行政院國家科學委員會補助專題研究計畫 **☑成果報告**
□期中進度報告

以運輸多樣性觀點建立都市永續運輸評估與資源分派模式

計畫類別：☑個別型計畫　□整合型計畫
計畫編號：NSC 96－2415－H－009－001－MY3
執行期間： 96 年 8 月 1 日至 99 年 7 月 31 日

執行機構及系所：國立交通大學交通運輸研究所

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摘要

運輸系統中不同權益關係人對於設施與服務有多元之需要，要滿足這些需求必須在供需及本益間進行權衡考量，過程中產生了運輸多樣性之課題，然而過去文獻鮮少提及運輸多樣性相關議題。因此，本研究建立一評估運輸多樣性以改善生活品質之架構，運輸多樣性定義為權益關係人需求被滿足之程度，且利用 Shannon-Weaver 指標（或稱之為熵）分析各需求現況與期望水準間落差衡量之。運輸多樣性可評估重要之需求是否公平地被滿足，並藉由目標值與基本生活水準之確認以監測運輸系統是否朝向永續發展。本研究所提架構認為評估運輸多樣性時應同時考量多元運輸需要，包括機動性、經濟健全度、可靠度、安全性、可及性、可負擔性、通用化設計程度、外部性及資源超限利用，且不可忽略不同權益關係人，如不同運具使用者、特殊需求使用者及非使用者之需要。因此，在考量生活中運輸需求與旅運行為時，運輸多樣性係達成永續發展及改善生活品質之必要條件。本研究冀望所研提運輸多樣性之概念架構得以協助決策者了解運輸多樣性與永續性之關係，並提供嶄新之評量方法以提升生活品質。

確認權益關係人需求後，本研究歸納文獻相關量化指標以利後續分析進行，並利用大臺北都會區 2000 年及 2005 年資料進行時間與空間分析，以探討運輸多樣性評量架構之可行性。縱軸分析結果顯示研究範圍之運輸多樣性有所改善，尤以安全性及可靠度之水準提升最為明顯，但污染排放、可及性及通用化設計水準之提昇則乏善可陳。根據運輸多樣性評量架構之分析結果，決策者得以採取較佳之資源配置策略，例如應更有效地改善交通能力弱勢使用者運輸生活之不便。

此外，資源配置策略可協助規劃者決定投資運輸設施或服務之時機與方式，然而，由於運輸系統中各要件間之關係存在複雜性、不確定性與回饋機制，改善運輸多樣性之資源配置策略之研擬、執行與量化皆相當困難，本研究統整量化之系統動態模型、質化之認知圖法及準量化之感受性模型之特性，建構一整合式系統模擬模型以克服上述問題。透過敏感度分析，顯示私有運具旅次之增加將使能源消耗、污染排放及肇事率加劇，導致運輸多樣性之下降。但政策執行後，其影響不論為即時或有所延滯，皆未顯著影響系統行為與表現。而模擬結果顯示，權益關係人需求滿意度之現況與期望水準間的落差與運輸多樣性存在反向關係，卻與私有運具旅次數成正比。這為提升大眾運輸旅次數可有效彌平使用者需求滿意程度之落差提供了有力之驗證。

根據上述整合性系統模擬模型所界定之運輸系統關係，本研究藉由以柏瑞圖最適理論為基礎之模糊多目標規劃法，解決非線性多目標問題，並以大臺北都會區大眾運輸系統為簡例，同時考量滿意度落差與運輸多樣性，進而探討資源配置對於權益關係人需求滿意水準之影響。由於同時考量滿意度落差與運輸多樣性，此一模式可避免無效率與不公平之資源配置。此外，分析結果顯示近年來大臺北都會區配置在大眾運輸間之投資，已同時考量捷運及公車權益關係人需求滿足程度之公平性，因而使運輸多樣性有所提升。

關鍵詞：運輸多樣性、永續性、生活品質、權益關係人需求、系統行為、資源配置

Abstract

Transport stakeholders have different needs for transport infrastructure and services. Meeting the needs of stakeholders implies a trade-off of benefits and costs and creates issues of transport diversity. However, the literature has ignored these issues. This study aims to provide a framework evaluating transport diversity to promote quality of life. Transport diversity is defined as the satisfied level of stakeholder needs in this study and measured in the form of the Entropy. Transport diversity can assess whether the level to which important needs are satisfied equitably, and monitor whether the transportation system is moving towards sustainability via confirming the targets and the basic level of quality of life. Improving the sustainability and quality of life with regard to transportation requires the support of transport diversity. The conceptual framework developed can assist decision-makers in understanding the relationship between transport diversity and sustainability, and provide a new assessing method for improvements in quality of life. Besides, a hybrid model integrating system dynamics, cognitive maps, and sensitivity model is employed to tackle the problems. The result of sensitivity model reveals that the increment of private vehicle trips reduces transport diversity due to the increase of energy consumption, emission and accident rate. Notably, the simulation results indicate that the gaps in stakeholder needs are generally opposite to transport diversity and positive proportion to private vehicle trips. This verifies that increasing public transit trips helps the system bridge the gap between user satisfactions of stakeholder needs. Based on the system relationships constructed by the hybrid model, fuzzy multi-objectives programming is employed to solve the non-linear multi-objectives problems focusing on urban public transit systems for determine the impact of resource allocation on need satisfactions related to stakeholder behaviors.

Keywords: Transport Diversity, Sustainability, Quality of Life, Stakeholder Needs, System Behavior, Resource Allocation

CHAPTER 1 INTRODUCTION

The chapter consists of four sections. Section 1.1 addresses the motivation, principal concept and issues on analyzing transport diversity and sustainability in this study. The research objectives and framework are introduced in Section 1.2 and 1.3, respectively.

1.1 Motivation

Transportation systems consist of infrastructure, modes, and stakeholders. Different transport stakeholders, for instance, users of different modes, the government, and non-users, with diverse demands have different needs for transportation infrastructure and services. Meeting the needs of stakeholders implies a balance of benefits and costs between supply and demand. This thus brings the reality of transport diversity. Diversity describes variety and difference of individuals and groups in a system (Hunter, 1990). The concept of diversity recently has come into vogue in research (Point and Singh, 2003). In fact, transport policy-makers must simultaneously consider the trade-off between differences in the supply of transport infrastructure or modes, in addition to the various needs of stakeholders in the transportation planning. However, few studies have discussed the implications of transport diversity and related issues, for example, what is the definition of transport diversity, how to measure it, and how it impacts transportation systems and daily life.

Moreover, sustainability is an increasingly important issue and incorporated into many levels of society since the Global Summit Conference in Brazil in 1992, although the common identified definition of sustainability is not available (Pope et al., 2004; Loo and Chow, 2006; Jeon et al., 2006). Different individuals, groups, or fields contribute to various descriptions, for example, World Commission on Environment and Development (WCED, 1987) defined that sustainable development meets the needs of the present without compromising the future generations. Munasinghe (1993) considered that the concept of sustainable development has evolved into economic, social and ecological perspectives. Phillis and Andriantiatsaholiniania (2001) proposed that the sustainable system would never drive it outside the boundaries of acceptable values of certain criteria. Additionally, how to assess sustainability objectively has been controversial. However, the evidence of sustainable indicators considering the diverse stakeholder needs is weak and little research explored the relationship between transport diversity and sustainability.

Most of the current evaluations for transportation system highlight the network performance, including level of service, travel speed, accident rate and so on. However, past studies neglect an integrated and comprehensive framework related to spatial sustainable development and an analysis of the relationship between the evaluation indicators and actual needs for regional development. Furthermore, the traditional planning of transportation infrastructure emphasized the economic benefit resulting in the problems concerning equity between artificial spaces and negative impact on natural environment. The policy-makers are difficult to decide the priorities to resource allocation for improving equitable need satisfaction without the appropriate sustainable transportation indicators and the causal effect among variables in transportation systems. This thus reduces the efficiency of investments and misleads the sustainability.

1.2 Research Objectives

The purpose of this study is to suggest a novel assessment framework for determining social needs of stakeholders in transportation systems, for improving the basic satisfaction of quality of life regarding to transportation with which each individual could travel without deficiency and for reducing satisfaction gaps between the present level and the expectation level towards sustainability. Accordingly, there are three primary objectives in this research:

1. Construct a framework for evaluating transport diversity based on the needs of stakeholders. The conceptual framework can help planners understand the relationship between transport diversity and sustainability, and clarify issues and implications related to transport diversity and quality of life. Furthermore, transport diversity, considered at the commencement of planning, is a new tool for assessing improvement in quality of life.
2. Propose a systematic model to simulate the effects of resource allocation policies on transport diversity. The decision support model for resource allocation policies can help planners decide when and how to invest transportation infrastructure and services.
3. Propose a mathematical programming model for solving the resource allocation to aid in the shift towards sustainability within transport diversity.

Transportation systems comprise international, intercity, and urban transportation in terms of service area. The characteristics and impact factors of transportation planning differ from spatial scales. This study aims to explore the diversity of the stakeholder needs in urban transportation system through a “meso-scopic” analysis and the Taipei metropolitan area, the largest in Taiwan, provides the empirical study to discuss the relationship between transport diversity and sustainability, as well as the managerial implications of the introduced assessment methods.

1.3 Research Framework

Given the objectives, the research framework is illustrated in Figure 1-1. Prior to defining transport diversity, framework of stakeholder needs is built up as the basis to select stakeholders, to determine the needs of stakeholders, and to identify the target and threshold values of appropriate indicators representing different needs. Meanwhile, the connections among stakeholder needs, quality of life, and sustainability are discussed to help identify the definition and the constitution of transport diversity.

Moreover, two studies are then conducted based on the coverage of data. The first study is undertaken for examining the causal effects in urban transportation from a systematic perspective. The second study is conducted to optimize the strategies of resource allocation. Empirical studies are presented in the next chapter. Finally, the related issues are discussed in Chapter 5 and the conclusion and recommendations is drawn in Chapter 6.

In Figure 1-1, the research procedure is divided into are three stages, such as determination of the issues of transport diversity, identification of urban transportation system and development of assessment model. First, the motivation and objectives are determined prior to the literature review. Transport diversity is defined and the conceptual framework is constructed based on the reviewed research including the sustainability, quality of life and diversity. A preliminary analysis is undertaken to test the feasibility and appropriateness of transport diversity. Before the preliminary spatiotemporal analysis, the information determining the scope and measurements of this research are provided from government database

Second, a systematical decision support model for improving transport diversity via strategies of resource allocation is proposed. This hybrid model integrated quantitative, qualitative and semi-quantitative system simulation tools to tackle the difficulty of complex relationship between system components. The decision support model simultaneously identifies the critical variables in urban transportation system as well as the causal relationships affecting system behaviors. Then the Taipei metropolitan area is employed as an empirical study. Some scenarios are simulated to assist policy-makers in understanding the variation of system behavior. Finally, a mathematic programming model for optimizing the resource allocation is constructed to discuss the impact of strategies on system performance which is assessed by the suggested transport diversity framework.

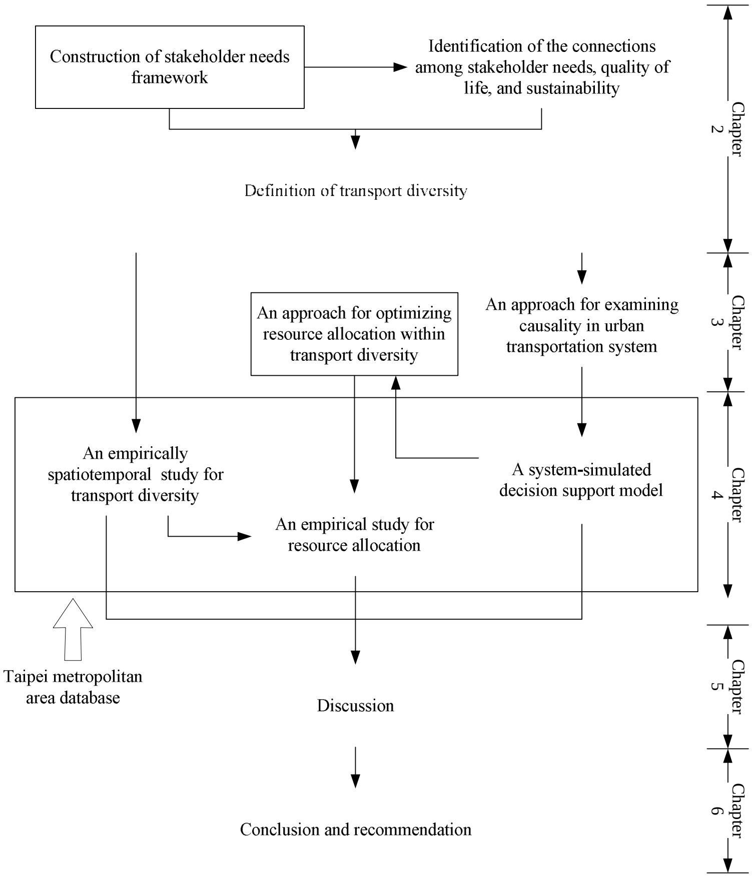


FIGURE 1-1 Research framework

CHAPTER 2 CONCEPTUAL FRAMEWORK OF TRANSPORT DIVERSITY

The purpose of this chapter is to introduce the conceptual framework of transport diversity based on the reviewed literatures related to transport diversity, including sustainability, quality of life and diversity. Section 2.1 describes the sustainability and followed the quality of life. Section 2.3 illustrates the commonly accepted definition and measure of diversity. The necessity and advantages of applying the assessment on analyzing and improving the performance of urban transportation system towards sustainability are revealed from the built framework.

2.1 Sustainability

Numerous definitions and indicators have been studied for their function with sustainability. The purpose of this section is to provide literatures reviews to identify the commonly acceptable definition and practical indicators for sustainable transportation.

2.1.1 Features of Sustainable Transportation

One of the popular definitions of sustainable development is reported by the WCED (1987) as "development which meets present needs without compromising the ability of future generations to achieve their own needs". The policies of sustainability have to simultaneously consider the external effect in environment, stakeholders' equity in society, and efficient use of natural resource in economy. Sustainable development is usually evaluated using a set of measurable indicators to track trends of areas and activities and to evaluate the performances of systems. The selected indicators significantly influence the results of analysis. Sustainability is always set in the components depended on the type of system and the spatiotemporal scales rather than an absolute concept (Allen and Hoekstra, 1994). Besides, Maclaren (1996) divided the generators of sustainable indicators into six categories, such as domain-based, goal-based, sector-based, issue-based, causal, and combination generator.

There is much research discussed the different sustainable indicators generators. Some studies related to transportation system are reviewed in this study. Canadian Centre for Sustainable Transportation (CST, 1997) proposed that a sustainable transportation system is based on three principles: First, the basic access needs of individuals and society should be satisfied under a safe, generation-equitable, and ecosystem-friendly condition. Second, the growing economy should be supported under the affordable, efficient, and multi-choice operations. Furthermore, the emissions, waste, noise, and consumption of natural resources should be limited. Additionally, The Organization for Economic Cooperation and Development (OECD, 2001) suggested sustainable indicators along a causal generator, named "Driving force–State–Response model," which is adapted to take into account the specificities of the public sector. The OECD indicators are established according to the tendencies for economic and environmental impact in the various sectors.

