has still been growing steadily in recent years (Chang and Yeh, 2007). This hints that people in Taipei have a strong dependence on motorcycle usage, and such motorcycle dependence might arise not merely from economic considerations, but

also mental preferences or habitual behavior.

4.3.2 Empirical questionnaire design

A questionnaire was designed (as shown in Table 4-1), in terms of eight items which represented the most common activities that attracted people to ride motorcycles, in order to explore motorcyclists' dependence on motorcycle usage in Taipei.

Table 4-1 Content of the questionnaire for motorcycle dependence

Variable/question	Type
Items to explore self-rated dependence:	
How bothersome will it feel if you cannot ride a motorcycle to achieve the following trips in Taipei city?	
Item 1: trips necessary for work or for visiting businesses	5-point scale
Item 2: trips for commuting to/from workplace	5-point scale
Item 3: trips for multistop street shopping	5-point scale
Item 4: trips for participating in recreational activities	5-point scale
Item 5: trips for visiting relatives and friends	5-point scale
Item 6: trips for achieving travel in a limited length of time	5-point scale
Item 7: trips for achieving occasional travel requirements	5-point scale
Item 8: trips for loitering around the streets without a specific purpose	5-point scale
Respondent's personal characteristics	
Age	Numeric response
Gender (male, 0; female, 1)	Binary response
Monthly income (in NTD)	Open response
Dual-mode user (yes, 1; no, 0)	Binary response
Exclusive automobile parking space (owned, 1; otherwise, 0)	Binary response

The respondent motorcyclists were asked to answer how bothersome it would feel if they could not ride their motorcycles in Taipei City to achieve the respective eight possible trip purposes. In addition to these items designed to measure motorcycle dependence, some characteristics of the respondents were also included in the questionnaire. These were age, gender, monthly income, whether the respondent was a dual-mode user (i.e. whether he/she

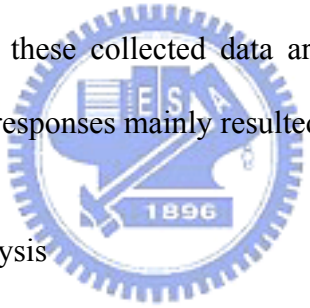
drove an automobile as well or not), and the ownership of exclusive automobile parking space (i.e. whether the respondent motorcyclist had his/her own automobile parking space or not). The reason for investigating dual-mode user status and parking space ownership arises from the competing usage between these two private vehicles. Some people in Taipei own and use both an automobile and a motorcycle for their daily trips; such travelers are referred to as dual-mode users in the following discussion.

Item 1 was designed to explore how motorcyclists depend on motorcycles for trips related to work or to visiting businesses; Item 2 was aimed at collecting information about motorcyclists' motorcycle dependence for commuting purposes; Item 3 was designed to find out how motorcyclists depend on motorcycles for multistop shopping in the streets; Item 4 was designed to explore motorcyclists' dependence on motorcycles for participating in recreational activities; Item 5 was designed to show the extent to which motorcyclists need to ride motorcycles to visit their relatives and friends in Taipei; Item 6 was designed to show the extent to which motorcyclists count on motorcycle riding for achieving particular journeys in a limited length of time; Item 7 was designed to explore motorcyclists' motorcycle dependence for occasional travel demands, such as accessing a transit station or picking up visitors; and Item 8 was designed to see how motorcyclists depended on their motorcycles for no specific trip purpose but just for loitering around the streets. All of these eight items were answered on a five-point Likert scale, namely "not bothersome at all," "a little bothersome," "bothersome," "strongly bothersome," and "very strongly bothersome." The responses in these five categories, from "not at all" to "very strongly," for each item, represented the motorcycle dependence, from low to high, respectively.

4.3.3 Data collection

The data for this empirical study were collected by investigating 321 motorcyclists

selected randomly in Taipei. The respondents' self-rated dependence for each item and their personal characteristics were gathered through completing the questionnaire with the assistance of well-trained investigators. Of these 321 motorcyclists, 187 (58.3%) were male and 134 (41.7%) were female; their average age was 28.7 years; and their average monthly income was about 28,000 NTD. There were 167 (52.0%) respondents who also traveled by driving, and only 43 of them had their own automobile parking spaces. The distributions of the respondent motorcyclists' gender and age were compared with those of registered motorcyclists published in official statistics, and no significant differences were found at $\alpha = 0.05$. It was believed that the sampled motorcyclists could reasonably represent the population. Inspection on the uni-dimensionality of the data via factor analysis was conducted. The first factor explained 81.2% of total variance while the second factor only explained 12.7% of total variance. Thus these collected data are suitable to apply the Rasch model because the information of the responses mainly resulted from one single latent construct.



4.3.4 Application of Rasch analysis

The Rasch measurement model provides a means for constructing interval measures from raw ordinal category data. On the basis of the Rasch model, a value on an interval scale was estimated for each item (i.e. the item parameter) and for each respondent (i.e. the personal parameter). The responses of the 321 motorcyclists for the eight items were analyzed with WINSTEPS (Linacre and Wright, 1997), an iterative computer program, which estimated θ_n for motorcyclist n and b_i for item i in logit units. WINSTEPS helps to deal with polytomous responses by applying the Masters–Andrich modification (Masters, 1982) of the Rasch model. The estimated parameters and model fit statistics could be therefore calibrated via a joint maximum-unconditional-likelihood estimating procedure (Wright, 1996).

The estimated parameters and fit statistics of our whole Rasch model are shown in Table 4-2. The Rasch assessment fixed the average measure of all item parameters at zero logit to be a comparative basis of the relative interval scale; the average value of the vehicle dependence of all of the motorcyclists was 1.46 logit. Such a positive value indicates that these motorcyclists generally depend on motorcycles highly. Before we start detailed discussions and interpretations of the estimated item and person parameters, however, the reliability and validity of this Rasch model must be discussed first.

Table 4-2 Model estimation and fit statistics obtained from Rasch analysis

Items: 8 input, 8 measured						Item reliability: 0.97
	Raw score	Number of observations	Measure	Standard error	Infit Zstd	Outfit Zstd
Mean	1207.2	321	0.0	0.54	0.0	0.1
Persons: 321 input, 321 measured						Person reliability: 0.81
	Raw score	Number of observations	Measure	Standard error	Infit Zstd	Outfit Zstd
Mean	30.1	8	1.46	1.45	–0.1	–0.1

Reliability is commonly defined as the consistency of the responses to a set of items or the consistency of scores from the same instrument. It is also defined as the degree to which scores are free from measurement errors. The WINSTEPS program provided reliability information for both items and persons, as shown in Table 2. The person and item reliability coefficients can be interpreted similarly to a Cronbach alpha reliability coefficient for the internal consistency of responses to items (Wright, 1996). The personal reliability index of 0.81 and item reliability index of 0.97 indicate that the data here are consistent with the assumptions of the Rasch model from the viewpoints of both items and persons.

Validity refers to the creation or selection of items to measure the same construct in

performing a measurement of a latent characteristic. The validity information is expressed by the fit statistics in a Rasch measurement. With the help of a comparison of the expected and the observed patterns, the fit statistics aid in quality control and in identification of data which do not meet the requirements of the model. Two fit statistics were estimated by WINSTEPS, namely an information-weighted fit ("infit") and outlier-sensitive fit ("outfit") (Smith, 1991). The infit and outfit are expressed as normalized residuals in Table 2. The *Z*-standardized fit statistic (Zstd) has previously been used to select items at the 0.05 significance level and according to ± 2. In our model, the infit and outfit statistics of the estimated parameters for both persons and items are all near to zero, which implies that the overall validity of our model is acceptable.