Moreover, the World Bank developed the Environmental Performance Monitoring Indicators based on the issue-based generator (Segnestam, 1999). The considered issues included forestry, biodiversity, land quality, air pollution, water pollution, global environmental problems, and institutional capacity. The Institute of Transportation Taiwan (2002) established the sustainable transportation indicators. The indicators had been generated by the method of complete enumeration. In addition, reports of Ontario Round Table argued indicators to evaluate the impacts of development on sustainability. The indicators adopted were based on a "Criterion – Influences – Actions – Measures" system in the combination generator. The concept of transport sustainability consists of three main criteria: acceptable emissions; limitation of resources consumption, and minimizing the disruption of ecological processes, land use, and sensitive habitats (Gilbert and Tanguay, 2000). The reviewed sustainable indicators related to transportation are shown in Table 2-1.

Different generator with diverse advantages as well as disadvantages fits distinct study purpose. For example, the domain-based generator organizes indicators based on the environmental, social, and economic dimensions of sustainability. Domain-based generator is not used to infer from ex post facto integration of functional resource outputs since it focused on the outcomes and states rather than on inputs and outputs of systems. This generator is the most effective one to ensure coverage of the three dimensions from which sustainability emerges, as well as to examine interactions within and among the three main components of sustainability. Because of the above characteristics, domain-based generator is used in this study.

TABLE 2-1 Sustainable transportation indicators

Sources	Indicators
OECD	Transport intensity, vehicles, fuels consumption, infrastructure, air pollution, safety risks, pricing and taxation, and subsidies.
World Bank	Percentage of reliable and affordable linked areas, freight and passenger tariffs, air pollution, and investment of roads.
IOT, Taiwan	*Economy*: Transit ridership, maintenance cost of roads, passenger transportation by aircraft and railway, growth rate of vehicles, and population density. *Environment*: Percentage of preservation areas, air pollution, noise pollution, fuels consumption, number of motorized mode, network density, recycle of disused vehicles. *Society*: Transportation intensity, accident rate, subsidies, infrastructures allocation, number of violations, fatal and injury accidents.
Ontario Round Table, Canada	CO_2 loading, ecological footprint, habitat disruption, employment, green GDP, tax revenues, commute cost, deaths and injuries, community disruption, distribution inequality index, Demotechnic index, E-index, vehicle access, energy efficiency, mixed land use, and trips with two or more modes.

2.1.2 Practical Sustainable Transportation Indicators

Indicators expressing the needs of stakeholders are established based on the criteria of transportation system performance, including mobility, accessibility, safety, and externality (Wachs and Koenig, 1979; CST, 1997; OECD, 2001; Levinson, 2003). The indicators are briefly described below. Different indicator systems yield the different results. Since this section aims to illustrate how to incorporate transport diversity during transportation planning, it does not focus on which and how many indicators should be included and by which process.

(1) Mobility

Mobility refers to the efficiency with which vehicles operate on roads (American Association of State Highway and Transportation Officials, 1994). As a result, mobility is defined as the capability to overcome spatial resistance. Moreover, mobility refers to the ability of individuals to travel and move (McGillivray and Kirby, 1979; Levinson, 2003), or individual ease of movement (Levine and Garb, 2002).

(2) Safety

Safety is defined as being safe from experiencing or causing hurt, injury, or loss. In fact, the meaning of safe is free from harm or risk. Traffic accidents currently are a major socio-economic problem. According to Kapp (2003), annual accidents account for 1.26 million fatalities, 50 million injuries, and economic losses of US$518 billion worldwide. Safety, as represented by accident rate, thus is an important indicator of the social cost of transportation.

(3) Accessibility

Accessibility has been applied to evaluate the network development in transportation planning and to measure the potential of regional economic performance in urban planning (Hansen, 1959). In fact, Martellato et al. (1998) provided that accessibility refers to the potential opportunities of the interactions between the urban spatial patterns. Levine and Garb (2002) measured the accessibility based on the ease of interactions between network nodes. Besides, accessibility represented the connection between origins and destinations (Ingram, 1971) or that between activities (Wachs and Koenig, 1979). In addition, accessibility indicated the difference in the attraction between activities (Burns, 1979).

(4) Externality

Governments traditionally have constructed extensive transport infrastructure to enhance transport efficiency. Mass emissions caused by motorized vehicles have led to the greenhouse effect and ozone hole, and have also threatened the ecological system upon which human life depends (OECD, 2004). Therefore, the transportation policies of developed countries have changed during recent years to mitigate adverse environmental impacts.

2.2 Quality of Life

In the transportation planning, transport policy-makers must simultaneously consider the trade-off between differences in the supply of transport infrastructure or modes, in addition to the various needs of stakeholders. Transportation needs are derived from daily life and comprise diverse urban activities. Failure to satisfy basic stakeholder needs can negatively impact quality of life. Quality of life is defined by the World Health Organization Quality of Life (WHOQOL) Group (1998) as the perceptions of individuals regarding their goals, expectations, standards, and concerns. Furthermore, Diener et al. (1999) defined quality of life as a multi-dimensional construct, comprising the level of satisfaction of important individual needs. As a result, the simultaneous consideration of richness and evenness creates issues related to transport diversity.

Although the common identified definition of sustainability is not available, van Kamp et al. (2003) examined the overlap between the concept so quality of life and sustainability, as a result of which the two concepts are frequently used as synonyms. In fact, Yang (2002) argued that the need for quality of life involves not only individual health, safety, social justice, income, and freedom, but also relationships with salient features of the environment, such as fresh air, clean water, and natural surroundings. Besides, Shafer et al. (2000) identified sustainability as the ability to develop good quality of life in both the present and the future. In addition to indicators, the Commission of the European Communities (2002) introduced the Sustainability Impact Assessment (SIA) process for developing an integrated assessment system based on existing fragmented sectoral systems, for identifying impacts of policies, and for determining the trade-off among competing objectives. McMahon (2002) examined whether the needs should combine both top-down and bottom-up approaches to measure quality of life and to monitor sustainability.

The concept and content of quality of life and sustainability are similar. However, satisfaction of needs differentiate quality of life from sustainability in this study. Quality of life represents the basic level of needs satisfied with which stakeholders certainly live without deficiencies. Likewise, Topolski et al. (2004) believed that quality of life, utilized as a descriptor, evaluative report, or normative statement, may assess the living status referring to the limitations of socio-economic activities. In comparison, sustainability indicates the expected target of sustainable development. Sustainable development is generally conceived as finding a balance among environmental, social and economic qualities (George, 2001; Kasemir et al., 2003; Steg and Gifford, 2005; Ness et al., 2007). Moreover, the WCED (1987) defined sustainability as “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. Additionally, Pope et al. (2004) suggested that it is necessary to explore not only the direction to sustainable target but also the distance from sustainability.

Transportation behaviors are the most common activities in daily life. Needs for transport infrastructure and services differ among transport stakeholders. Although most transport services are provided by public sections, the service levels of transport system have increased substantially around the world during past decades, particularly in metropolitan areas of developed countries, due to a shift towards a culture of requiring that the performance of government should be as efficient as that of private businesses. This raises concerns regarding maintaining transport quality in the face of changing social and lifestyle patterns that are generating increasingly diverse travel needs. In fact, policy-makers cannot simply create services, provide them, and hope for the best. To decide how to improve service quality of transport system, policy-makers must first understand how stakeholders view their services via valid measuring instruments to effectively measure user reactions to those services (Carr, 2007).

Numerous studies have discussed service quality in transport industries. Nathanail (2008) addressed service quality for railway passengers. Qualitative studies of bus users were presented to improve understanding of traveler attitudes regarding public transport and explore perceptions of bus service quality (Hensher et al., 2003; Wall and McDonald, 2007). Moreover, lots of literatures assessed service quality for airline and air cargo services through various constructs and measures to analyze the relationships among performance, competition, critical factors, and customer satisfaction (Rhoades and Waguespack Jr, 2000; Tsaur et al., 2002; Gilbert and Wong, 2003; Gursoy et al., 2005; Chen and Chang, 2005; Liou and Tzeng, 2007; Wang, 2007; Pakdil and Aydm, 2007; Park, 2007). Additionally, Beirao and Cabral (2007) conducted in-depth interviews to obtain the main influences on modal choice of travelers and attitudes towards public transport and private cars. However, few studies have discussed total quality management as a method of improving urban transport system service quality to satisfy stakeholder needs.

Service quality is more difficult to describe and assess than product quality owing to the intangibility, heterogeneity, inseparability, and perishability of the service industry. Gronroos (1984) argued that customer perceptions of service quality comprise technical quality, namely the assessment of the core services that the buyer receives from the seller, and functional quality, namely the evaluation of the service delivery process reflecting customer experiences of service quality. Parasuraman et al. (1985) proposed a gap framework that identifies overall service quality using five gaps, where the first gap occurs when customer expectations regarding service differ from managerial perceptions of those expectations. Meanwhile, the fifth gap, service quality, refers to the degree and direction of difference between customer perceptions and expectations. For service providers, precisely identifying customer expectations is the most critical step in defining service quality (Zeithaml et al., 1990). Besides, Parasuraman et al. (1988) suggested the SERVQUAL scale based on factor analytic psychometric research in which service quality was assessed using five constructs, including tangibles, responsiveness, assurance, empathy, and reliability.

SERVQUAL has clearly contributed substantially to understanding service quality as well as highlighting the importance of stakeholder reactions to services (Carr, 2007). The original SERVQUAL involves 22 items arranged into five dimensions, and provided a basis for the following labels and concise definitions (Parasuraman et al., 1988). Tangibles: Physical facilities, equipment, and personnel appearance; Responsiveness: Willingness to assist stakeholders and provide prompt service; Assurance: Service provider knowledge and ability to inspire trust and confidence; Empathy: Provision of individualized care and attention for stakeholders; Reliability: Ability to perform the promised service dependably and accurately. However, the fact that numerous studies utilize SERVQUAL and the conceptual model to measure service quality results in inconsistency in attributes among different industries (Triplett et al., 1994; Jiang et al., 2000; Kettinger and Lee, 2005). Furthermore, Carman (1990) suggested that the items and dimensions should be redesigned based on the procedures proposed by Parasuraman et al. (1988) according to industry characteristics since SERVQUAL has been developed to provide a basic skeleton for measuring service quality. Additionally, Hinkin (1998) provided a process for developing survey questionnaire scales. The items for assessing service quality of transport system are thus based on the five dimensions and scale development process mentioned previously.

2.3 Diversity

Transport diversity is defined based on numerous concepts including sustainable transportation, quality of life regarding to transport behaviors and the diversity considering difference as well as equity simultaneously. However, no attempt is made to provide a complete coverage of all components. Instead, the aim is to introduce the representative elements and organize them to construct the conceptual framework.

2.3.1 Characteristics of Diversity

Ecologists believe that ecosystems are influenced by various levels of diversity. From the perspective of system analysis, the diversity of components in ecosystem has been useful in constructing feedback loops among elements (May, 1976). Links among feedback loops have enabled nutrient cycles and information feedbacks as well as provided a basis for ecosystem self-regulation (Odum, 1983). Ecosystem resilience has resulted from system diversity, as well as energy and information flow speed (Ferguson, 1996). Furthermore, Rammel and van den Bergh (2003) suggested that higher diversity may contribute to ecosystem stability. Diversity thus critically influences ecosystems. Additionally, several studies have attached importance to the relationship between diversity and stability in socioeconomic systems. Malizia and Ke (1993) identified diversity and competitiveness as important influences on unemployment and stability. Furthermore, Templet (1999) examined the relationship between diversity and economic development via empirical studies of energy consumption. Templet proposed that sustainability is enhanced by strategies that promote diversity and resource use efficiency in economic systems. Moreover, de Vasconcellos (2005) proposed that transportation policies should consider the social diversity expressed by income level to meet the demand of non-automobile users.

Diversity has been considered in analyses of the heterogeneity of community structure. Indicators used to measure biodiversity are based on two essential factors, namely species richness and evenness (Hamilton, 2005). Richness refers to the species number, while evenness denotes the relative abundance of the different species. The most common index used to assess diversity is the Shannon-Weaver Index, also known as Entropy, shown as Eqn. 2-1 and Eqn. 2-2 (Odum, 1993).

$$H = -\sum_i P_i \times \ln P_i \tag{2-1}$$

$$P_i = \frac{n_i}{\sum_i n_i} \tag{2-2}$$

where n_i denotes the number of individuals belonging to species i, P_i represents the proportion of the population of species i to the total population, and *H* is the value of diversity. The diversity index has a value exceeding 0. Evenness, shown as Table 2-2, refers to that the distribution becomes more uniform with increasing diversity while system A and system B include equal number of species.

TABLE 2-2 An example describing the relationship between diversity and evenness

		Proportion of species			
Systems	Diversity value	Species 1	Species 2	Species 3	Species 4
System A	0.940	0.7	0.1	0.1	0.1
System B	1.386	0.25	0.25	0.25	0.25

In contrast, higher diversity indicates a larger number of species under the same distribution of each species population. For example, the system A with a richer species has a higher diversity while both systems have a uniform distribution in Table 2-3.

TABLE 2-3 An example describing the relationship between diversity and richness

		Proportion of species				
Systems	Diversity value	Species 1	Species 2	Species 3	Species 4	Species 5
System A	1.609	0.2	0.2	0.2	0.2	0.2
System B	1.386	0.25	0.25	0.25	0.25	--

In fact, Reeves (2005) believed that diversity without equity could only address difference. From the perspective of transport diversity, richness indicates that stakeholder needs are considered more comprehensively. Conversely, evenness denotes a condition in which needs are satisfied more equitably. Therefore, greater diversity indicates that as the distribution between compartments becomes more equitable, the gradients between compartments reduce, and larger numbers of compartments come to be involved in the system (Muller, 1998)

2.3.2 Definition and Measurement of Transport Diversity

Diverse transport stakeholders have different needs for urban transport infrastructure and services. The main issue in transport diversity thus becomes how to more equitably satisfy diverse stakeholder needs. Transport diversity is defined as different levels of satisfaction within stakeholder needs, expressed as appropriate indicators and measured using the variations in achievement among indicators. Additionally, minimizing the indicator gaps, the remainder of the needs achievement, between the expected goals and present values (as shown in Eqn. 2-3) is a key objective in urban transportation planning. The normalized value prevents indicator gaps resulting from differences in unit scale.

$$m_y = \frac{O_y^{goal} - V_y}{O_y^{goal} - O_y^{threshold}} \qquad (2\text{-}3)$$

where m_y denotes the normalized gap of the indicator referring to stakeholder need y, O_y^{goal} and $O_y^{threshold}$ represent the expected goal and minimum threshold of need y, respectively, and V_y is the present value of need y. The value of the normalized gap exceeds 0, and the degree of need satisfaction increases as the gap approaches 0. Meanwhile, n_y denotes the positive remainder of the gap of indicators, namely the achievement indicated by Eqn. 2-4, which is plugged into Eqn. 2-2. Moreover, transport diversity represents the equal satisfaction of stakeholder needs in the form of the Shannon-Weaver Index, presented in the form of Eqn. 2-3. Transport diversity calculated with Eqn. 2-3 comprises two components: richness, measured by the number of stakeholder groups, which determines the number of terms in the summation, and equability, measured by the evenness of needs distribution across groups.

$$n_y = Max(0, \quad 1 - m_y) \tag{2-4}$$

2.3.3 Measurement with Goal and Threshold Value

Based on Muller (1998), higher transport diversity implies that needs are satisfied more equitably when they are considered more comprehensively. Different transport stakeholders, such as users of different modes, operators, engineers, planners and regulators, have diverse needs in relation to transportation infrastructure and services (Eckton, 2003; Koontz, 2003; Sohail et al., 2006; Soltani and Allan, 2006). Additionally, the needs of vulnerable groups, including low-income, disabled, elderly and remote users, should not be neglected (de Vasconcellos, 2005; Loo and Chow, 2006). Urban transportation system quality should be acceptable to all individuals, and moreover should consider their specific needs and abilities. Higher transport diversity may be caused by planners taking more stakeholder needs into consideration. However, transport diversity is not increased by policy-makers considering the involvement of more stakeholder needs but ignoring the need to provide for different needs equitably. For instance, given four needs with achievements of 0.2, where system diversity is 1.39, if a new need with achievement of 0.9 is added to the system, then system diversity will reduce to 1.34. Therefore, more comprehensive consideration of stakeholder needs within an urban transportation system cannot ensure higher diversity. The equity of the level of needs satisfaction thus should be regarded as the essential factor for transport diversity.

Biodiversity depends on both richness and evenness. In this context evenness describes the equality between the populations of every species in Eqn. 2-2. However, formal equality does not represent the substantive equity from the perspective of social science. For example, the equality between mode-shares, including mass transit, private vehicle, taxi and bicycle, denotes that each mode shares 25% of the trips in a transportation system. This sharing would increase diversity but would not be a sustainable target in urban development. To make the equity of needs satisfaction meaningful, setting targets and thresholds is crucial to diversity analysis. Planners could set targets and thresholds for each mode. For instance, the mode-share target and minimum level of transit might be set at 60% and 30%, respectively. The achievement of transit would be 0 while the present value (25%) would be lower than the threshold (30%), which would reduce diversity. Loo and Chow (2006) demonstrated that the threshold value for sustainability varies with the perceptions of stakeholders, which differ across time and space. Moreover, goals reflecting the expectations of management as well as stakeholder needs must be accepted at the commencement of the process (Barlas and Yasarcan, 2006). Additionally, Steg and Gifford (2005) proposed that governments should set target and monitor transport system progress towards sustainability. Consequently, goal and threshold values should be set via collaborative planning, specifically through consensus building, based on stakeholder and public opinions, along with feedback from experts.

2.3.4 The Priority of Needs

No consensus norm exists for the best method of achieving the stakeholder needs equitably in transport diversity to suit all conditions because the diverse cities provide distinct development backgrounds. In fact, critical priorities, standards, and constraints differ among groups, time and space (Steg and Gifford, 2005; Jeon et al., 2006). Issues related to weighting method thus become important Ordinary weighting methods weigh the criteria according to the importance through preference survey. For example, the proportion of needs achievement including w_i, the weight of indicator *i*, with Simple Additive Weight (SAW) can be calculated by Eqn. 2-5.

$$P_i = \frac{w_i n_i}{\sum_i w_i n_i} \qquad (2\text{-}5)$$

However, Eqn. 2-5 appears not to represent the different importance of needs but rather of needs achievement, leading to loss of a convincing planning rationale. Accordingly, the traditional weighting method does not be applied to the importance of needs in this study. This study thus suggests that the importance of needs should be implied by the goal and threshold value settings. Studies of service quality reveal that expected satisfaction can substitute for the priority of importance (Chen and Chang, 2005; Deng, 2007) while needs are one-dimensional quality elements (Kano et al., 1984). The more important needs require higher threshold values to promote sustainable quality of life. This study thus sets the weight of stakeholder needs regarding transport diversity by setting the goal and threshold values via consensus building meeting in which stakeholder needs are surveyed via questionnaires, the sustainable targets, and the basic level of quality of life. The needs which are the furthest from the target, especially those not reaching threshold, should be given the highest priority.

2.4 Conceptual Framework

This chapter contains a review on literature for crucial factors and their possible connections to transport diversity. The review ended in the construction of a conceptual framework of transport diversity. The fundamental of transport diversity fits both the concept of quality of life and sustainability in terms of the transport needs. Accordingly, the method used here to assess transport diversity considers the balance between sustainable development and quality of life objectives through consensus among stakeholders, government, and experts. By setting goal and threshold values, as well as measuring progress towards targets, the framework presented in this study effectively assesses sustainability and quality of life.

Stakeholder needs are determined based on criteria of sustainability as well as quality of life. The emerging consensus is that sustainable transport systems should efficiently provide users with equitable and safe access to basic needs effectively, stimulate economic development, and not cause environmental harm (Pope et al., 2004; Jeon et al., 2006). Sustainability and quality of life have recently become key planning objectives. Items widely considered in measuring sustainability and quality of life in relation to transport system include social justice, accessibility, safety, universal design, economic health, environmental quality etc. (McMahon, 2002; Pope et al., 2004; Jeon et al., 2006; Ness et al., 2007). Improving the sustainability and quality of life with regard to transportation requires the support of transport diversity. The conceptual framework used to assess transport diversity for promoting sustainability and quality of life is shown in Figure 2-1 based on the references above. Figure 2-1 shows the stakeholders affecting or affected by subsystems, such as roads, MRT, parking and pedestrian lanes, are. Since transportation needs prevail over those of daily life including diverse socio-economic activities, the constitution of diversity indicates different needs for daily activities based on quality of life.

2.4.1 Economic Efficiency

The construct of economic efficiency is composed of mobility, economic health, and reliability. Mobility refers to the efficiency of vehicle movements through the road system. Moreover, mobility describes individual ease of movement (Levine and Garb, 2002; Levinson, 2003). As a result, satisfying the user need for mobility refers to developing the capability to overcome spatial resistance. Besides, both short-term and long-term cost efficiency should be considered in the construct of economic health. Stakeholder needs in this construct include robust public funding, economic growth, technical research and development, and the revenue of operators (McMahon, 2002; Pope et al., 2004; Topolski et al., 2004; Loo and Chow, 2006; Jeon et al., 2006). Furthermore, reliability describes the consistent, stable and standard outcomes when the experience is repeated under the same conditions. Sanchez-Silva et al. (2005) addressed the fact that a reliable transport system should provide a stable level of service. Therefore, the key factor influencing needs satisfaction with regard to reliability thus represents whether the extraneous travel time and expenses are invested.

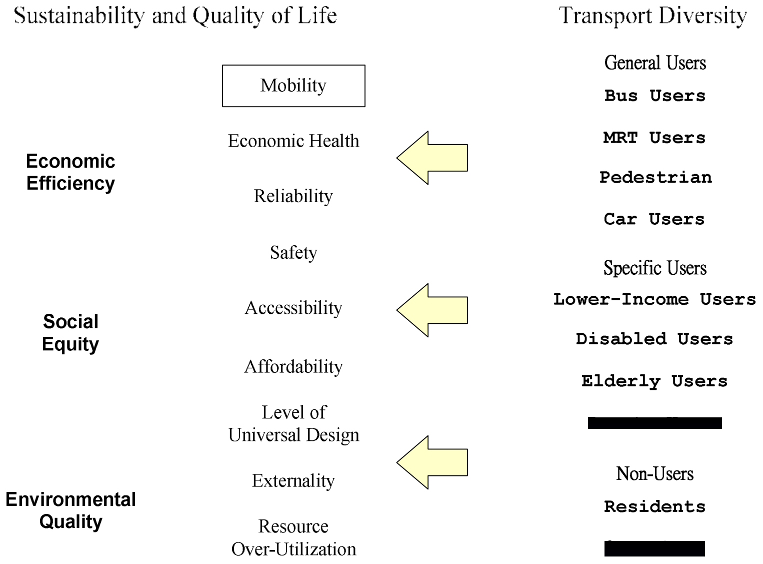


FIGURE 2-1 Conceptual framework

2.4.2 Social Equity

Social equity issues in transportation involve equitable accessibility to major socio-economic centers and equitable level of safety (Jeon et al., 2006). Safety is defined as minimizing risk of hurt, injury, or loss. Traffic accidents are a major socio-economic problem, accounting for millions of fatalities and injuries, as well as billions of dollars of economic losses worldwide. Safety thus is an important criterion in social equity with regard to (McMahon, 2002; van Kamp et al., 2003; Pope et al., 2004; Steg and Gifford, 2005; Ness et al., 2007). To achieve the need of safety, planners should consider methods of decreasing the traffic accidents and mitigating associated casualties. Additionally, accessibility is utilized to evaluate network development in transportation planning and to measure the potential of regional economic performance in urban planning. In fact, Martellato et al. (1998) demonstrated that accessibility refers to potential opportunities with regard to the interactions among the urban spatial patterns. Levine and Garb (2002) measured accessibility using the ease of interactions between network nodes. Besides, accessibility represents the connection between origins and destinations or between activities (Wachs and Koenig, 1979). Additionally, accessibility indicates differences in attraction between activities (Burns, 1979).

Moreover, a poverty gap caused by income level and distribution leads to issues of affordability to support socio-economic activities (van Kamp et al., 2003; Steg and Gifford, 2005; Jeon et al., 2006; Loo and Chow, 2006; Ness et al., 2007). Likewise, de Vasconcellos (2005) addressed that the problem of low-income users paying the highest proportion relative to disposable income to make essential trips of any group of public transport users. Consumption of daily essentials may have to be reduced in the event of transportation becoming unaffordable. Quality of life thus is negatively affected. Therefore, ensuring the affordability of basic trips is necessary for achieving an equitable society. Besides, universal design, otherwise known as barrier-free design, relates to infrastructure and services satisfying the basic needs of vulnerable groups, such as the handicapped, disabled, or elderly users (Loo and Chow, 2006). Furthermore, level of universal design could improve the safety, comfort, and convenience of transportation systems. As a result, the level of universal design should be the critical item in constructing social equity.

2.4.3 Environmental Quality

Governments have traditionally constructed extensive transport infrastructure to enhance transportation efficiency. Motor-vehicle emissions have contributed to the greenhouse effect and ozone hole, and consequently threatened the very ecological system upon which human life depends (OECD, 2001). Emissions also influence health and quality of life. Past research on environmental quality focused on negative externalities, like emissions, noise, waste, water pollution, and habitat destruction (McMahon, 2002; van Kamp et al., 2003; Pope et al., 2004; Steg and Gifford, 2005; Jeon et al., 2006; Soltani and Allan, 2006; Ness et al., 2007). In response to such research, transportation policies in developed countries have changed during recent years to mitigate adverse environmental impacts. Moreover, excessive use of resources, especially of non-renewable resources, should also be considered in relation to environmental quality (McMahon, 2002; van Kamp et al., 2003; Pope et al., 2004; Steg and Gifford, 2005; Loo and Chow, 2006; Ness et al., 2007). As a result, the development of green energy and energy-saving vehicles offer means of addressing concerns in this area.

Accordingly, the proposed transport diversity framework represents a long-term planning viewpoint for improving sustainability and quality of life. Nine criteria referring to transportation needs based on transport diversity, such as mobility, economic health, reliability, safety, accessibility, affordability, level of universal design, externality and resource over-utilization, with distinct levels of expected and threshold values for different stakeholder groups are derived from previous literatures. For example, the threshold value of low-income users to deficiently support their basic travel needs might significantly differ from the threshold values of general users. In fact, the improvements of transportation infrastructures and services to assist specific users in achieving their basic needs levels would not negatively impact the perceptions of general users in their trips.

In urban transportation system, an individual belongs to various stakeholder groups in the different space or time. For instance, from the trip chain perspective, an individual utilizing seamless intermodal system might play several roles in the trip. The individual indicates one of residents (non-user) before starting his/her trips, a private vehicle and transit user in park and ride situation, as well as a pedestrian after leaving transit system to the destination. In order to clarify the determinations of following analyses, the criteria identifying the priorities of classifications of stakeholder group are described in Figure 2-2.

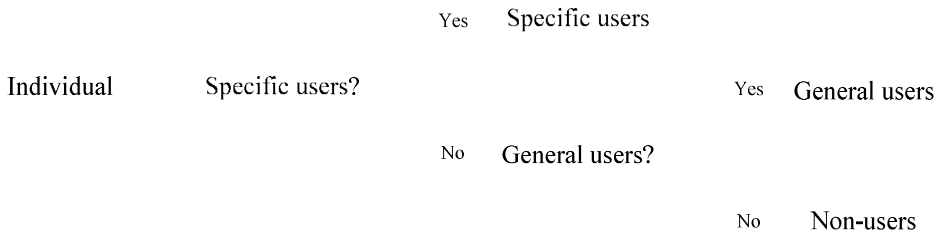


FIGURE 2-2 Classification of stakeholder group

CHAPTER 3 RESEARCH APPROACHES

The purpose of this chapter is to introduce the methodologies applied in this study. An optimal indicator system for transport diversity is determined in this chapter. Such a system should identify stakeholder needs and determine appropriate indicators that reflect those needs via the questionnaires and professional information. Section 3.1 discusses the related indicators referring to stakeholder needs based on the determination. A hybrid system simulation method for examining causality in transportation system is presented in Section 3.2. The mathematical programming for optimizing resource allocation within transport diversity is proposed in Section 3.3.

3.1 Indicators of Stakeholder Needs

According to the transportation user needs resulted from the factor analyses and the transport diversity criteria based on sustainability and quality of life, the quantitative indicators representing stakeholder needs are introduced in the following, including externality (environmental impact), safety, accessibility, mobility, reliability, affordability, resource over-utilization, operator profit (economic health) and level of universal design.

(1) Externality

Along with the waste, hydro-resource pollution and the negative habitat impacts during constructing transportation infrastructures, externalities caused by transportation consist of air pollution, noise and vibration in operation periods. Regarding to the quality of life and sustainability, the greenhouse effect causing global warming has come into vogue discussions in recent decades. In fact, how to mitigate the emissions has become more crucial challenges than other negative influences nowadays.

Air pollution, measured in terms of emissions per trip by each mode of transportation, is considered as the substitute for externality. Most costly types of emissions are nitrogen dioxide (NO_2) and particulate matter (PM10). In Taiwan, the Pollutant Standard Index (PSI) is utilized for representing atmospheric pollution emissions. The index consists of the criteria pollutants, such as PM10, sulfur dioxide (SO_2), NO_2, carbon monoxide (CO), and ozone (O_3). For each pollutant, a sub-index is calculated from a segmented linear function that transforms ambient concentrations onto a scale ranging from 0 to 500. The PSI is calculated as the maximum of sub-index. The value of PSI exceeding 100 is considered by USA EPA research to negatively impact human health. The indicator of externality shown in Eqn. 3-1 is summed up the maximum of sub-index, the same calculation but the different duration and unit as PSI.

$$V_{Emi_x^m} = \sum_m \alpha_{Emi}^m \times T_x^m \tag{3-1}$$

$V_{Emi_x^m}$: Emission for mode m in zone x,
T_x^m : Monthly trip amount for mode m in zone x,
α_{Emi}^m : Average emission per trip for mode m.