4.4 Findings and Interpretations

4.4.1 Findings for item parameters

Estimates of the item parameters are displayed in Table 4-3. The first column contains a description of each item; the second contains the raw score (a linear combination of item scores) for each item; the third shows the estimate for each item; and the fourth and fifth show the infit and outfit statistics, which provide the evidence to determine the validity for each item. The fit statistics for these eight items are all in the range ± 2, which implies that the item responses do not deviate significantly from the assumptions of the Rasch model. The items in Table 4-3 have been ordered by their estimated values for comparison purpose.

It is important to notice that all estimates from a Rasch model are relative. It is generally suggested that the average for all item estimates should be fixed at zero logit, and therefore the estimates for each respective item and person have been calibrated with reference to that average item estimate. The items with lower raw scores are those trips which are generally

considered as less bothersome when motorcycle riding is not available. Such trip purposes would be assessed as having higher estimates of their item parameters, which can be interpreted as meaning that those trips would have higher inherent resistance against dependence on motorcycle riding and people would tend not to travel by motorcycle. In contrast, items with higher raw scores would be assessed as having lower estimates of their item parameters, which can be interpreted meaning that these kinds of trips would have lower inherent resistance against dependence on motorcycle riding and would tend to attract people to travel by motorcycle.

Table 4-3 Estimates of item measures and fit statistics from Rasch analysis

Item	Raw score	b_i	Infit Zstd	Outfit Zstd
Item 3: trips for multistop street shopping	1384	–0.81	–1.4	–1.7
Item 8: trips for loitering around the streets without a specific purpose	1320	–0.49	–2.0	–1.9
Item 7: trips for achieving occasional travel requirements	1294	–0.32	–0.4	–1.0
Item 2: trips for commuting to/from workplace	1291	–0.29	1.6	1.9
Item 6: trips for achieving travel in a limited length of time	1230	0.02	1.2	1.3
Item 4: trips for participating in recreational activities	1103	0.50	0.6	0.9
Item 1: trips necessary for work or for visiting businesses	1099	0.59	–1.4	–1.3
Item 5: trips for visiting relatives and friends	1069	0.79	1.1	1.6

The item parameter estimates for the eight trip purposes are shown in Table 4-3. The study results show that Item 3 has the lowest value of the item estimate, which indicates that multistop street shopping trips have the lowest resistance against dependence on motorcycle riding, and will attract people to travel by motorcycle most and induce the highest motorcycle dependence. The scarcity of automobile parking spaces near roadside stores forces people not to approach them by car, and the long distance that people have to walk results discourages

them from going there by public transportation. Motorcycle riding provides riders with convenience in accessing each stop of their shopping tour. Therefore, motorcycle riding has a dominant superiority over automobile driving and public transportation usage for the purpose of multistop street shopping, and this might be the reason why multistop street shopping is the most important activity in inducing people's motorcycle dependence in Taipei.

Items 8, 7, and 2 are the other three items with negative values of the item parameter. This indicates these three kinds of trips also have a relatively low resistance against dependence on motorcycle riding and may induce motorcycle dependence in the long run. Motorcycle riding provides maneuverability that is advantageous for loitering around the streets without a specific purpose. Riders can easily ride or stop their motorcycles on main streets or minor alleys in the city. In the case of occasional travel requirements, the convenience of riding a motorcycle provides people with much flexibility to meet their needs. Some motorcyclists depend on motorcycle riding to commute, for it enables them to escape from jammed traffic more easily in the rush hour. The reasons that drive motorcyclists to depend on motorcycle usage might vary between different motorcyclists. However, the trip purposes with negative values of the item estimate are consistent with prior observations (Chang, 2002).

Oppositely, Item 5 was found to have the highest positive value among all eight estimated item parameters. This indicates that trips for visiting relatives and friends have the highest resistance against dependence on motorcycle riding. It might be the case that people usually perform these trips accompanied by family members and therefore these trips are not suitable for motorcycle usage. In addition, motorcycle riding is customarily considered as a symbol of inferior socioeconomic status in Taiwan. Thus, people tend to drive automobiles to represent their social status when participating in formal or official visiting.

Items 1 and 4 also have high positive values of the item parameter. This means that these two types of trips have somewhat high inherent resistances against dependence on motorcycle usage. Some work or business trips might be performed with colleagues or with heavy documents or materials, and would therefore not be suitable for motorcycle riding. As to trips for recreational activities, people tend to travel accompanied by family or friends. This makes motorcycle riding less applicable, owing to the capacity constraints. Finally, Item 6 has an item parameter value near to zero. This indicates that there was no significant tendency to achieve requirements for travel in a limited time by motorcycle riding, as compared with other trip purposes.

4.4.2 Findings for person parameters

The Rasch model also helped us to estimate the self-rated vehicle dependence of the 321 motorcyclists who participated in the study. Some summarized relative measures of vehicle dependence and fit statistics for persons are shown in Table 4-4. The raw score of each person has been transformed monotonically into a measure of motorcycle dependence on a logit scale from –2.96 to 5.00. The fit statistic for each person's motorcycle dependence estimate is generally acceptable, which shows that the person responses generally fit the Guttman scale (Guttman, 1950) well.

Figure 4-2 illustrates the distribution of infit and outfit Zstd statistics for the estimates of θ. Each data point represents the infit and outfit Zstd values for an individual respondent. About 15% of the surveyed motorcyclists have fit statistics outside the ± 2 Zstd tolerance box. The scattered points located in the upper right area outside the tolerance box imply that these person responses are over-dispersed compared with the Guttman scale (Smith, 1992). Such a result is generally derived from a violation of the monotonic property in the Rasch model. That is, respondents might achieve the requirement easily for items with higher

difficulty but behave poorly for items with lower difficulty. Oppositely, the scattered points located in the lower left area outside the tolerance box in Fig. 4-2 imply that these person responses are under-dispersed compared with the Guttman scale. Such results might arise from respondents who are unable to judge the relative level of categories well; that is, their responses do not vary with the difficulty of items. Both over-dispersed and under-dispersed responses are regarded as indicating respondents that may possibly violate the properties of the Rasch model. If a person estimate is going to serve as a variable in an extended study, it has been suggested that these questionable responses should be modified or deleted (Bond and Fox, 2001).

Table 4-4 Summarized estimates of person parameters and fit statistics from Rasch analysis

Person number	Raw score	θ_n	S.E.	Infit Zstd	Outfit Zstd
18	39	5.00	1.08	–0.1	–0.4
37	38	4.14	0.81	0.1	0.6
22	37	3.57	0.71	1.7	2.1
9	36	3.12	0.64	0.9	0.8
24	35	2.73	0.60	0.8	0.7
314	34	2.38	0.57	–1.6	–1.5
		.			
		.			
		.			
236	20	–0.91	0.45	–1.2	–1.2
292	19	–1.11	0.46	–1.2	–1.1
296	18	–1.32	0.46	–1.2	–1.0
186	16	–1.78	0.49	1.4	1.7
277	13	–2.61	0.57	–1.1	–1.1
178	12	–2.96	–0.62	–0.7	–0.6
Mean	30.1	1.46	0.55	–0.1	–0.1
S.D.		1.45	0.12	1.4	1.4

In order to explore the useful information contained in the person parameters estimated from the Rasch model, the estimated person parameters were then further investigated by

studying their corresponding personal characteristics. Only the 273 well-fitted respondents, who obeyed the assumptions of the Rasch model, were used for this extended study and discussion. The self-rated motorcycle dependence and personal characteristics of these 273 well-fitted motorcyclists are shown in Table 4-5.