(2) Safety

Accidents, such as injure, loss of life and property damage, are potential results of transportation behavior. The accident rate traditionally is calculated in terms of accidents per million vehicle-kilometers or the number of accident fatalities and injuries (casualties) per 10,000 registered vehicles. However, the weightings in fatality accidents (class A1) and injury accidents (class A2) are assumed as equal because of the absence of the global acceptable equivalents for the different accident classifications. Moreover, evaluating annual vehicle-km is difficult owing to limited data availability. This study thus defines accident rate as the number of accident casualties per 10,000 registered vehicles, as shown in Eqn. 3-2, with lower accident rate implying higher safety.

$$V_{AR_x} = \frac{N_x \times 10^4}{RV_x} \tag{3-2}$$

V_{AR_x} : Accident rate of zone x,
N_x : Number of accident casualties in zone x,
RV_x : Number of registered motor vehicles in zone x.

(3) Accessibility

The indicators of accessibility are different due to the distinct definitions of accessibility among public transit, private vehicle and pedestrian. Based on the literature review, accessibility can be used to assess the equitable distribution of transport infrastructure and services. In public transit sub-system, the accessibility indicated in Eqn. 3-3 is defined as the ratio of the resident population served by public transit, including mass rapid transit (MRT) and bus, to total population. Public transit serving population is identified as the population residing in the service area in which the public transit service is accessible on foot, i.e. 500 meters from the MRT, bus or feeder bus stations.

Because accessibility is determined as the opportunities of the interactions between spatial patterns, higher accessibility implies more nodes served by public transit and users move from their origins to destinations more easily.

$$V_{Ac_x^m} = \frac{\sum_k p_x^k}{TP_x} \qquad (3\text{-}3)$$

$V_{Ac_x^m}$: Accessibility in zone x, $m = MRT, bus$

TP_x : Total population in zone x,

p_x^k : Resident population in service area of station k in zone x.

On the other hand, road connectivity is employed as the indicator to examine accessibility for private vehicles in this study. Eqn. 3-4 shows the gamma index, one of the measures of road connectivity, which considers the relationship between the numbers of observed and potential links. The gamma is between 0 and 1 where a value of 1 indicates a completely connected network.

$$V_{Ac_x^m} = \frac{2\gamma_x}{nd_x(nd_x - 1)} \qquad (3\text{-}4)$$

$V_{Ac_x^m}$: Accessibility in zone x, $m = motorcycle,\ passenger\ car$

γ_x : Number of links in zone x,

nd_x : Number of nodes in zone x.

Furthermore, pedestrian accessibility shown in Eqn. 3-5 is determined by average pavement width. Meters provide the average measurement unit. The pedestrian friendliness of the system improves with increasing pavement width.

$$V_{Ac_x^m} = \frac{\sum_{j \in x} A_j \times L_j}{\sum_{j \in x} L_j} \qquad (3\text{-}5)$$

$V_{Ac_x^m}$: Accessibility in zone x, $m = pedestrian$,

L_j : Length of link j,

A_j : Effective pavement width of link j.

(4) Mobility

The mobility of transport users is investigated for all transport users except MRT users and pedestrians. In fact, the mobility of MRT users is relatively higher and more predictable than that of other transport users. Meanwhile, the mobility of pedestrians is lower and more stable. Mobility performance for private vehicle users is judged based on the travel speed. Eqn. 3-6 shows the average travel speed calculated by weighting the speed at each link by the length of links. The unit of measurement used is kilometers per hour. Average travel speed is in direct proportion to mobility.

$$V_{M_x^m} = \frac{\sum_{j\in x} S_j \times L_j}{\sum_{j\in x} L_j} \tag{3-6}$$

$V_{M_x^m}$: Mobility of mode m in zone x, $m =$ *passenger car*, *motorcycle*

S_j : Average speed of link j.

The mobility for bus users is measured using the ratio of the travel time from zone *x* to zone *z* by private vehicles to the travel time by bus. The indicator of level of bus service is based on the network performance developed by Blunden and Black (1984) and indicated in Eqn. 3-7. Bus user travel time is calculated from the summation of actual bus travel time (in-vehicle time) and average waiting time. Average waiting time is calculated as half of average bus headway, while average bus headway has a frequency of over 60, and the bus reliability. Bus mobility ranges from 0 to 1. A level closer to 1 indicates higher bus mobility; i.e. smaller difference in travel time from zone *x* to other zones between car users and bus users.

$$V_{M_x^m} = \frac{\sum_{z} TT_{xz}^{private}}{\sum_{z}\left(TT_{xz}^{bus} + \frac{1}{2} \times \frac{60}{Freq_{xz}} \right)} \tag{3-7}$$

$V_{M_x^m}$: Mobility of mode m in zone x, $m = bus$,

$TT_{xz}^{private}$: Ideal travel time (by car) from zone x to zone z in minutes,

TT_{xz}^{bus} : Actual bus travel time from zone x to zone z in minutes,

$Freq_{xz}$: Service frequency in departures from zone x to zone z per hour per direction.

(5) Reliability

Reliability is defined as the probability of failure-free operation for a specified time and space. In transportation system, reliability refers to facilities durability in engineering aspect while it represents punctuality in management aspect. In fact, the discussion of private vehicle reliability is deficient due to the difficulty for determining the failure. Besides, engineering reliability highly relates to what safety concerns. This study thus focuses on the public transit reliability in management aspect.

Public transit sub-system consists of MRT and bus in this study. However, the train punctuality of MRT is relatively higher stable since exclusive right-of-way reduces the impact of external force. The bus reliability indicated in Eqn. 3-8 is the probability of the punctuality in which buses does not fail, i.e. the average waiting time for bus users are less than half of bus headway.

$$V_{rel} = \Pr\left(\overline{TT}^{bus} \leq \frac{1}{2} h^{bus} \right) \tag{3-8}$$

V_{rel} : Bus reliability,

$\overline{TT}^{bus}$: Average bus waiting time,

h^{bus} : Average headway of buses.

(6) Affordability

Affordability refers to the ability of particular consumer groups to bear the cost for a minimum level of a certain service (Fankhauser and Tepic, 2007). The discussion of the relationship among social diversity represented by household income levels, mobility and expenses with transportation in Brazil revealed that the people with the lowest household monthly income had a very low mobility but spent about 30% of income with transportation (de Vasconcellos, 2005). Affordability thus becomes a key issue of social equity.

Moreover, a common acceptable measurement of affordability is expressed as the share of utility payments in monthly disposable income. Therefore, the indicator for affordability considered in transport diversity is calculated as Eqn. 3-9, in which the total transportation expenditure is the product of average cost per trip and the amount of monthly trips.

$$V_{Af^m} = \frac{\hat{T}_q^m \times F^m}{Inc} \tag{3-9}$$

V_{Af^m} : Affordability in mode m, $m = MRT, bus, passenger\ car, motorcycle$,

$\hat{T}_q^m$: Monthly trip amount for individual q taking mode m,

F^m : Average travel cost (fare box revenue) per trip for mode m,

Inc : Monthly disposable income.

(7) Resource Over-Utilization

Along with externality, indicators that focus on non-renewable resources are a particularly important environmental issue for sustainability. For instance, Canadian sustainable development indicators emphasize the use of non-renewable resources, renewable resources, land and soils, and air and water qualities (Wale, 2000). Tong et al. (2008) argued that the efficiency of non-renewable resources utilization is a critical indicator for assessing sustainable development performance.

Additionally, the most important non-renewable resource in transportation system implies fossil energy. The indicator shown as Eqn. 3-10 expresses the consumption of fossil energy by the product of monthly trips and the average energy consumption per trip for each mode *m*, where *m* includes MRT, bus, passenger car and motorcycle. Oil equivalent provides the average measurement unit.

$$\begin{gathered} V_{EnCs} = \sum_m \alpha_{Cs}^m \times T^m \\ \sum_x T_x^m = \sum_q \hat{T}_q^m = T^m \end{gathered} \tag{3-10}$$

V_{EnCs} : Consumption of fossil energy,

α_{Cs}^{m} : Average energy consumption per trip for mode m.

(8) Operator Profit

From operator perspective, health economy implies positive profit assisting enterprise in financial sustainability. Eqn. 3-11 reveals the operator profit represented by the product of monthly trips and the difference between average fare box revenue and average operational cost per trip for MRT and bus.

$$V_{R^m} = \left(F^m - C^m\right) \times T^m \tag{3-11}$$

V_{R^m} : Operator profit for mode m, $m = MRT, bus$,

C^m : Average operational cost for mode m.

(9) Level of universal design

Level of universal design emerged from barrier-free design and assistive technology strives to be a broad-spectrum solution to helps everyone rather than separate and stigmatizing solutions for people with disabilities. Level of universal design is a part of activities around daily life. However, level of universal design is not adopted towards any great extent in transportation industries, particularly in public transit. The measurement of level of universal design is thus determined as the ratio of barrier-free facilities to crucial equipment (Eqn. 3-12), such as the entrances to terminals, platforms and vehicles, circulation and so on.

$$V_{UD^m} = \frac{\sum u^m}{Fac^m} \tag{3-12}$$

V_{UD^m} : The level of universal designt for mode m, $m = MRT, bus$,

u^m : Amount of barrier - free facilities for mode m,

Fac^m : Amount of toal facilities for mode m.

3.2 A Hybrid Systematic Simulation Tool

To explore system behavior, this study constructs a systematic simulation model to determine the causal relationship among fundamental factors in urban transportation system. The proposed decision support model for simulating the effects of resource allocation policies on transport diversity can help planners decide when and how to invest transportation infrastructure and services.

3.2.1 Resource Allocation

Transportation systems consist of infrastructure, modes, and stakeholders. Different transport stakeholders with diverse demands have different needs for transportation infrastructure and services resulting in a diversity of needs. In fact, in transportation planning, transport policy-makers must simultaneously consider the trade-off between differences in the supply of transport infrastructure or modes, as well as the various needs of stakeholders. Feng and Hsieh (2009) suggested the concept of transport diversity, defined as different levels of satisfaction within stakeholder needs and measured using the variations in achievement among needs, to assess the performance of urban transportation system. Two approaches to improving transport diversity are goal setting (demand side) and resource management (supply side). If demand side parameters, such as classifications and expected goal values, are given, the critical issue for decision-makers is how to allocate finite available resources to realize greater transport diversity referring to more equitable achievement of stakeholder needs.

Resource management can improve transportation system performance by increasing resource quantity, capacity and utilization. Resource utilization is the main tool used to influence transportation performance, while the quantity and related capacity of resources are finite and either expensive or difficult to increase. Additionally, decision-makers can impact resource utilization via the strategies used to allocate resources among policies. Applying inappropriate investments to given stakeholder needs causes bias that reduces equity and wastes resources which could otherwise be utilized more efficiently (Shohet and Perelstein, 2004). Consequently, the efficient and effective allocation of limited resources among policies offers a realistic management opportunity for improving transportation performance.

Kuhn and Madanat (2006) proposed optimization models to deal with asset allocation of the magnitude of maintenance and rehabilitation. Furthermore, Bigotte and Antunes (2007) compared the exact model and the heuristic methods, such as Genetic Algorithms (GA), Tabu Search, and a specialized local search heuristic, to illustrate the social infrastructure allocation. Wang et al., (2007) proposed a GA model for equipment investment and allocation in portfolio planning. Moreover, Chu and Durango-Cohen (2008) introduced a time-series model named ARMAX to support the allocation of resources to preserve infrastructure facilities. Withanachchi et al., (2007) assessed the impact of resource allocation on public health service provision according to the discussion of relationship among mortality rate, capital-stock, labor-stock and the patient characteristics. With data from the German economy, Conrad (2000) provided a comprehensive discussion of transportation resource allocation based on detailed microeconomic model. Resource allocation is often based primarily on the societal benefits of transportation infrastructure and service investment.

Resource allocation policies impact system performance. Gorman (2008) aimed that appropriately designed infrastructure allocation can decrease the cost and improves the quality of life since resource allocation policies direct influence on safety, environment and delays. However, few studies have explored resource allocation policies because of the difficulty of designing, implementing, and quantifying system relationships due to associated uncertainty, feedback interaction, and complexity (Nguyen and Ogunlana, 2005; Kang and Jae, 2005). The design of resource allocation policies is complicated by iteration and delays in implementing allocation decisions (Udwadia et al., 2003). Iteration creates closed work flow in which interactive or interdependent relationships between parameters can be traced and checked for optional change requirement (Yeh et al., 2006).

3.2.2 Systematic Approaches

Resource allocation for systems in which diverse variables are linked by rich interactions offers various macro benefits (Simon, 1996). The interactions among system elements are crucial for understanding and managing the behavior and performance of transportation systems. However, effectively explaining and controlling system evolution over time is difficult (Lee et al., 2007). To overcome the weakness of traditional techniques, including the inability of traditional tools to explain compounding effects, as well as the inability to handle uncertainty, feedback loops, and iterative processes (Nguyen and Ogunlana, 2005), systems approaches, combining servo-mechanism thinking with simulation for systems analysis (Sterman, 2000), have been introduced to model complex and uncertain behavior and performance of systems (Alberts et al., 2004). Simulated outputs are inadequate for optimizing policy decisions but are considered useful for discussing allocation policies and performances. System dynamics, one of the primary established tools for system analysis, can address rationality in system management (Lane, 2000). Quantitative methods are adopted in system dynamics; for example, the travel speed shown in Figure 3-1(A) is calculated precisely as trip distance divided by travel time. This method enables decision-makers to understand the influence on transport diversity of specific policies and external characteristics, such as population, income and strategy delays.

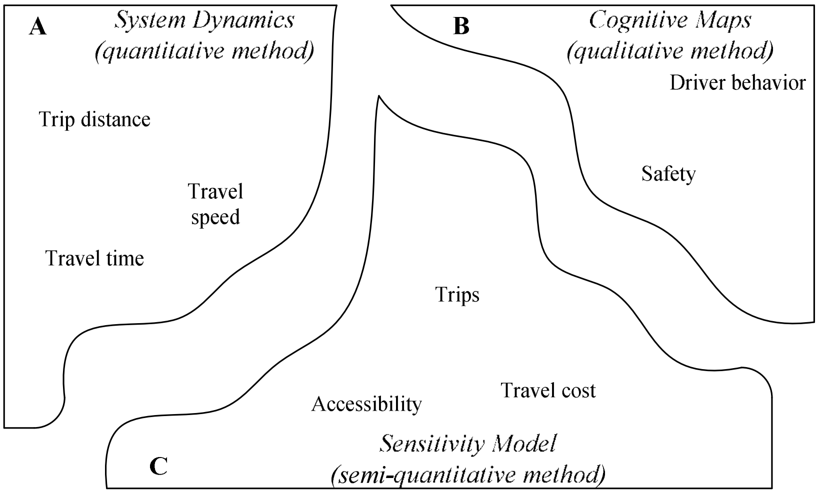


FIGURE 3-1 Torn system approaches

However, the precise relationships between factors might be unavailable owing to the complexity of systems (Stylios and Groumpos, 2000; Chan and Huang, 2004). Cognitive maps are introduced to solve the problems of qualitative factors and linkages. System dynamics modeling emphasizes process, data and exact cause-effect relationships, whereas cognitive maps imply that decision-makers make sense of reality and decide what they should do to forecast how the world would be more preferable in the future (Eden and Ackermann, 2004). For instance, the impacts of driver behavior and travel speed on safety, shown in Figure 3-1(B), are identified via the qualitative cognition of experienced experts. Cognitive maps are employed to resolve conflicts, establish brainstorming, and assist negotiation (Pidd, 1996). Moreover, Kwahk and Kim (1999) identified the characteristics of cognitive maps as: understanding causal relationships, promoting the identification of opportunities and threats, and facilitating system thinking. A major difficulty of cognitive maps lies in determining relationship intensity with a qualitative feature reflecting the cognitive condition of individuals, something which cannot be directly measured. Some researchers indicated relationships using weighted connections, i.e. simple additive weighting (SAW) and analytic hierarchy process (AHP) (Georgopoulos et al., 2003; Kwahk and Kim, 1999). Carbonara and Scozzi (2006) suggested that a collective map representing the consensus of all the stakeholders should be created by analyzing the maps of participants in a decision-making group. Besides, Kang et al. (2004) proposed that the relationships could be derived via a statistical approach.

The most severe challenge of the cognitive maps refers to the algorithm of multiplying an input vector with an adjacency matrix. This implies that the relationships between all factors are linear and addible while the impact intensions are constant. The sensitivity model developed by Vester and von Hesler (1982) is thus employed, which includes system thinking, fuzziness, and simulation of semi-quantitative data. The sensitivity model focuses on pattern recognition and feedback mechanism rather than mono-causal relationship and enabling analysis of complex systems possible via fuzzy logic, which provides a systematic method in which systems can be understood without detailed precision but accurate ordinal parameters (Chan and Huang, 2004). The relationship between variables is identified as the adjustment factors provided by the Transportation Research Board (2000). For example, variation in trip patterns over time, indicated in Figure 3-1(C), is influenced by the levels of cost, accessibility, safety and speed via a semi-quantitative connection. Consequently, to obtain different kinds of relationships that fit real world situation, a hybrid model integrating system dynamics, cognitive maps, and sensitivity model is described in the future.

3.2.3 Decision Support Model

A decision support model is developed to help decision-makers understand system behavior and make investment decisions in relation to urban transportation systems. The decision support model is suitable for any spatial scale considered a holistic system of transportation planning regardless of individual stakeholder needs. The Taipei metropolitan area, the largest in Taiwan, provides the empirical study to discuss the managerial implications of the model. Moreover, owing to the dynamic interactions between the various transportation system elements, systems seem to be misinterpreted by excessive insistence on a specific sector without consideration of the inter-relationships. Therefore, the simplified interactions in the urban transportation system are represented in Figure 3-2. The model comprises various variables and equations and is first divided into four subsystems, namely MRT, bus, passenger car and motorcycle. These subsystems are interrelated via shared parameters, for instance, congestion, safety, and so on. A feedback system is then constructed with all of the variables and connections. Furthermore, the subsystems of pedestrians and bicycles, paratransit (taxi and demand response transportation) as well as parking and the land use patterns are assumed as the external environment.

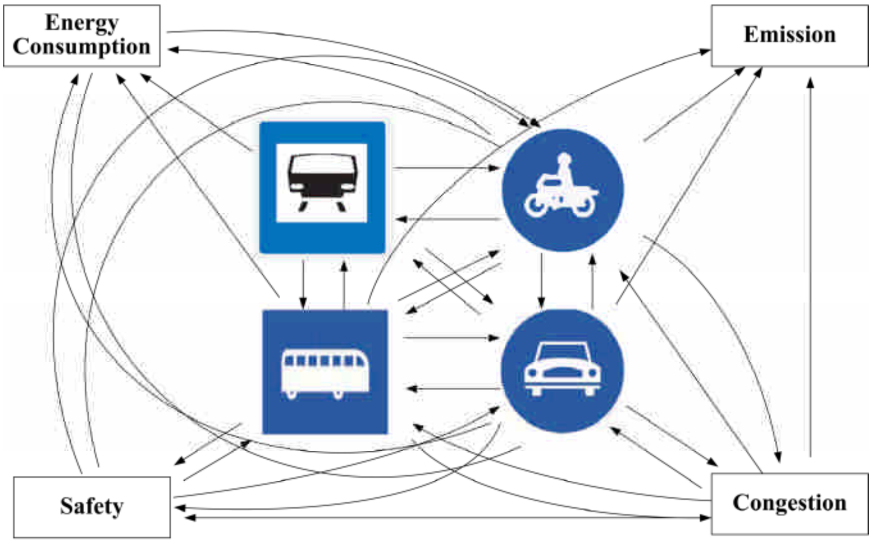
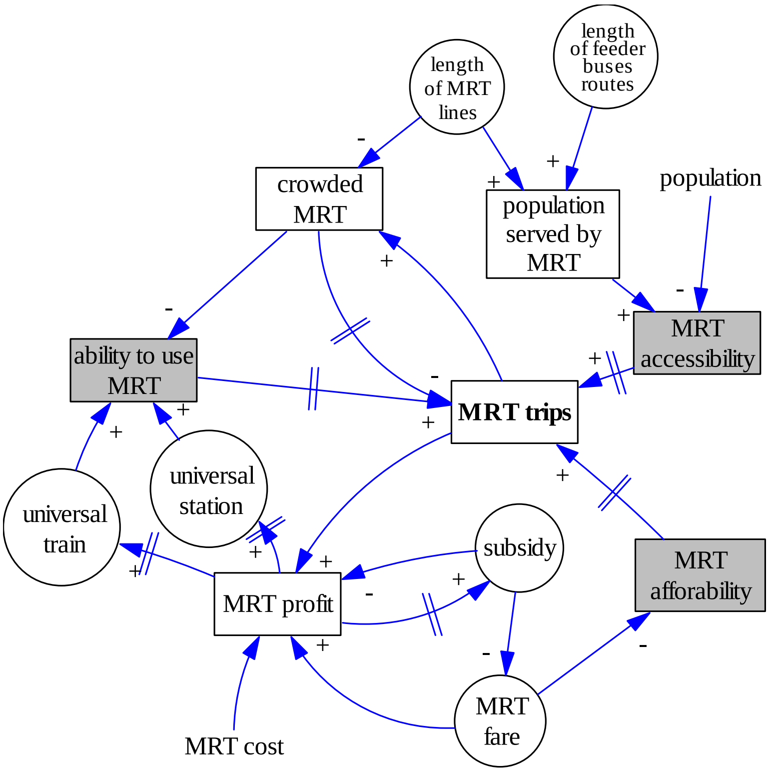


FIGURE 3-2 Simplified interaction in the urban transportation system.

The structure of the MRT subsystem (Figure 3-3) describes both the supply of MRT infrastructure and the needs of MRT users. The crowd phenomenon and subsidy strategy involve two balancing feedback loops, whereas MRT line construction reduces crowd size. On the other hand, there are several growing feedback loops involved in stakeholder needs. The common management instruments for attracting people from other modes, such as infrastructure investment, pricing and subsidy, are taken into account in the subsystem.

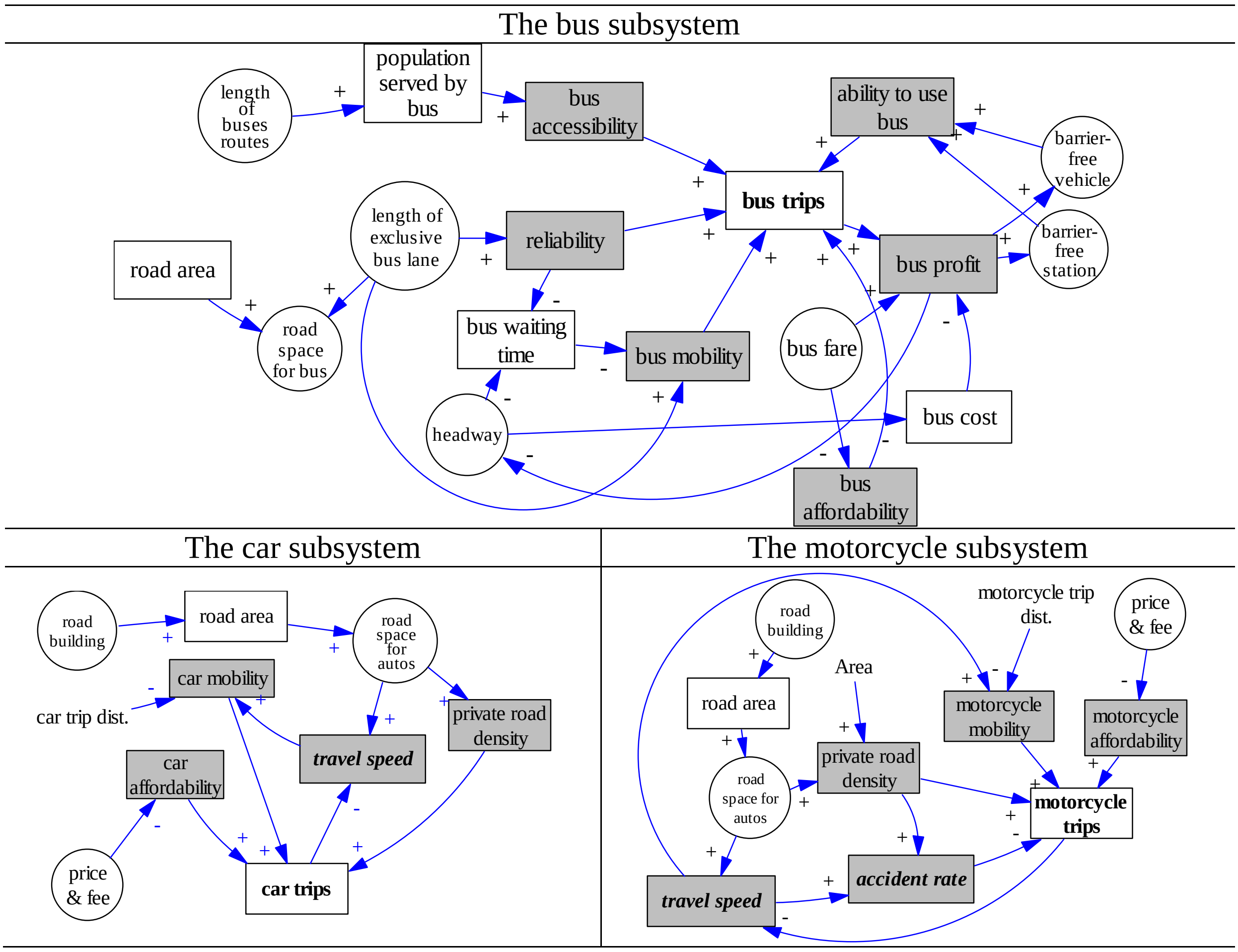
The feedback structures of other subsystems, shown in Figure 3-4, resemble the MRT subsystem described above. The subsystems are capable of self-adjustment because of the negative feedback loops. The negative feedbacks also make the subsystem independent from quantitative growth. Moreover, these subsystems consider that the policies suggested by European Commission (2006), including infrastructure building, road space allocation, pricing, subsidy, regulation, and tax and fees, are used to improve urban transportation systems. The model maps the cause-effect of stakeholder behaviors in transportation systems and policies employed to allocate resources. The interactions among the components represent the use of information and managerial policies to impact system progress.



Legend:
→: a causal relationship with + (-) signs indicating a positive (negative) effect
// signs on the arrows represent the delay effect
▨: variables reflecting stakeholder needs; ○: policy variables

FIGURE 3-3 Feedback structures in MRT subsystems

This study utilizes experimental approaches to examining the relationships between resource allocation policies and transportation system performance are utilized in this study. Individual relationships are specified with simple algebraic formulations indicating the interactions among factors. Many critical inputs are obtained by data mining and expert discussion during pattern identification, model construction, and system simulation. Open participatory meetings emphasize communication, cooperation and compromise among different participants with the objective of building consensus regarding system behavior. These experts fully understanding the information of transportation in Taipei metropolitan area, including the planners, government and scholars, are invited to build consensus. This process is relatively time consuming but provides a significant incentive for group learning.



Legend:
→: a causal relationship with + (-) signs indicating a positive (negative) effect
▨: variables reflecting stakeholder needs; ○: policy variables

FIGURE 3-4 Feedback structures in subsystems

The decision support model integrates the algorithms of system dynamics, cognitive maps and sensitivity model. Different equation types are applied to distinct interactions according to the various attribute linking different elements. For example, the MRT accessibility in Figure 3-3 is defined as the ratio of the population served by MRT and feeder buses to the total population. This is a precise quantitative relationship and represented by Eqn. 3-3, in which the service population of MRT is related to the length of MRT lines and feeder buses routes (Eqn. 3-13). This study explores the connections among the metadata from geographic information system (GIS), such as resident population served by MRT and length of MRT lines and feeder buses routes, through regression model. The analytical results reveal that a non-linear regression model, particularly a logarithm regression model (shown as Eqn. 3-14), has a better goodness of fit and the coefficient *b* is statistic significant at level 0.05.

$$\sum_k p_t^k = \sum_m g_m(L_t^m) \tag{3-13}$$

$$g_m(L_t^m) = a + b\ln L_t^m \tag{3-14}$$

p_t^k : Resident population in service area of station k at time t,
L_t^m : Length of operational lines for mode m at time t, $m = MRT,\ feeder\ bus$.

For example, the coefficients of the function for determining the impact of length of MRT lines on MRT service population are estimated as $a = -3.775$ and $b = 1.141$. The estimated coefficients illustrate a concave downward increasing function which provides a reasonable explanation for decreasing increment of service population due to extended MRT lines. The R^2 of $g_{MRT}(L_t^{MRT})$ achieves 0.92.

Additionally, some linear addible parameters without precise connection are simulated in the form of cognitive maps. For instance, the initial value of universal station and universal train in Figure 3-3 are evaluated via Eqn. 3-12. However, it is difficult to obtain the exact relationships among level of universal design, crowded system and the ability for user taking the MRT. The experts invited to discussion constructed consensuses on influences in Eqn. 3-15 as $\beta_1 = 0.6$, $\beta_2 = 0.75$ and $\beta_3 = -0.8$.

$$V_{Ab_t^{MRT}} = \beta_1 \times V_{UD_t^{MRT,station}} + \beta_2 \times V_{UD_t^{MRT,train}} + \beta_3 \times V_{Cr_t^{MRT}} \tag{3-15}$$

$V_{Ab_t^{MRT}}$: Ability for user taking MRT at time t,
$V_{Cr_t^{MRT}}$: User restrictions caused by crowded MRT at time t.

To transfer the ability for user taking MRT to a feasible domain, this study employs a threshold function to filter insignificant values. The filtered ability for user taking MRT determined as Eqn. 3-16 is applied in following iterations.

$$V_{\overline{Ab}_t^{MRT}} = \frac{1}{1 + e^{-5\times Ab_t^{MRT}}} \tag{3-16}$$

$V_{\overline{Ab}_t^{MRT}}$: Filtered ability for user taking MRT at time t.

Besides, the operation of sensitivity model is applied to formulate some interactions that acted as the adjustment coefficient. For example, Figure 3-3 shows that MRT trips are impacted by MRT accessibility, affordability, crowdedness, and ease of use, and presented as Eqn. 3-17.

$$T_t^{MRT} = \prod f_y^{MRT}(V_{y,t}^{MRT}) \times T_{t-1}^{MRT} \tag{3-17}$$

T_t^{MRT} : MRT trips at time t,
f_y^{MRT} : Ajustment function of need y on MRT trips,
$V_{y,t}^{MRT}$: Level of MRT related need y at time t,
$y = accessibility,\ affordability,\ ability,\ crowdedness.$

The functions of these adjustment relationships are defined such that the vertical axis is the status value of the influencing variable and the horizontal axis is the influence level of adjustment factor on affected variable. For instance, participants built consensus that MRT accessibility positively impact on MRT trips in the expert meeting, as well as the comment agreement of threshold accessibility level and influence intensity. Figure 3-5 illustrates the adjustment function which is similar to S-curve and indicates that the variation of impacts turn into slightness if MRT accessibility places on extreme values. When the status value of MRT accessibility exceeds 0.8, the increment of MRT trips is approximately constant. While the value of MRT accessibility is greater than 0.75, MRT system can positively attracts trips from other modes. The value of MRT trips diminishes exponentially when MRT accessibility is small than 0.7. Different algorithms are applied to the distinct relationships between factors in a holistic system to establish a decision support model that creates realistic and complex behavior in spite of the simplicity of the equations.