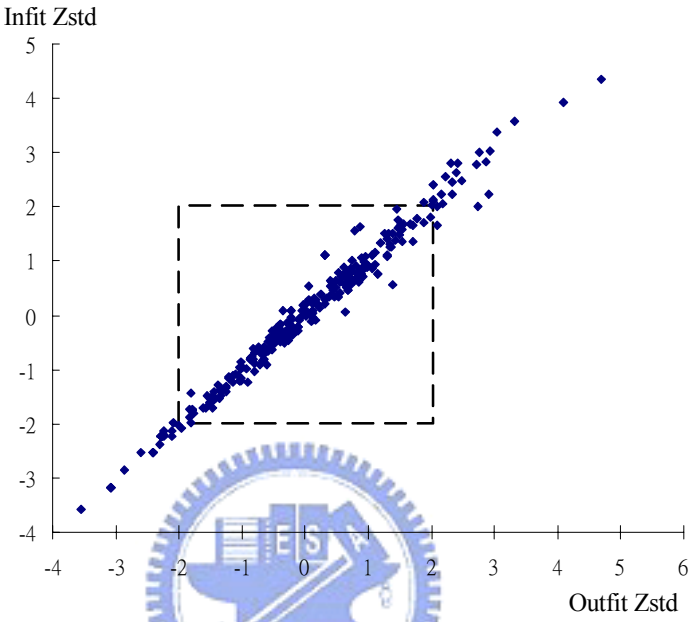


Fig. 4-2. Scatter plot of infit and outfit statistics for estimates of person measures. Each point represents a different respondent. (The square bounds the 95% confidence limits)

These respondents were categorized into two groups for each characteristic, namely age, gender, monthly income, and automobile-driving status. The 144 respondent motorcyclists who also traveled by automobile are referred to here as dual-mode users. These dual-mode users were further divided into two groups by their ownership of a personal, exclusive parking space. The average measures of motorcycle dependence for each group were calculated and compared with their counterpart groups. The statistical significance of the mean differences between groups for each social characteristic was tested, and the *p*-value is shown in the last column in Table 4-5.

The average motorcycle dependence for motorcyclists aged under 25 is significantly

higher than that for motorcyclists aged over 25. This implies that younger motorcyclists in Taipei tend to depend more on motorcycle riding to achieve their trips than older motorcyclists do. The difference between the motorcycle dependence of male and female motorcyclists is not significant, which indicates there is no obvious gender gap in the motorcycle dependence of motorcyclists in Taipei. Motorcyclists with a monthly income lower than 30,000 NTD depend on motorcycles significantly more than do those with a monthly income higher than 30,000 NTD. In view of the average monthly income per capita of 40,142 NTD in Taipei (Official Statistics, 2005), it appears that those who are economically inferior in Taipei tend to depend more on motorcycles to travel.

Table 4-5 Self-rated motorcycle dependence for different groups of motorcyclists

Personal characteristics	Group	Number of observations	Mean of estimated motorcycle dependence	*p*-value
Age	≥ 25	179	1.289	0.010*
	< 25	94	1.720	
Gender	Male	162	1.378	0.453
	Female	111	1.501	
Monthly income	≥ 30,000 NTD	113	1.188	0.004*
	< 30,000 NTD	160	1.651	
Dual-mode user	Yes	144	1.095	0.000*
	No	129	1.829	
**Exclusive automobile parking space	Owned	39	0.982	0.000*
	Non-owned	105	1.427	

* Significance level at $\alpha = 0.01$.

** This analysis was based on the 144 dual-mode users.

The dual-mode users have significantly lower dependence on motorcycles than have those

motorcyclists who do not drive automobiles. It might be the case that the former have the "car-driving" alternative for travel available, and therefore depend less on motorcycle riding than do the latter. This is consistent with the findings of previous studies (Chang, 2002) that automobile driving and motorcycle riding are partially competitive for residents of Taipei.

In addition, the dual-mode users who owned their personal automobile parking spaces were found to have less motorcycle dependence than those who did not own automobile parking spaces. In such an intensively occupied city as Taipei, owning a personal, exclusive automobile parking space is very costly. It is much harder to find a free or cheap automobile parking space than to find a free motorcycle parking space in Taipei. Therefore, once a dual-mode user without his/her own automobile parking space parks his/her automobile on a cheap or free parking space, that person will try his/her best to travel by motorcycle unless he/she is forced to travel by automobile to perform some special activity. This is a common behavior in Taipei, especially for those who belong to the medium-income group, and can be used to explain the relationship between automobile parking space ownership and motorcycle dependence for dual-mode users.

4.5 Discussion

In this case, vehicle dependence was conceptualized as the combined effect of an individual's objective constraints and subjective considerations on the usage of a specific vehicle, and was thought of as a latent trait that is determined by economic considerations, psychological preference, and habitual behavior. The need to travel by a specific vehicle (i.e. a motorcycle) to achieve all possible daily activities for a person was used to design the items of a questionnaire to measure people's dependence on that vehicle. The Rasch model was used to estimate the parameters on an interval scale from the ordinal raw data collected via the questionnaire. The application of the Rasch model enabled us not only to estimate each

person's vehicle dependence, but also to identify the difficulty of each test item, which represented the inherent resistance against using a specific vehicle to achieve each daily activity. An empirical analysis of motorcycle dependence was performed by use of self-rated information about eight items, contained in responses from 321 motorcyclists in Taipei. Convincing results from this empirical study supported our conceptual framework related to vehicle dependence. This study introduced the previously unexplored aspect of the psychological nature of vehicle dependence, suggested an operational method to measure such a latent construct, provided information about how much travelers need a specific vehicle to maintain their daily life, and offered an insight into travelers' behavior in relation to their mode usage.

In our experimental exploration of the self-rated motorcycle dependence of motorcyclists, we used a Rasch assessment to score this latent construct. Some other approaches, such as factor analysis and path analysis, are also widely applied in measuring latent constructs related to travelers. However, those approaches accept raw scores at face value and rely heavily on inferential arguments to validate scales that are calibrated. The Rasch analysis offers a more reasonable approach to transferring ordinal responses to interval scales, which enables researchers to estimate a latent variable through assessing the performance of each item as a contributor to the measurement. Such an approach is especially useful when one is trying to measure a construct that is not extensively discussed in references. Not only can the validity of items for exploring the construct be examined, but also the findings from the measures of both items and persons can be interpreted as useful information.

Saleh and Farrell (2007) argued against the theory of equilibrium as the basis for the forecasting models in travel demand; they pointed out that travelers' willingness should be taken into account in predicting their travel behavior after a new policy is implemented.

Exploring vehicle dependence enables policy makers to realize why and how people rely on their vehicles and provides important cues to them for enacting their policies effectively. This study provides a new concept and approach to pretest the practicability of a new policy. When a policy is enacted, vehicle usage for trip purposes with lower resistance parameters will be relatively hard to alter. Therefore, if a policy is to seriously influence people's travel demands, policy makers should provide travelers with acceptable alternatives in advance. Otherwise, such a policy would induce strong resistance from people and thus fail. Recently, some policy makers have been aware of this point and have started to adjust the content of their policy in response to such possible obstacles. For example, credit-based congestion pricing (Kockelman and Kalmanje, 2005) is a novel road-pricing strategy that both ensures people's basic right to travel and encourages people to reduce their unnecessary private-vehicle usage.