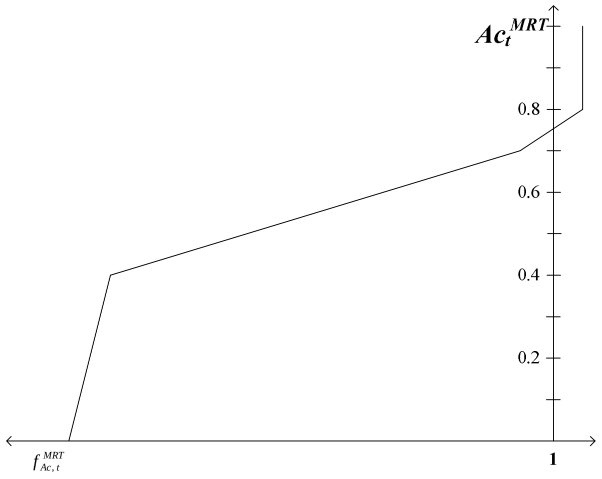


FIGURE 3-5 Function of adjustment factor of MRT accessibility

3.3 Mathematical Programming

To evaluate the sustainability of public sector investment in transportation infrastructure and service, this study proposes a mathematical programming model to solve multi-objectives optimization problems. A non-linear multi-objectives model, in which transport diversity and the gaps between sustainable target and present situation are simultaneously considered as the objectives, for resource allocation is thus established.

3.3.1 Fuzzy multi-objectives programming

Most real-world optimization problems are multi-objectives in nature. This implies that several objectives should be simultaneously considered. However, the complexity of multi-objectives optimization problems comes from the fact that there is no single optimal solution for these problems but rather a set of trade-offs called efficient solutions or Pareto-optimal solutions subject to resource constraints. The most crucial challenge is to find efficient feasible solutions in many multi-objectives planning issues. Consequently, methodologies to solve resource allocation problems, ones of the most discussed issues in combinatorial optimization theory, should address the following questions: Given a set of limited resource, what is the best allocation for a given task according to distinct targets? The best or potential efficient solutions should be determined considering a set of diverse and conflicting criteria (Belfares et al., 2007). Therefore, some researchers utilized heuristic algorithms to solve multi-objectives optimization problems (Altiparmak and Karaoglan, 2008; de Cea et al., 2008). However, an aggregative approach is employed to reduce the multi-objectives problem to a single objective optimization problem in most cases. A convex solution set is the necessary condition that aggregative approaches generate proper Pareto optimal solutions (Das and Dennis, 1997).

This study aims to construct a prototype model to analyze the allocation of investment for urban public transit system. The previous literature exploring operations for public transportation has identified single objective, such as to minimize total costs or to maximize the consumer surplus, and constraints comprise service capacity and user trip demand (Ceder and Wilson, 1986; Martins and Vaz Pato, 1998). However, meeting the multiple objectives of sustainable transportation implies making trade-offs in considering the benefits and costs to different stakeholders. Lee and Moore (1973) argued that single objective models have neglected conflicting targets influencing decision processes related to transportation issues. Some scholars solved the resource allocation problems for transportation operation by analytical models (van Nes and Bovy, 2000; Aldaihani et al., 2004; Ceselli et al., 2008), simulation analysis (Alterkawi, 2006) and heuristic algorithms (Gao et al., 2004; Jha et al., 2007).

During recent decades, fuzzy multi-objectives programming, which is a good method for identifying compromised solutions for optimization problem, has been applied to solve multi-objective linear, as well as nonlinear, programming problems (Bit et al., 1992; Lee and Li, 1993; Chang, 2007). Fuzzy multi-objectives programming combines fuzzy set theory and multi-criteria decision-making problems. The objective functions are represented via a fuzzy set, and the decision rule is used to select the solution with the highest membership of the decision sets. Zimmermann (1978) developed a fuzzy linear program, identical to the max-min program, and applied the fuzzy set theory concept with suitable membership functions. Solutions obtained by fuzzy multi-objectives programming are always efficient and optimize the comprised solution.

Moreover, fuzzy multi-objectives programming has been used in many fields. Li and Lee (1990) proposed a two-phase approach to get non-dominated solution and adapt it to de Novo programming with fuzzy parameters. Bhattacharya et al. (1992) utilized fuzzy multi-objectives programming to solve a multi-objective facility location problem. The genetic algorithm approach has been proved to be able to solve fuzzy multi-objectives programming with fuzzy nonlinear function goals and nonlinear constraints (Sasaki et al. 1995). Liang (2008) utilized fuzzy linear programming to assist in interactive multi-objectives transportation planning decisions. Furthermore, some studies concluded that using fuzzy multi-objectives programming for large problems, a compromise solution can easily be found, and is applicable to all types of multi-objective transportation problem (Bit et al., 1993; Islam and Roy, 2006). All the achievements of past studies increase the practicability of fuzzy multi-objectives programming.

Accordingly, fuzzy multi-objectives programming is utilized in this allocation model. In the compromise programming, the weights indicate the importance of the relative deviation of the objectives from the ideal, but in the fuzzy multi-objectives programming they express the importance of the deviations from the anti-ideal (Martinson, 1993). Following the procedures of the fuzzy multi-objectives programming algorithm, the ideal solution set $I^* = \{W_s^*\}$ and the anti-ideal solution set $I^\# = \{W_s^\#\}$ should first be determined for the basic model, where W_s^* denotes the independently optimal performance for each indicator s while $W_s^\#$ represents the worst performance for each indicator s due to the optimization of the objective indicators non-s. For example, the model considers two objectives including transport diversity and the gap between sustainable goal and present value, e.g. $s = 1, 2$. W_1^* shows the optimal solution when transport diversity is identified as the objective function. Conversely, $W_1^\#$ illustrates the worst value among the performance for transport diversity in the optimization for minimizing the gap between sustainable target and present situation.

Furthermore, both the ideal and anti-ideal solution set are employed as a reference point to define the membership function, $DS_s(W_s)$, indicating the satisfaction degree of each objective W_s. The membership functions are represented as Eqn. 3-18 for minimization problems.

$$DS_s(W_s) = \begin{cases} 1, & W_s^* > W_s \\ \dfrac{(W_s^\# - W_s)}{(W_s^\# - W_s^*)}, & W_s^\# > W_s > W_s^* \\ 0, & W_s > W_s^\# \end{cases} \tag{3-18}$$

Moreover, a compromise-grade λ, referring to overall satisfaction of the optimization model, is expressed as Eqn. 3-19.

$$\lambda = \underset{s}{Min}\,\{DS_s(W_s)\} \tag{3-19}$$

Through maximizing λ, the multi-objective problem can be transformed into the following problem and the compromised solutions, including the values of decision variables x_i, compromise-grade λ and compromised objectives W_s with each degree of satisfaction DS_s, are thus obtained.

$$\begin{aligned} &Max \quad \lambda \\ &s.t. \quad \lambda \le \frac{(W_s^\# - W_s)}{(W_s^\# - W_s^*)} \\ &\qquad\; \sum A_i x_i \le B \\ &\qquad\; 0 \le \lambda \le 1 \end{aligned}$$

3.3.2 Resource Allocation Model

Aggregate indicators representing stakeholder needs for optimal public investment to support transport diversity are identified. From a research perspective, this study integrates research and draws on techniques from literatures in economics, sociology and environmentalism to achieve recommendations for resource allocation. This study considers numerous complicating factors affecting public investment allocation including externality, safety, accessibility, mobility, reliability, affordability, resource over-utilization, operator profit and level of universal design. From a policy perspective, this work characterizes improved resource allocation in conflict stakeholder needs.

Capturing all of the characteristics of urban public transit system in a single model is a challenging task. This study first lays the indicators referring to urban public transit stakeholders including users and operators of MRT and bus along with non-users for a precise mathematical description of problem in this section. Then objectives and constraints of the proposed resource allocation model are formulated.

According to the mentioned indicators in Section 3.2, this study selects 10 indicators representing urban public transit stakeholder needs (y), such as accessibility, affordability and operator profit in both MRT and bus system, reliability and mobility for bus operation, as well as emission, safety and energy over-consumption for non-users (as shown in Eqn. 3-20 ~ Eqn. 3-29). The existent value of transportation infrastructure and service are marked with the suffix 0 for each variable and calculated as a constant in following analyses.

$$V_{Ac^{MRT}} = \frac{g_1(L_0^{MRT} + x_1) + g_2(L_0^{f-bus} + x_2)}{P_0} \tag{3-20}$$

$$V_{Af^{MRT}} = \frac{\hat{T}_0^{MRT} \times (F_0^{MRT} - x_3)}{Inc_0} \tag{3-21}$$

$$V_{R^{MRT}} = (F_0^{MRT} - C_0^{MRT}) \times T^{MRT} \tag{3-22}$$

$$V_{Ac^{bus}} = \frac{g_3(L_0^{bus} + x_4)}{P_0} \tag{3-23}$$

$$V_{Af^{bus}} = \frac{\hat{T}_0^{bus} \times (F_0^{bus} - x_5)}{Inc_0} \tag{3-24}$$

$$V_{R^{bus}} = (F_0^{bus} - C^{bus}) \times T^{bus} \tag{3-25}$$

$$V_{M^{bus}} = \frac{TT_0^{private}}{TT^{bus} + \dfrac{(h_0^{bus} - x_6)}{2 \times V_{rel^{bus}}}} \tag{3-26}$$

$$V_{rel^{bus}} = \Pr(\overline{TT}^{bus} \le \frac{1}{2}(h_0^{bus} - x_6)) \tag{3-27}$$

$$V_{EnCs} = \alpha_1 \times T^{MRT} + \alpha_2 \times T^{bus} + \alpha_3 \times T^{private} \tag{3-28}$$

$$V_{Emi} = \alpha_4 \times T^{private} + \alpha_5 \times T^{bus} \tag{3-29}$$

To calculate the probability in Eqn. 3-27, this study assumes that the average travel time during the interval of bus stops follows the normal distribution. The bus reliability is assessed by the cumulative distribution function of bus headway indicated in Eqn. 3-30.

$$V_{rel^{bus}} = \int_{-\infty}^{\frac{1}{2}(h_0^{bus} - x_6)} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\overline{TT}^{bus} - \mu)^2}{2\sigma^2}} d\overline{TT}^{bus} \tag{3-30}$$

Additionally, Eqn. 3-31 reveals the travel time of bus affected by the length of bus exclusive lane when the average travel speed of system is assumed as external factor. The operational cost, as shown in Eqn. 3-32, relates to the policy variable namely headway. The monthly trips of MRT and bus, indicated as Eqn. 3-33 and Eqn. 3-34, respectively, are influenced through the satisfaction of each need in terms of urban public transit stakeholders. The functions of adjustment factors are established by expert consensus building meeting. Moreover, this study explores the connections among the metadata from GIS through regression model. The analytical results reveal that a non-linear regression model, particularly a logarithm regression model (shown as Eqn. 3-14), has a better goodness of fit and the coefficients are statistic significant at level 0.05. A detailed description of regression formulations are attached in appendix B.

$$TT^{bus} = g_4(L_0^{BEL} + x_7) \tag{3-31}$$

$$C^{bus} = g_5(h_0^{bus} - x_6) \tag{3-32}$$

$$T^{MRT} = f_1(V_{Ac^{MRT}}) \times f_2(V_{Af^{MRT}}) \times T_0^{MRT} \tag{3-33}$$

$$T^{bus} = f_3(V_{Ac^{bus}}) \times f_4(V_{Af^{bus}}) \times f_5(V_{M^{bus}}) \times f_6(V_{rel^{bus}}) \times T_0^{bus} \tag{3-34}$$

The Taipei metropolitan area, the largest in Taiwan, provides the empirical study to discuss the managerial implications of the model. Except the unavailable data including driver behavior and patterns of conflict, the average speed assumed as constant here and the tiny variation of trips can not express the accident rate well. Besides, it is difficult in quantitatively determining the impact of level of universal design on system behavior. Therefore, accident rate and level of universal design are excluded from this study. Furthermore, it is assumed that the impacts of subsystems pedestrians, bicycles, private vehicles, as well as the land use patterns are given. Diverse transport stakeholders have different needs for urban transport infrastructure and services. The main issue in transport diversity thus becomes how to more equitably satisfy diverse stakeholder needs. Transport diversity is defined as different levels of satisfaction within stakeholder needs, expressed as appropriate indicators and measured using the variations in achievement among indicators.

Additionally, minimizing the indicator gaps, the remainder of the needs achievement, between the expected goals and present values (as shown in Eqn. 3-35) is a key objective in urban transportation planning and thus the first objective in proposed model. The normalized value prevents indicator gaps resulting from differences in unit scale.

$$Min \quad \sum_y \left(\frac{O_y^{goal} - V_y}{O_y^{goal} - O_y^{threshold}} \right) \tag{3-35}$$

where O_y^{goal} and $O_y^{threshold}$ represent the expected goal and minimum threshold of indicator y, respectively, and set via collaborative planning, specifically through consensus building, based on stakeholder and public opinions, along with feedback from experts. V_y is the present value of indicator y. The value of the normalized gap exceeds 0 and the degree of need satisfaction increases as the gap approaches 0. Meanwhile, n_i denotes the positive remainder of the gap of indicators, namely the achievement indicated by Eqn. 3-36. The non-negative achievement avoids misleading evaluation in transport diversity.

$$n_y = Max\left(0, \quad \frac{O_y^{goal} - V_y}{O_y^{goal} - O_y^{threshold}} \right) \tag{3-36}$$

Moreover, the second objective is to maximize transport diversity in the form of Entropy (as shown in Eqn. 3-37) for equitably achieving the various conflicting needs of urban public transit stakeholders. Transport diversity calculated with Eqn. 3-37 comprises two components: richness, measured by the number of stakeholder groups, which determines the number of terms in the summation, and equability, measured by the evenness of needs distribution across groups.

$$Max \quad -\sum_y \left(\frac{n_y}{\sum_y n_y} \times \ln \frac{n_y}{\sum_y n_y} \right) \tag{3-37}$$

Besides, this study considers constraints. Budget constraint indicated as Eqn. 3-38 expresses the limited resource which should be allocated efficiently and equitably. Eqn. 3-39 denotes transportation capacity for public transit system. Moreover, the total trips in the Taipei metropolitan area are constant (as shown in Eqn. 3-40) due to the deficient consideration of trip generation. Because MRT operator makes a fixed positive profit, Eqn. 3-41 prevent bus operators from money-losing. The domain of each policy variable x is identified from Eqn. 3-42 to Eqn. 3-44, respectively. The upper boundaries of policy variables, x_3, x_5 and x_6, are employed to keep the unreasonable negative travel costs and headway off.

$$\sum_r c_r x_r \le B_0, \quad r = 1, 2, \cdots, 7 \tag{3-38}$$

$$T^m \le b_0^m, \quad m = MRT, bus \tag{3-39}$$

$$T^{MRT} + T^{bus} + T^{private} = T_0 \tag{3-40}$$

$$V_{R^{bus}} \ge 0 \tag{3-41}$$

$$0 \le x_r \le F_0^m, \quad r=3 \quad if \;\; m=MRT, \; r=5 \quad if \;\; m=bus \tag{3-42}$$

$$0 \le x_6 \le h_0^{bus} \tag{3-43}$$

$$0 \le x_r, \quad r=1, 2, 4, 7 \tag{3-44}$$

CHAPTER 4 EMPIRICAL STUDY

The objective of this chapter is to demonstrate the methodologies presented in Chapter 3. Prior to these demonstrations, a preliminary spatiotemporal analysis adopting the Taipei metropolitan area data is introduced in Section 4.1. Subsequently, the empirical study of the approach for exploring the causality and behavior of urban transportation systems, as well as of the approach for examining the impact of resource allocation on transport diversity are shown in Section 4.2 and 4.3, respectively.