Although motorcycle usage is not popular in some western countries because of the historical background and climatic limitations, it still plays an important role in road transportation in some developing countries, such as Taiwan, Vietnam, the Philippines, Malaysia, and Thailand (Hsu et al., 2003). These countries have some common patterns in their economic development. First, their industrialization started after World War II. Second, the urban areas of these countries are intensively occupied. Third, government investment in public transportation during the early period of industrialization was insufficient owing to a national shortage of finance. As a result, the traffic authorities in these countries let their people ride motorcycles in a laissez-faire approach to offset the scarcity of public transportation services. Now, according to the empirical evidence from Taipei, even though mass public transit and bus services have been established, operated, and intensively promoted, the high dependence on motorcycle usage generated by travelers' daily experience is still hard to change. A significant proportion of travelers would like to choose motorcycle

riding rather than the use of public transportation. The lesson learned from Taipei indicates that overindulging people who ride motorcycles will raise their dependence on motorcycle usage, which might result in inefficiency in subsequent investment in public transportation. This could serve as a real reference for countries with intensive motorcycle usage.

CHAPTER 5

Exploring the Elderly Passengers' Physical Abilities and Difficulties When Using Buses

Without support from existing techniques and standard scales for measuring such an issue, this study started by designing a self-rated questionnaire to collect elderly passengers' subjective judgment of their performance on taking buses. However, such a judgment is only a latent construct of each elderly passenger's generalized evaluation of achieving the necessary actions and motions of bus taking. In order to ensure the validity of the material collected and the precision of the measures estimated, we will briefly introduce our concept of applying the Rasch model to serve as a measuring tool on this issue first. The design and execution of the empirical exploration on senior bus passengers' considerations would be illustrated in the following parts.

5.1 Concept for Applying the Rasch Model for Measuring the Perceived Physical Ability of the Elderly Bus Passengers

Presumably, every elderly passenger n has a unique value of his/her physical ability θ_n to take the bus, which is the personal parameter to be measured. Such a latent construct can be revealed by the elderly passenger's answers to the designed items. That is, elderly travelers who have higher physical abilities for using bus will respond with high scores (i.e. relatively easy to accomplish) on a greater number of items than will those with lower physical abilities. In addition, items in the questionnaire represent the necessary actions or motions that the elderly passengers need to achieve during bus travel. Some items might be easy but others might be difficult to achieve, thus we can consider that there is a unique item difficulty value

b_i (the item parameter) for item i in this study. Items with higher difficulty values are considered as harder for elderly passengers to achieve. Such items might be the potential obstacles to using buses for elderly people and need to be improved.

Like the common knowledge in an educational test, it is apparent that the difference between the person parameter θ_n and the item parameter b_i will determine the response of traveler *n* in considering his/her own performance of item *i*. This observed response could then be formulated as a function of a probability and determined by the value of $\theta_n - b_i$. Furthermore, in order to provide a basis for comparison, the person parameters and item parameters must be measured on a consistent interval scale.

5.2 Design of Empirical Study on the Exploration of the Physical Ability Perceived by the Elderly Bus Passengers

The aim and scope of this study are to explore the elderly bus passengers' physical abilities and difficulties in achieving the necessary actions or motions in taking buses, and try to find the required improvements for bus service or facilities to help and encourage elderly people to travel by bus. Thus, the elderly who are aged over 65 and actually experienced bus-taking in the past one year were defined as the study population for ensuring their responses could well represent the real concerns of elderly bus passengers.

Besides, only some major cities such as Taipei, Taichung, and Kaohsiung offer intensive bus service which forms tessellation networks. In rural area of Taiwan, bus service provides mainly the lineal town-to-town transportation, which hardly helps the elderly in reaching their daily necessary travels. For obtaining the reliable information, we had to focus the exploration upon the urban elderly bus passengers' consideration, and thus selected the elderly bus passengers in Taipei as the statistical population in the empirical study.

5.2.1 Questionnaire design for gathering the latent information

Latent constructs are commonly explored by means of questionnaires that include appropriate items that the respondents can answer on the basis of their daily experience. Since there was no available questionnaire to follow, we had to design our own questionnaire for this study. Essentially, considering the procedures of taking buses as a physical ability test for elderly passengers, the necessary actions and motions can thus be considered as the items in the test. Personal responses to these items can be used as a tool to reflect the elderly passengers' evaluation of their own physical ability to use buses.

A questionnaire was designed with 18 items which represent the necessary actions or motions that an elderly bus passenger has to perform (Table 5-1). The respondent elderly passengers were asked to state the level of ease with which they could achieve each item. All 18 items were answered on a five-point Likert scale, namely "very difficult", "difficult", "neutral", "easy", and "very easy". The responses in these five categories, from "very difficult" to "very easy" for each item, represented the physical ability from low to high, respectively. In addition to these items designed to measure elderly passengers' considerations when taking the buses, the age and gender of the respondents were also included in the questionnaire as the socio-economic characteristics for statistical comparisons.

5.2.2 Data collection

Data collection in this study was conducted via interviewing 304 elderly bus passengers appeared at several bus stations in Taipei. Under the assistance of our well-trained investigators, elderly respondents' physical ability for each item and personal characteristics were gathered through completing the questionnaire. Among these 304 elderly passengers aged from 65 to 92 years old with a mean of 72.7 years, 139(45.7%) were male and

165(54.3%) were female. The respondent elderly passengers were not found to differ significantly from the study population of interest at $\alpha = 0.05$ in terms of the distribution of sex for elderly people published in the official statistics (2006). It was believed that the elderly passengers sampled could reasonably represent the population of our interest, though the sample size was lower than expected due to the difficulty to find the cooperative elderly bus passengers who can precisely express their perceived abilities on bus taking.

Table 5-1 Content of the questionnaire for perceived physical ability of elderly bus passengers

Variable/question	Type
Items to explore the self-rated physical ability to use buses	
How easy can you achieve the following specific action or motion when taking the bus?	
Item 1 : walking independently to the station	5-point scale
Item 2 : reading the information posted at the station	5-point scale
Item 3 : discerning the approaching bus	5-point scale
Item 4 : beckoning the bus	5-point scale
Item 5 : stepping onto the bus	5-point scale
Item 6 : purchasing the ticket on the bus	5-point scale
Item 7 : moving to the seat on the bus when it starts to move	5-point scale
Item 8 : keeping balance on the seat of the moving bus	5-point scale
Item 9 : keeping a standing balance on the moving bus	5-point scale
Item 10: keeping a standing balance when the bus is accelerating/decelerating	5-point scale
Item 11: realizing the location and direction along the route	5-point scale
Item 12: being aware of the approaching destination stations	5-point scale
Item 13: informing the driver and preparing to leave the bus	5-point scale
Item 14: stepping down from the bus	5-point scale
Item 15: realizing the way to the destination	5-point scale
Item 16: realizing the bus information for the return trip	5-point scale
Item 17: walking independently to the destination	5-point scale
Item 18: finding the location of the station for the return journey	5-point scale
Respondent's personal characteristics	
Age	Numeric response
Gender (male, 1; female, 0)	Binary response

Besides, an inspection on the uni-dimensionality of the data via factor analysis was also

conducted. The first factor explained 77.4% of total variance while the second factor only explained 11.2% of total variance. Thus these collected data are suitable to apply the Rasch model because the information of the responses mainly resulted from one single latent construct.

5.2.3 Application of the Rasch measurement model

The Rasch measurement model provides a means for constructing interval measures from raw ordinal category data. A value on an interval scale will be estimated for each item (i.e. the item parameter) and each respondent (i.e. the personal parameter) respectively. The responses of the 304 elderly bus passengers for the 18 items were then analyzed with WINSTEPS (Linacre and Wright, 1997), an iterative computer program, which estimated θ_n for person n and b_i for item i in logit units. WINSTEPS helps to deal with these polytomous responses by applying the Masters–Andrich modification (Masters, 1982) of the Rasch model. The estimated parameters and model fit statistics could therefore be calibrated via a joint maximum-unconditional-likelihood estimating procedure (Wright, 1996).