4.1 Preliminary Spatiotemporal Analyses

The preliminary spatiotemporal study is conducted in the Taipei metropolitan area, the largest metropolis in Taiwan, in which population is estimated at 6.63 million inhabitants and the total area is 2,265 km^2 in 2005. Besides, the number of registered private vehicle is 4.67 million involving 1.51 million cars and 3.16 million motorcycles. The length of roads is estimated at 4,007 kilometers with the exception of roads whose width is lower than 6 meters.

In order to explore the difference of transport diversity in the spatial aspects, the Taipei metropolitan area was divided into five sub-zones, such as urban core, urban area, satellite towns, suburban area, and rural area, according to socio-economic characteristics. GIS was utilized to overlay pictures with data layers. For instance, the MRT accessibility is overlaid with resident population and service area of feeder buses as shown in Figure 4-1.

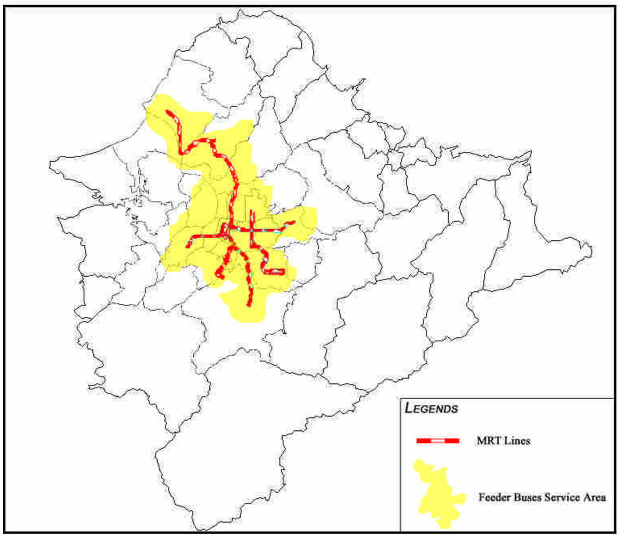


FIGURE 4-1 MRT accessibility layers

According to Section 3.2, this section chooses 12 indicators based on the conceptual framework as shown in Figure 2-1 to demonstrate the feasibility and usefulness of transport diversity analysis. The present values of indicators are gained from the statistics and metadata. In addition, the goal values of indicators are generated by the Taipei's White Paper to identify the targets towards sustainability from the government perspectives in planning process. An expert interview program is adopted for understanding each appropriate level with which stakeholder satisfies the basic needs to live without deficiencies. Both the goals and thresholds are employed for normalizing the gap of each stakeholder need between the goal and present values.

The results of transport diversity analysis consist of temporal and spatial aspects. In the temporal aspect, a representative set of indicators and transport diversity in 2000 are shown in Table 4-1. The achievements within the indicators are extremely low except MRT accessibility. In fact, safety, emission, bus reliability and level of universal design are the lowest because the present value has not reached the threshold. Affected by the shortage of needs' groups, the value of transport diversity is relatively lower to 2.15.

TABLE 4-1 Performance on transport diversity in 2000

Indicator	*Present Value*	*Goal Value*	*Threshold Value*	m_i	n_i	$P_i = \frac{n_i}{\sum_i n_i}$
Emission	46.93	25.00	45.00	1.10	0	0
Safety	1.13	0.20	1.00	1.16	0	0
MRT Accessibility	0.78	0.85	0.60	0.28	0.72	0.17
Bus Accessibility	0.61	0.85	0.60	0.96	0.04	0.01
Road Connectivity	0.27	0.50	0.25	0.92	0.08	0.02
Pedestrian Accessibility	1.31	2.00	0.80	0.58	0.43	0.10
Auto Mobility	26.50	35.00	20.00	0.57	0.43	0.10
Bus Mobility	0.63	0.80	0.40	0.43	0.58	0.13
Bus Reliability	0.61	0.85	0.65	1.20	0	0
MRT Affordability	0.10	0.07	0.15	0.38	0.63	0.15
Bus Affordability	0.06	0.04	0.10	0.33	0.67	0.16
Resource Over-Utilization	229.25	150.00	250.00	0.79	0.21	0.05
MRT Operator Profit	144.56	20.00	150.00	0.96	0.04	0.01
Bus Operator Profit	72.60	120.00	30.00	0.53	0.47	0.11
Level of Universal Design	0.35	0.70	0.50	1.75	0	0
			$\sum m_i =$	***11.92***	$H = -\sum P_i \ln P_i =$	***2.15***

Table 4-2 shows the performance on transport diversity in 2005. The summation of normalized gap has been decreased from 11.92 to 8.57 due to the significant reductions in the accident rate and the contaminated air, as well as the improvement of bus reliability. Moreover, the transport diversity value has been increased to 2.51. The analytical results reveal that the stakeholder needs in 2005 had been satisfied more equitably than that in 2000. However, the modification of level of universal design has not achieved the expectation of stakeholders, along with deficient satisfactions of air pollution, bus accessibility and road connectivity.

In the spatial aspect, the transport diversity of sub-zones would be explored with the exception of rural area because the transport infrastructures and services in rural area have been insufficient for the basic needs of most stakeholders and the limited data availability. Furthermore, some indicators including reliability, affordability, operator profit, resource consumption and level of universal design excluded from the spatial analysis due to the unavailable zonal data. Figure 4-2 indicates that safety could be improved considerably. In particular, the present values of safety are 0 in both satellite towns and suburban area. Additionally, the achievements of emission for all sub-zones have not exceeded 35%. On the contrary, the achievements of

MRT accessibility and bus accessibility in urban core have reached the goal. The performances of auto mobility and MRT accessibility in urban area are relatively higher. Furthermore, the higher needs satisfaction in satellite towns and suburban area are bus accessibility and auto mobility, respectively.

TABLE 4-2 Performance on transport diversity in 2005

Indicator	*Present Value*	*Goal Value*	*Threshold Value*	m_i	n_i	$P_i = \frac{n_i}{\sum_i n_i}$
Emission	43.39	25.00	45.00	0.92	0.08	0.01
Safety	0.53	0.20	1.00	0.41	0.59	0.09
MRT Accessibility	0.76	0.85	0.60	0.36	0.64	0.10
Bus Accessibility	0.65	0.85	0.60	0.80	0.20	0.03
Road Connectivity	0.29	0.50	0.25	0.84	0.16	0.02
Pedestrian Accessibility	1.47	2.00	0.80	0.44	0.56	0.08
Auto Mobility	27.70	35.00	20.00	0.49	0.51	0.08
Bus Mobility	0.68	0.80	0.40	0.30	0.70	0.10
Bus Reliability	0.73	0.85	0.65	0.60	0.40	0.06
MRT Affordability	0.09	0.07	0.15	0.25	0.75	0.11
Bus Affordability	0.06	0.04	0.10	0.33	0.67	0.10
Resource Over-Utilization	203.18	150.00	250.00	0.53	0.47	0.07
MRT Operator Profit	52.67	20.00	150.00	0.25	0.75	0.11
Bus Operator Profit	48.32	120.00	30.00	0.80	0.20	0.03
Level of Universal Design	0.45	0.70	0.50	1.25	0	0
				$\sum m_i =$ **8.57**	$H = -\sum P_i \ln P_i =$ **2.51**	

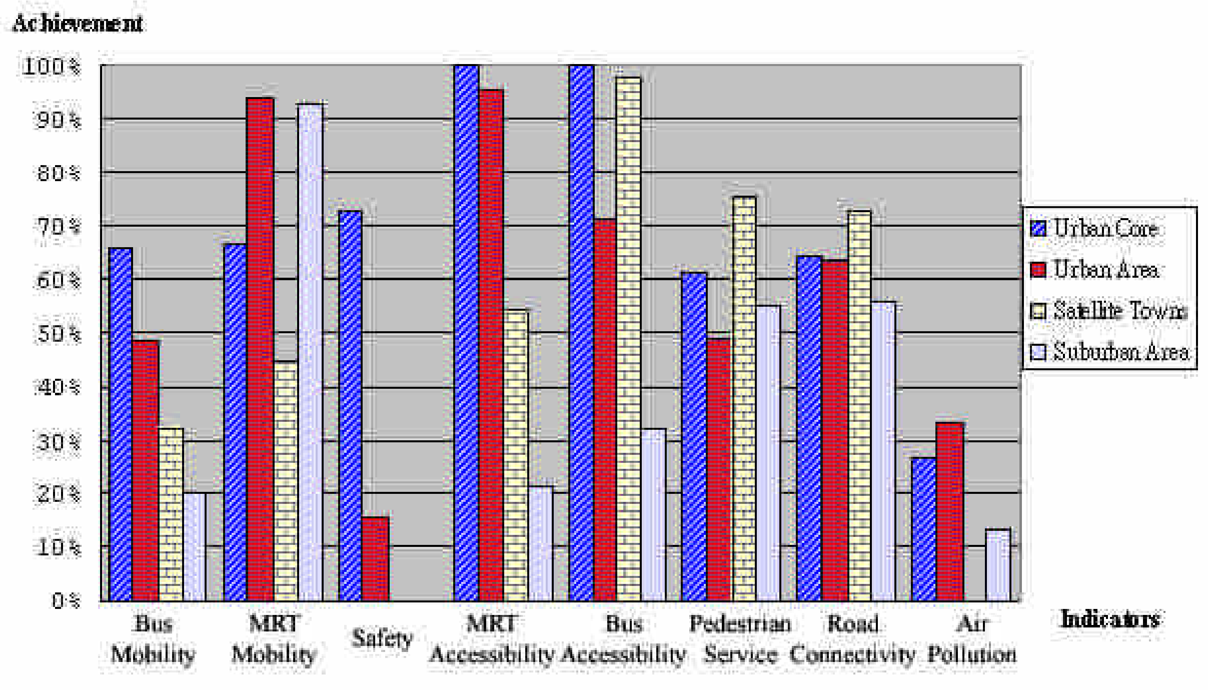


FIGURE 4-2 Achievement of indicators in spatial patterns

The additional information of spatial analysis could be determined from Table 4-3. The sub-zone namely satellite towns, having the most numerous indicators failing to stand on the thresholds, shows the lowest diversity. By comparison, urban core with the stakeholder needs that are satisfied more equitably has the greatest value of transport diversity and the smallest gap. Further analysis of Table 4-3 would appear to suggest that the higher diversity sub-zones have a trend to be smaller in gap. In fact, the outcomes of the analysis would help transport planners to understand what infrastructures or services at where have to be improved. For example, the speed limit, road shape, and directional divided facility have to be reassessed in the satellite towns and suburban area to reduce the accident rate. Therefore, none of the stakeholder needs could be neglected.

TABLE 4-3 Transport diversity in spatial patterns

	Indicator	*Urban Core*	*Urban Area*	*Satellite Towns*	*Suburban Area*
P_i	**Level of Bus Service**	0.12	0.10	0.09	0.07
	Auto Mobility	0.12	0.20	0.12	0.32
	Safety	0.13	0.03	0	0
	MRT Accessibility	0.18	0.20	0.14	0.07
	Bus Accessibility	0.18	0.15	0.26	0.11
	Level of Pavement Service	0.11	0.11	0.20	0.19
	Road Connectivity	0.11	0.14	0.19	0.19
	Air Pollution	0.05	0.07	0	0.05
Summation of Normalized Gaps:		***2.42***	***3.30***	***4.84***	***5.80***
Transport Diversity		***2.03***	***1.97***	***1.73***	***1.76***

4.2 Urban Transportation System Causality and Behavior

To explore the complexity of causal relationships and behaviors of urban transportation systems, a hybrid systematic simulation tools, mentioned as decision support model, is introduced. However, the validation of the decision support model should be tested via boundary adequacy tests suggested by Sterman (2000). Many methods of system assessment are used in the model formulation such as structure diagrams, inspection of model equations and opinions of experts, professionals and scholars. All structures are first verified by scholars and professionals experienced in urban transportation planning. Historical data and information from expert discussions are used to validate the model structure in capturing feedback process. Therefore, the structure of the model is able to illustrate the real urban transportation system well. Additionally, the model described here has two features that significantly impact resource allocation policies: (1) sensitivities of external factors, i.e. population, income, trip length and trip number, to the model and (2) policy delay size and uncertainty. Transport diversity under different conditions is explored to understand the influence of uncertainty on policy effectiveness. Several scenarios which might impact system behavior and the efficiency of policies involving external factors are undertaken within this analysis. Different amounts of uncertainty about the influence of policy delays on stakeholder behavior are also modeled to reflect levels of managerial implication.

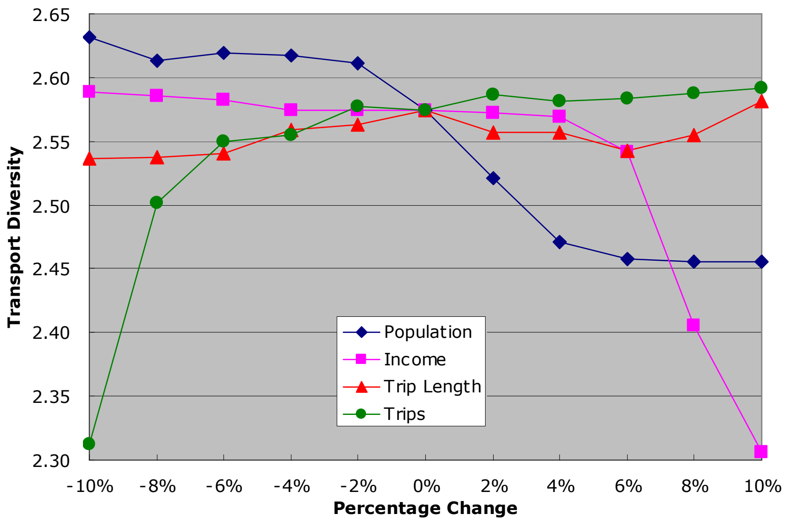


FIGURE 4-3 Sensitivity analysis for proposed simulation model

To investigate external conditions involving different levels of socioeconomic factors from the present situation, system behaviors are simulated, with the change percentage ranging from -10% to 10%. Figure 4-3 shows the results of sensitivity analysis of external factors. Variations in transport diversity vary from 2% (average length of trips) to 11% (income and amounts of trips per month). Average trip length does not significantly influence travel behavior. Besides, diversity is slightly inversely proportion to total population while all parameters are fixed except the changes of served population since consideration of more stakeholders implies the need to satisfy more diverse needs and thus brings lower diversity. Notably, travel behavior varies with increasing disposable income suggesting that the increased disposable income can enhance the affordability of private modes and then increase the emission, energy consumption and accident rate and lower diversity. In comparison, the reduction of disposable income does not transfer trips from private modes to public transit. Similarly, fewer trips per month can reduce travel costs and raise affordability, thus changing modal choices. All of the sensitivities are reasonable in practical situations.