The estimated parameters and fit statistics of our whole Rasch model are shown in Table 5-2. The Rasch measurement anchored the mean value of all item parameters at zero logit in order to provide a basis for cross comparisons between item difficulties and person abilities. The study results showed the average value for the estimated abilities of all respondent elderly bus passengers was 1.07 logit. It implies that the required actions or motions for bus taking are perceived easy by most of the respondent elderly bus passengers.

The WINSTEPS program also provided the reliability information for both items and persons as shown in Table 5-2. The item reliability index of 0.98 and person reliability index of 0.87 indicate that the data are well consistent with the assumptions of the Rasch model in

the item and person aspects respectively. In addition, the infit and outfit Zstd statistics of the whole model are all near zero in both item and person aspects, indicating the overall validity of our model is acceptable.

Table 5-2 Model estimation and fit statistics obtained from the Rasch analysis

	Number of measures	Number of observations	Mean of raw scores	Mean of Measures	Standard error	Infit Zstd	Outfit Zstd	Reliability
Item	18	304	1071.1	0.0 logit	0.11	–0.1	–0.1	0.98
Person	304	18	63.4	1.07 logit	0.34	–0.2	–0.3	0.87

5.3 Findings and Interpretations

5.3.1 Findings from item parameters

Estimates of the item parameters are displayed in Table 5-3. The first column contains a description of each item; the second shows the estimated parameter for each item; the following columns are the infit and outfit statistics, which are represented by the forms of both mean square statistics (MnSq) and Z-standardized statistics (Zstd). All the Zstd statistics for these 18 items are in the acceptable range of ± 2, which implies the responses do not significantly deviate from the assumptions of the Rasch model. The items in Table 5-3 have been ordered by their estimated values for comparison purpose.

All the estimates from a Rasch model are relative, thus it is generally suggested to anchor the mean value of all item estimates at zero logit, and then the estimates for each item and person can be calibrated with this reference point. Items with higher estimates on difficulty are those actions or motions which are generally considered to be more difficult to achieve for these elderly passengers; item with lower estimates on difficulty are those actions or motions which are generally considered to be easier to achieve. From Table 5-3, the results show that Item 10 has the highest value among all the item estimates, which indicates that keeping a standing balance when the bus is accelerating or decelerating is the most difficult action for

the elderly bus passengers. Next to that is Item 9, which represents keeping a standing balance on the moving buses. Results from these two item estimates indicate one important cue that standing on a moving bus is the most severe challenge for elderly bus passengers. Combined with the 4th highest ranking item estimate of keeping balance on the seat of the moving bus (Item 8) and the 6th highest ranking item estimate of moving to the seat on the bus when it starts to move (Item 7), these results all reflect the elderly passengers' fear of losing their balance and falling on the moving bus, and they need more protection in order to retain their stability when the bus is in motion.

Table 5-3 Estimates of item measures and fit statistics from Rasch analysis

Item	b_i	Infit		Outfit	
		MnSq	Zstd	MnSq	Zstd
10. keeping the standing balance when the bus is accelerating/decelerating	1.69	1.16	0.7	1.17	0.8
9. keeping the standing balance on the running bus	1.12	1.13	0.6	1.11	0.4
2. reading the information at the station	1.08	1.20	0.8	1.24	1.2
8. keeping balance on the seat of the running bus	0.74	1.10	0.5	1.19	0.9
3. discerning the coming bus	0.33	1.27	1.4	1.15	0.7
7. moving to the seat on the bus when it stats to move	0.25	0.98	-0.1	0.96	-0.3
11. realizing the location and direction along the route	0.16	0.94	-0.3	0.91	-0.7
4. beckoning the coming bus	-0.14	0.80	-1.5	0.76	-1.9
12. being aware of the coming destination stations	-0.19	0.86	-0.9	0.81	-1.4
16. realizing the bus information for the way home	-0.25	1.08	0.4	1.06	0.3
5. stepping up the bus	-0.26	0.83	-1.1	0.82	-1.1
14. stepping down the bus	-0.29	0.86	-0.9	0.84	-1.1
1. walking independently to the station	-0.41	0.87	-0.9	0.79	-1.6
17. walking independently to the destination	-0.47	0.87	-0.9	0.82	-1.4
18. finding the location of station for returning travel	-0.48	0.91	-0.6	0.85	-1.0
15. realizing the walking path to the destination	-0.49	0.93	-0.4	0.91	-0.6
13. informing the driver and preparing for getting off the bus	-0.84	0.97	-0.2	0.90	-0.7
6. purchasing the ticket on the bus	-1.57	0.81	-1.1	0.79	-1.7

Besides the four items related to the elderly passengers' physical abilities to retain their balance on the moving buses, reading the information posted at the station (Item 2) and

discerning the approaching buses (Item 3) are another two items with relatively high estimates in our findings. These two items are both related to elderly passengers' visual abilities, which indicate that they need more help or guidance at the station. According to the values of difficulty for these two items, it is noted that elderly passengers might find it more troublesome to read the announced information (static text) than to discern the approaching buses (moving objects), which indicates that the current sizes of words or graphs at the bus station might be too small and unclear for them to read.

Items 11, 12, 15, 16, and 18 are the five items related to elderly bus passengers' cognitive ability and mental capacity. Except for Item 11 with a smaller positive parameter than the average item measure (zero logit), the other estimates are all negative. It represents that being aware of the location as well as direction on the bus and finding their way home are relatively easy for the elderly passengers. Items 1, 4, 5, 14, and 17 are the five items which were designed to test the elderly passengers' physical strength and muscle coordination. However, the negative parameters for these item estimates seem to indicate that the elderly bus passengers do not feel very difficult to achieve these requirements such as walking along the streets, waving hands to make a call for the approaching buses, and stepping up or down the bus steps. Stepping up and stepping down the bus are not considered as the difficult tasks by the respondent elderly passengers as expected. We wonder this might be the case that some ground levels and platforms of bus stops have been raised in Taipei City in recent years and further investigation is needed for verification. In all, compared with those items related to balance keeping, it can be seen that the elderly bus passengers generally feel themselves able to act or move well on the stationary buses, but are quite poor on the shaking or moving buses.

The items with the two lowest difficulty estimates are "informing the driver and preparing

to leave the bus (Item 13)" and "purchasing the ticket on the bus (Item 6)". These results might indicate the current facilities for making a leaving notice to inform the bus driver and for purchasing a ticket are quite suitably designed for elderly passengers in Taipei. The notice bell buttons are commonly installed near passengers' seats, so that the passengers can push the button and pass the unloading message to the bus driver easily. Purchasing a ticket on the bus is not difficult at all because charge of bus fare in Taipei is commonly made via throwing coins into the fare box or via the contactless electronic payment of EasyCard. Besides, elderly passengers aged over 70 are allowed to travel free in Taipei if they show their senior citizen identification cards. That is why this item was generally regarded as the easiest action by the elderly passengers in Taipei.

5.3.2 Findings from person parameters

The Self-rated physical abilities of these 304 elderly bus passengers were estimated from –2.46 to 3.26 logit by the Rasch model. Since the item and person parameters are both measured on the same interval scaled unit of "logit", in which the difference between the item and person estimates has a consistent meaning. The item-person map (as shown in Fig. 5-1), which plots the values of all item and person parameters together, provides a straightforward and graphical illustration to disclose the worthy information behind the cross comparison between person and item parameters.

The left field of the item-person map indicates the distribution of the self-rated bus-taking ability of the respondent elderly bus passengers. The levels of ability are in order from the top to the bottom. The number of respondents located in each level is represented by the combinations of the "#" and ".", and the respondents located in the higher positions indicate their abilities are relative high. The right field of the map shows the difficulty of each necessary action or motion in taking buses. When an item is located at a higher position along

the vertical axis, it is thought to be a tougher action or motion for elderly bus passengers to achieve. For the values of both person ability and item difficulty are relative, it is common to anchor the average value of all item parameters at zero and provides the basis for cross comparison. When an elderly bus passenger and an item are located at the same level on the item-person map, he/she will have the probability of 0.5 to achieve this item. If most of respondents' abilities are located at the positions higher than the difficulty measure of a specific item, it implies this item is considered as relatively easy to achieve by these respondents.

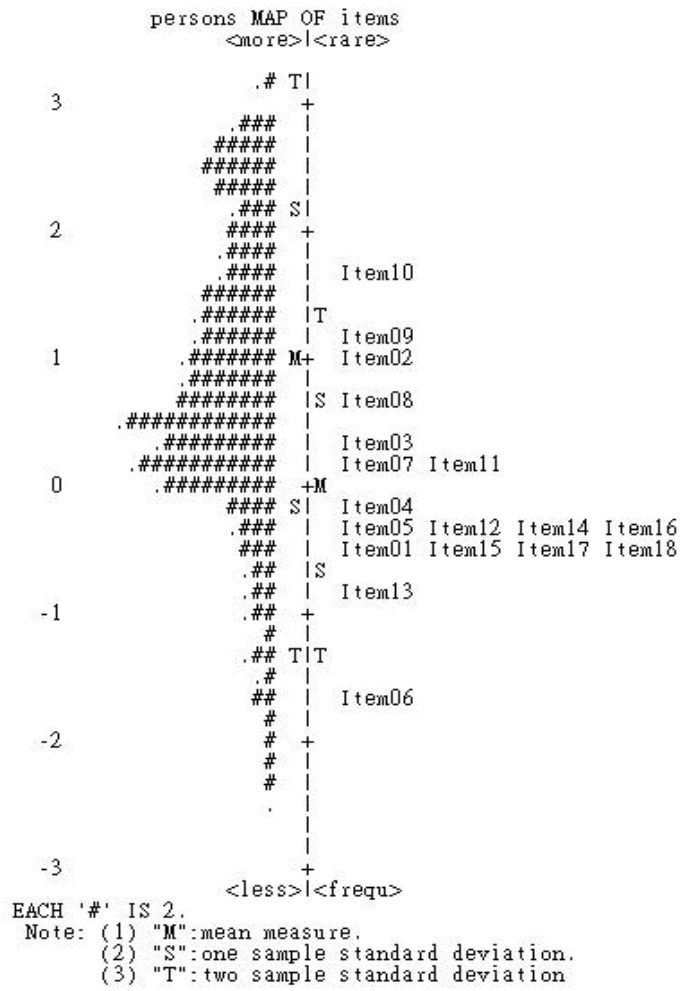


Fig. 5-1. Item-person map for the responded elderly bus passengers

According to the estimates shown on the item-person map (see Fig. 5-1), we can find that Item 10 is the most difficult item among all 18 items and only one fourth of the respondent

elderly bus passengers could achieve it with ease. Item 9 and Item 2 are the next two most difficult items, and only about one third of the elderly bus passengers could pass them easily. Furthermore, we can also find that more than eighty percent of the respondent elderly bus passengers could easily achieve those eleven items with negative values of item difficulty, and even more than ninety percent of elderly passengers could achieve Item 13 and Item 6 without any difficulty. Thus, the proportion of elderly passengers that can not achieve a given item with ease can be easily identified by the item-person map. It provides a clear illustration about what services or facilities should be improved with priority in order to provide a safer and friendlier travel service for the elderly bus passengers.

The interval scale property of Rasch measurement also enables us to extend the results for further explorations. By relating each respondent's ability measure to his/her age, some useful information can be easily observed from the Fig. 5-2. Each respondent's age and physical ability measure are diagrammed by the horizontal and vertical axes respectively in the Fig. 5-2. In the horizontal axis, the elderly respondents are divided into three subgroups by their ages, namely the younger elderly (aged 65-70), middle elderly (aged 71-79) and older elderly (aged 80 and above) respectively. In the vertical axis, four thresholds (1.69 logit, 0.74 logit, -0.49 logit, and -1.57 logit) are applied to categorize the perceived physical ability into five groups denoted from A to E.

Respondents in the group A were those elderly passengers with ability measures higher than the highest difficulty measure of all items. These elderly respondents were believed as being able to achieve all the necessary actions or motions when using buses with ease. Elderly respondents with ability measures from 0.74 to 1.69 logit were categorized into the B group. These elderly respondents' ability measures were around the levels of difficulty measure for the top four difficult items. It indicated that these respondents could achieve the necessary

actions or motions with ease except for the top four difficult items. The C group included those elderly respondents with ability measure from -0.49 to 0.74; this range covered the difficulty measures of 12 items which were regarded as the necessary actions or motions with moderate difficulty to achieve when using buses. Except for the easiest two items, respondents whose ability measures were lower than the difficulty measures of the remaining 16 items were categorized into the group D. Such elderly bus passengers will face lots of threats when trying to achieve the necessary actions or motions in the bus trips. Elderly passengers whose ability measures were lower than the difficulty measures of all items are categorized into the group E. Every necessary action or motion in using the bus would threaten this group of elderly bus passengers. Their bus usage might be inappropriate but would be the only available way of their travel. These elderly passengers would need the most cares for their outdoor travels.

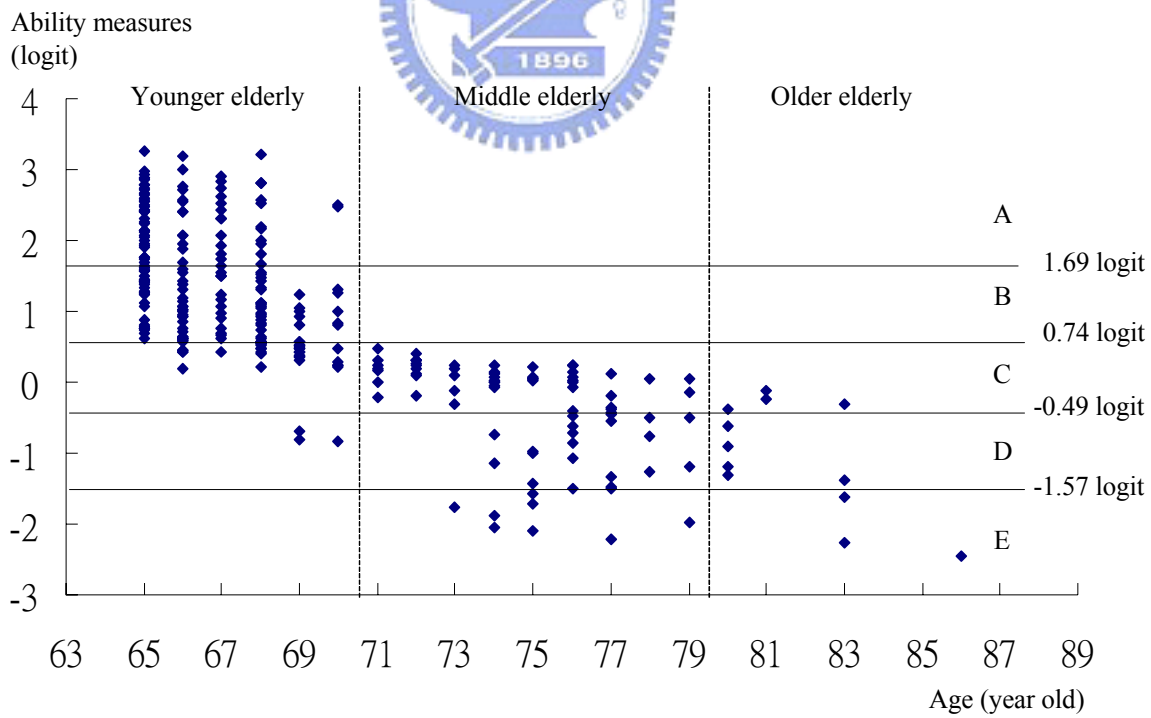


Fig. 5-2. Distribution of the ages and ability measures of the responded elderly bus passengers

The numbers of the responded elderly bus passengers in the groups of younger, middle

and older elderly were 211, 81, 12 respectively, and the numbers of these responded elderly bus passengers in the groups of ability level from A to E were 73, 83, 110, 28 and 10, respectively. Among the 211 younger elderly passengers, 73, 83, and 52 respondents are categorized into the groups of ability level from A to C respectively; only 3 of them were categorized into group D and nobody belonged to the group E. Among the 81 middle elderly, no one was categorized in the ability group A and B; there were 54, 20, and 7 respondents being categorized into the C to E groups respectively. In the remaining 12 older elderly respondents, their ability measures were also distributed from group C to E as well (4 in C, 5 in D and 3 in E). Findings from these two groups of elderly respondents aged over 70 pointed out a critical problem behind the existing subsidy policy on the elderly passengers. Elderly people aged over 70 are allowed to take bus with free charge; however, there were no elderly people in our samples who could achieve the top 4 difficult items with ease. The necessities for achieving these four actions or motions could be the big obstacle to encourage the elderly people aged over 70 to patronize the bus service. Thus improving the bus facilities and service to enhance the elderly people's willingness on bus patronage would be the critical requisite.

An obvious negative correlation between the ages and ability measures of the elderly bus passengers was disclosed in the Fig. 5-2. Such an observed relation can be easily verified owing to the property of interval-scaled measures offered by the Rasch measurement. The Pearson correlation coefficient between the age and ability measures was -0.779 and significant at $\alpha = 0.01$, which supported our hypothesis that the perceived physical ability will decrease as the elderly are getting old. The significant difference ($\alpha = 0.01$) between the perceived physical ability measures of the elderly aged under 70 and those of the elderly aged over 70 could be also verified by applying the "independent samples t-test" directly. With the reasonable experimental designs, such interval-scaled measures from Rasch model can be further extended to some meaningful explorations.

5.4 Discussion

In this study, the bus-taking actions/motions with higher difficulty were found to be related to elderly passengers' balance keeping ability, which is consistent with some previous studies on the mobility of the elderly. Leslie et al. (2003) found that half of the elderly people experienced fear of falling after taking a fall. Fear of falling would decrease elderly people's willingness to travel by bus. To reduce such fear, more effort should be made to reduce the risk of falling and its aftermath when using buses. Instant warning about the bus operations or moving situations (e.g. starting, acceleration, deceleration, right/left turn) might be helpful to warn elderly passengers to take the necessary actions. Providing more priority seats for elderly passengers could avoid the risk of standing on the moving buses. Moreover, providing seatbelts for all priority seats would offer further protection for elderly passengers to keep them balanced on the seats. Aids, such as armrest or guardrail, made of flexible materials, are also suggested in order to reduce the impact of bumping. The inner-bus monitoring and broadcasting system is also suggested to be equipped near the seat of driver. Once the bus driver detects some tottering elderly people standing on the moving bus, s/he can immediately announce the seat-yielding request via such a broadcasting system without any delay

Items related to vision ability are also found to be the difficult tasks for the elderly bus passengers when using buses. Although the bus passengers need not rely on their vision to react with the traffic when the bus is moving; their decline in vision still disturbs their ability to read the information and discern the approach of the bus service. These annoyances might not endanger their safety directly, but somehow could reduce their willingness to travel by bus.

Improvements via simple corrections or innovations are expected not only to provide a safer and friendlier bus-taking environment for existing elderly bus passengers, but also to

attract those elderly people who are able but refuse to take bus due to the safety or less physical ability considerations to patronize bus service through the mouth-of-word reputation. For instance, enlarging the size of characters for the necessary information on the station or bus, setting the press-to-start vocal instruction buttons on the station, and establishing the bus approaching light or voice warning are believed to help the elderly overcome the obstacles due to their visual disabilities. Besides, some short-range wireless communication system between bus-stations and bus-drivers might also help the elderly to discern the coming bus. It is suggested to emplace the specific "boarding request" buttons on the bus stations for each bus service route. When the button is pressed, such a boarding request would be transmitted wirelessly and be received by the on-board equipment of the corresponding buses. Thus the bus-drivers can decelerate the bus smoothly in advance, which avoids bypassing the bus station or making a sudden deceleration of the bus.

Another positive parameter on the difficulty of these possible actions or motions was found on "realizing the location and direction along the route". In fact, degrees of memory losing and senile dementia were also important issues when the outdoor mobility of the elderly is discussed. Since the "helping-hand", a prototype of integrated aid to the elderly for mobility assistance and monitoring, was disclosed by the PAMM project (Dubowsky et. al, 2000), several portable personal GPS guidance aids have been invented to provide the directions for the elderly users and enable the rescue in case of emergency. It is hoped in the near future that the communication conventions of such personal facilities can be standardized and integrated with the bus GPS system. Thus not only the elderly bus passengers' safety can be better ensured, but also the elderly people's willingness for taking bus might increase accordingly.

To sum up, this empirical study has conducted a demonstration on introducing a new

approach to measure perceived physical abilities and difficulties of elderly bus passengers in their bus patronage, and showing its capability to provide the interval scaled measures for further investigation or comparison purposes. The Rasch measurement, which can convert raw ordinal responses into values on an interval scale, was reviewed and employed as the instrument for assessing the relative level of ability of each person and difficulty of each item. With relating the measures of person ability and item difficulty, the item-person map provides a straightforward and graphical illustration on the corresponding proportion of elderly bus passengers that can achieve in each given item with ease. By extending the measures with indicative variable such as age, some worthy information is clearly disclosed, which provide valuable information to enhance the hardware and software of existing bus systems. In addition to the demonstration on introducing a new approach, this study also raises some practical suggestions on the critical items found in the empirical study results. Not only providing an academic example for related researchers, it is also hoped that our efforts can make practical contribution to building a safer and friendlier bus service for the elderly people.

CHAPTER 6

Conclusion and Future Study

6.1 Conclusion

This study has conducted the explorations on two latent constructs of travelers' considerations. The first topic aims to explore the vehicle dependence of motorcyclists, and the second topic is to measure the physical ability perceived by the elderly bus passengers.

In the first part of this study, we have explored vehicle dependence, taking account of subjective considerations of individual travelers. Vehicle dependence, arising from economic considerations, psychological preference, and habitual behavior, is formulated here as a subjective latent construct that acts in a person's mode choice. The Rasch model is reviewed, and suggested as an instrument to measure such a latent construct. An empirical analysis of motorcycle dependence was performed using self-rated information about eight items from 321 motorcyclists in Taipei. The detailed measures with respect to the items and persons have been reported, and the validity of Rasch measurement has been verified by reliability indices and fit statistics. We have also interpreted the results from assessing the degree of the generalized motorcycle dependence on each kind of trip purpose respectively. By relating the measures of the individual motorcyclist's dependence with his/her personal socioeconomic characteristics, the findings from these potential relationships have been pointed out.

The empirical results showed that motorcyclists in Taipei tend to depend on their motorcycles to achieve unaccompanied, short-distance, multistop trips; motorcyclists under the age of 25 who were inferior in economic terms and did not use an automobile showed relatively higher measures of motorcycle dependence. Some interesting results showed that

the dual-mode users have significantly lower dependence on motorcycles than have those motorcyclists who do not drive automobiles. This is consistent with the findings of previous studies (Chang, 2002) that automobile driving and motorcycle riding are partially competitive for residents of Taipei. In addition, the dual-mode users who owned their personal automobile parking spaces were found to have less motorcycle dependence than those who did not own automobile parking spaces. This finding can be used to explain the relationship between automobile parking space ownership and motorcycle dependence for dual-mode users.

In summary, we have conceptualized the vehicle dependence in terms of both its socioeconomic and its psychological nature. The measures of vehicle dependence can be further applied into the extending studies on mode choices or travel behavior. For the interval scale property, such a measure can be directly served as explanatory or dependent variable in statistical inference. We believe our effort on exploring the vehicle dependence would benefit researchers in modifying their formulations of mode choice, and policy makers in enacting more effective policies.

The second topic is an explorative trial to realize how the senior bus passengers perceive their own physical abilities when using buses. Such a self-assessment of elderly passengers on their own physical abilities plays a critical role on their willingness of bus patronage. We have developed an approach to measure elderly passengers' abilities and to explore their difficulties in accomplishing the actions and motions required to patronize the bus service. A conceptual framework about the required actions and motions in bus taking was established and a questionnaire with 18 items was designed to test their ability to use buses. A face-to-face survey was conducted to collect the self-rated information from 304 elderly bus passengers in Taipei. The Rasch model was applied to estimate the difficulty of each item and the ability of each person to use a bus. Detailed measures with respect to the items and persons had been

reported and the validity of Rasch measurement had been verified by the reliability indices and fit statistics. We have interpreted and discussed the findings from the measures of item difficulty, and also have presented the measures on each person and item on a single diagram to see what proportion of the elderly passengers would consider it as difficult in achieving each of the necessary actions or motions in taking the buses.

Results showed the relatively difficult items are mostly about keeping balance on the moving bus and reading the information or discerning the approaching buses at the stations, and the considered levels of physical ability showed negative associated with respondents' age. Suggestions are made based on improving the facilities or service to help the elderly passengers achieve the necessary actions or motions, which can be summarized as follows:

1. The instant warnings about the bus operations or moving situations might be helpful to warn elderly passengers to take the necessary actions.
2. Providing more priority seats for elderly passengers could avoid the risk of standing on the moving buses.
3. Providing seatbelts for all priority seats would offer further protection for elderly passengers to keep them balanced on the seats.
4. Aids, such as armrest or guardrail, made of flexible materials, are suggested in order to reduce the impact of bumping.
5. The inner-bus monitoring and broadcasting system is also suggested to be equipped near the seat of driver. Once the bus driver detects some tottering elderly people standing on the moving bus, s/he can immediately announce the seat-yielding request via such a broadcasting system.

6. Enlarging the size of characters for the necessary information on the station or bus.

7. Setting the press-to-start vocal instruction buttons on the station and establishing the bus approaching light or voice warning can help the elderly overcome the obstacles due to their visual disabilities.

8. The short-range wireless communication system between bus-stations and bus-drivers might also help the elderly to discern the coming bus. It is suggested to emplace the specific "boarding request" buttons on the bus stations for each bus service route. When the button is pressed, such a boarding request would be transmitted wirelessly and be received by the on-board equipment of the corresponding buses.

9. Integrating the portable personal GPS guidance aids of senior people with the bus GPS system can better ensure the safety and security of the elderly travelers.

To the conclusion, this study has conducted a demonstration on introducing a new approach to measure perceived physical abilities and difficulties of elderly bus passengers in their bus patronage, and on showing its capability to provide the interval scaled measures for further investigation or comparison purposes. The Rasch measurement, which can convert raw ordinal responses into values on an interval scale, was reviewed and employed as the instrument for assessing the relative level of ability of each person and difficulty of each item. With relating the measures of person ability and item difficulty, the item-person map provides a straightforward and graphical illustration on the corresponding proportion of elderly bus passengers that can achieve in each given item with ease. By extending the measures with indicative variable such as age, some worthy information is clearly disclosed, which provide valuable information to enhance the hardware and software of existing bus systems.

6.2 Suggestion for Future Study

This doctoral dissertation presents our concept and approach for exploring the latent constructs of travelers. However, it is important to note that our work is just a first stone which is used to attract more concerns about such issues. Suggestions on these two topics have been illustrated in the discussion sections respectively (see Sec 4.5 & Sec 5.4). At the end of this dissertation, we would give the future study suggestions on the developments of the psychometric studies based on the Rasch measurement.

Essentially, the Rasch model is the methodology of measurement applied in this dissertation. Just like we have discussed in the review of Rasch model (see Chapter 3), such a conventional Rasch model is a simplified IRT model based on the assumption of the Guttman scale, which can be regarded as a prototype psychometric model in conducting the exploration on the latent construct which is not well-identified or well-defined. In recent studies, the application of Rasch model has been innovated for obtain better explanatory effectiveness or efficiency. Some major developments on the psychometric studies based on the Rasch measurement are briefed as the follows:

1. By relaxing some of the fixed parameters ($d = 1$, $c = 0$, and $a_i = 1$) of the Rasch model, the original IRT model can be applied in designing the scientific questionnaires for some specific latent constructs. The applications of IRT model have been widely applied in the educational or psychometric studies. In realizing the travelers' behavior, instruments to explore many important latent constructs (e.g. the risk perception, or the road rage intension) have not been specified. The IRT model can help to select items in designing the related questionnaires, which would help the researchers who collect their data via questionnaire to obtain more reliable information. As a result, we suggest that researchers in the science of traveler behavior can try to develop the rigorous specification of the related latent constructs. If possible, it is hoped that the normalized scales for these latent

constructs can be established and applied by the related researchers.

2. Increasing the influential factors (i.e. the facets) in the Rasch measurement, the Multi-Facet Rasch Model (MFRM) has been widely applied in purifying the effects of person ability, item difficulty, and otherwise facets. For example, in the exploration of the n th examinee's ability was evaluated by the j th rater with the i th item, by adding up a facet r_j arisen from rater effect, (i.e. $\ln\left(\frac{P_{nik}}{P_{ni(k-1)}}\right) = \theta_n - b_i - r_j - F_{ik}$), the partial-credit MFRM can separate the revealed scores as three parts of effect and disclose more information behind those scores. One of authors' articles entitled as "A mutil-facet Rasch analysis on rating the academic scientific papers" has been accepted for publication in the Psychological Testing Journal (in Chinese); readers can refer to that paper for the detailed demonstration of applying the MFRM.

3. The conventional Rasch model is limited to explore one single latent construct at a time because of the assumption of the unidimensionality. Recently, some psychometric researchers have relaxed this assumption. The multi-dimensional Rasch model, which recognizes the correlations and estimates the parameters among the latent constructs, has been developed (Wang et al, 2004). Such a development provides a communication platform for the researchers from the classical test theory and item response theory. It could be the mainstream of the psychometrical studies in the coming future.

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