Moreover, decision-makers cannot control delays in policies of resource allocation which impact the travel behaviors of stakeholders. Delays in effects of the strategies experienced for policy implementation in Taipei metropolis from 1 to 12 months are simulated to discuss the impact of delay durations on transportation system behavior. The effects of mean delay size and adopted policy on transport diversity are illustrated in Figure 4-4. The relationship between the delay sizes and diversity is consistently concave suggesting that improving resource allocation policies by adjusting the delays does not simply involve reducing delay sizes. However, reductions in diversity vary slightly from 0% to 1.8%. On the whole, the impacts of delays in strategy implementation on system behavior are insignificant and thus delay sizes might not be an important feature of resource allocation policy effectiveness. Generally, system behavior does not change significantly when assumptions about parameters, boundary, and relationships are varied over the plausible range of uncertainty. Consequently, the model is a robust replication of resource allocation policies for transportation systems.

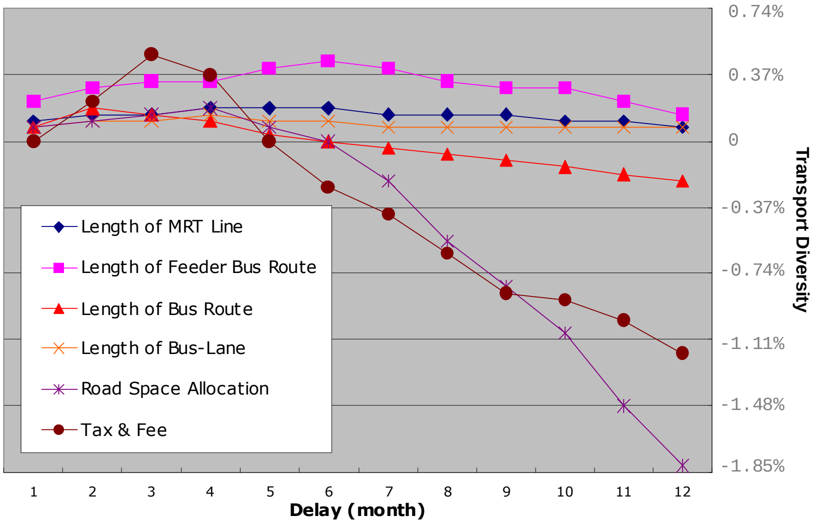


FIGURE 4-4 Policy delay analysis for proposed simulation model

To obtain a baseline, a 5-year simulation without policy intervention is conducted for the Taipei metropolitan transportation system. The time period unit is month and the initial point (period 0) starts in July,

2006. The results of the baseline simulation are shown from Figure 4-5 to Figure 4-8. Figure 4-5 is the simulation of transport diversity and the sum of the normalized gaps between stakeholder needs. It shows that transport diversity is approximately negatively related with the gaps between stakeholder needs. The baseline result of the modal trips is illustrated in Figure 4-6. This figure shows that car trips rise smoothly after the 16th month, most of which are transferred from motorcycle and bus trips.

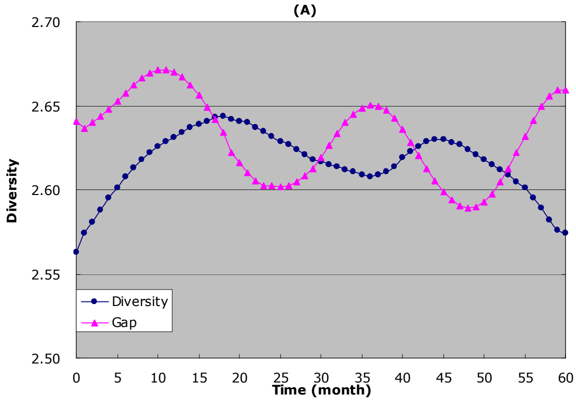


FIGURE 4-5 Diversity and gap in baseline

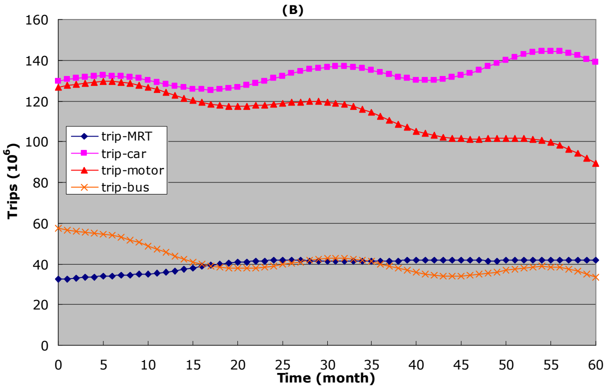


FIGURE 4-6 Modal trips in baseline simulation

Besides, the gaps in Figure 4-5 are closely related to car trips in Figure 4-6 providing evidence that controlling car trip growth significantly influences the reduction in gaps of stakeholder needs. Figure 4-7 and 4-8 depict the accident rate and travel speed of the system, respectively. The accident rate declines as a result of decreasing number of motorcycle trips. These baseline simulations demonstrate possible problems for Taipei if there is no effective policy to implement. Moreover, decision-makers are supported via the baseline simulation in deciding when and how to adopt strategies.

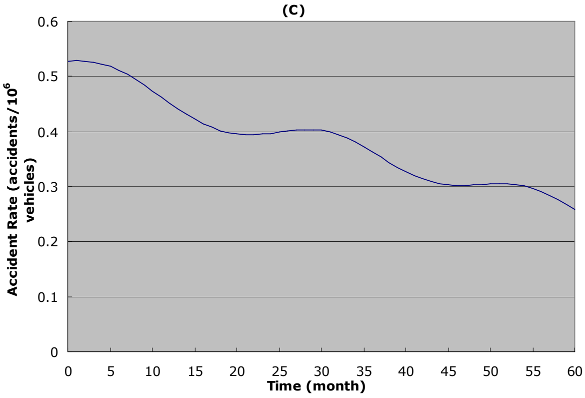


FIGURE 4-7 Accident rate in baseline simulation

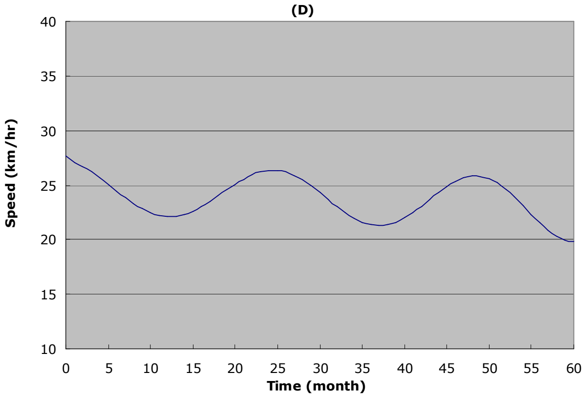


FIGURE 4-8 Travel speed in baseline simulation

To improve the performances shown in the baseline simulation above, in addition to the scheduled MRT infrastructure some feasible policies subject to the budget are proposed by gathering information from the previous discussions. The results of simulation of policies intervention are illustrated from Figure 4-9 to Figure 4-12. To curb excessive growth of car trips, strategies including levying taxes, restricting car entry, and gradually reallocating road space were introduced in periods 5, 21 and 23, and Figure 4-10 shows a lower average number of car trips than Figure 4-6. The new MRT infrastructure operates at period 30, in which transport diversity increases sharply and the gap is bridged (Figure 4-9). However, the MRT trips do not go up with a leap because MRT accessibility remains low and MRT capacity does not increase significantly. Additionally, to encourage bus use, policies such as subsidies and release of route rights are adopted in periods 30 and 40, respectively. Travel speed (Figure 4-12) causes the previous trend to move upwards and the average accident rate to decline more than 25% (Figure 4-11) because of the policies. Other conditions are simulated in the same way to observe how strategies can be controlled to improve the system and help decision-makers determine resource allocation.

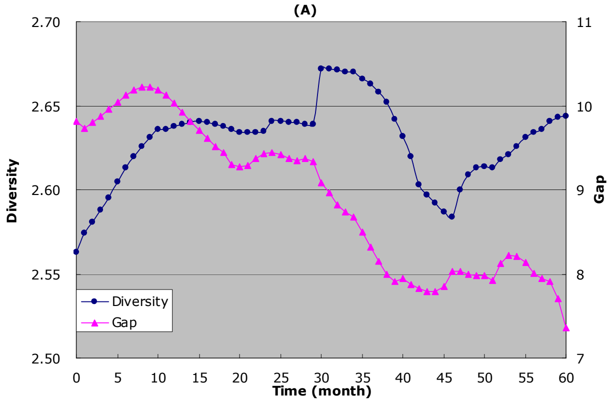


FIGURE 4-9 Diversity and gap in intervention

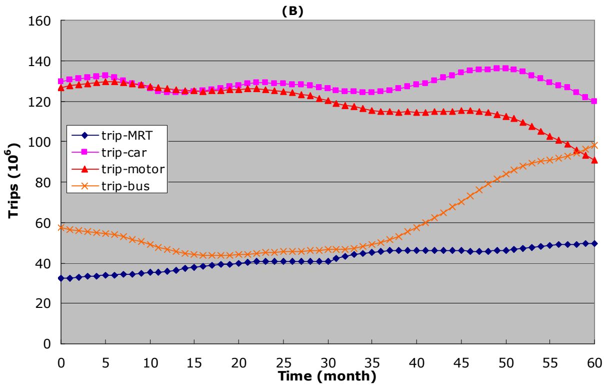


FIGURE 4-10 Modal trips in intervention

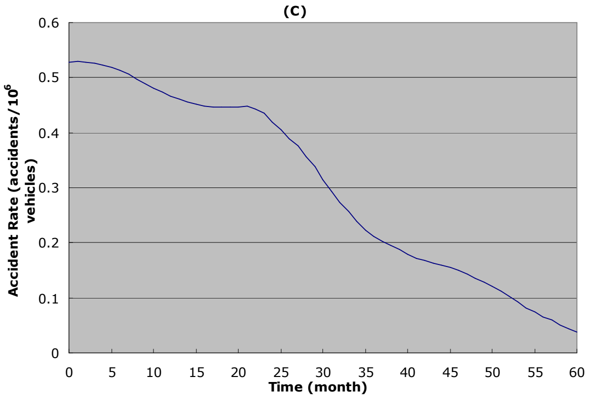


FIGURE 4-11 Accident rate in intervention

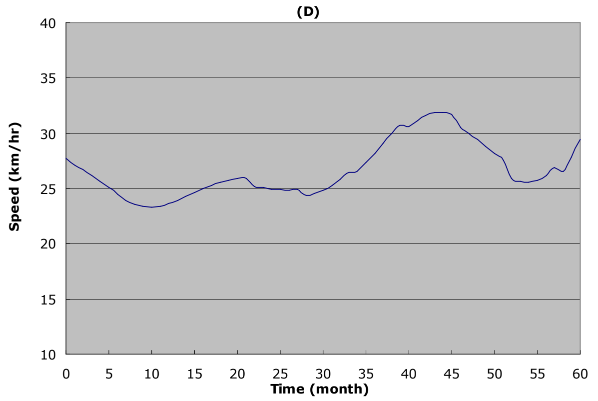


FIGURE 4-12 Travel speed in intervention

4.3 Resource Allocation Model

TABLE 4-4 Results of the baseline (no-action) alternative

Indicator	*Present Value*	*Goal Value*	*Threshold Value*	m_i	n_i	$P_i = \frac{n_i}{\sum_i n_i}$
MRT Accessibility	0.7565	0.85	0.60	0.37	0.63	0.13
MRT Affordability	0.0811	0.05	0.15	0.31	0.69	0.14
MRT Operator Profit	65.3247	20.00	150.00	0.35	0.65	0.13
Bus Accessibility	0.6867	0.85	0.60	0.65	0.35	0.07
Bus Affordability	0.0508	0.03	0.10	0.30	0.70	0.14
Bus Operator Profit	140.4401	200.00	50.00	0.40	0.60	0.12
Bus Mobility	0.5794	0.80	0.40	0.55	0.45	0.09
Bus Reliability	0.7300	0.85	0.65	0.60	0.40	0.08
Energy Consumption	35.8534	20.00	45.00	0.63	0.37	0.07
Emission	28.1338	15.00	30.00	0.88	0.12	0.03
				$\sum m_i = 5.04$	$H = -\sum P_i \ln P_i = 2.227$	

The main contribution of this study is to develop a non-linear programming approach for simultaneously assessing the achievement level as well as the transport diversity of the satisfactions of urban public transit stakeholder needs. If maximizing the total achievement level of satisfaction, i.e. minimizing the summation of the normalized gaps between the targets and the present values, for stakeholder needs is considered as the single objective, the finite resource may be allocated inequitably. The inequitable allocation leads to the neglect of some needs with which transportation stakeholders certainly live without deficiencies. On the other hand, an equitably but inefficiently resource allocation may reduce the total quality of urban public transit system if the achievements of stakeholder needs sink to an even low level. Therefore, the proposed multi-objectives model helps decision-makers allocate resources equitably and efficiently.

To further demonstrate the applicability of the constructed model, an experimental analysis from public transit system of the Taipei metropolitan area is conducted. Along with the consentaneous influence functions provided by expert discussion (as shown in appendix B), the actual data, such as population, length of operation lines, average income, headway, and so on, are taken in this analysis according to the annual reports published by Ministry of Transportation and Communications. Table 4-4 reveals the results of the baseline alternative considering actual data nowadays without resource allocation policies. The goal values denoting the expected target of sustainable development and the threshold value referring to the basic level of needs maintaining quality of life are set by government to monitor system.

4.3.1 Single Objective Problem - Minimizing Gap

The optimal allocation corresponding to seven policies are determined by the proposed constraints with a single objective to minimize the summation of normalized gaps. The analytical results are indicated in Table 4-5. The summation of normalized gap declines from 5.04 to 3.89, a 22.96% improvement, due to the significant improvements of MRT affordability, bus affordability and bus mobility. The investment policies include subsidizing the fares of public transit and constructing bus exclusive lanes. However, the affordability of each public transit system has been reached relatively high satisfaction level in the baseline alternative. The variation between achievements of different stakeholder needs is enlarged from 0.04 (in the baseline alternative) to 0.09 due to the inequitable allocation. Accordingly, the transport diversity diminishes by 47.98% to 2.190 because the values of energy consumption and emission are calculated by the trips distributed around modal trips, namely the modal share, increasing the modal share of public transit is an effective strategy to mitigate the environmental impact. For the same purpose of transferring trips from private vehicles to public transit, the resources could be allocated to the infrastructures related to those needs with lower satisfaction, such as accessibility and reliability, prior to affordability.

TABLE 4-5 Solution to the allocation model under a minimum gap objective

Indicator	*Present Value*	*Goal Value*	*Threshold Value*	m_i	n_i	$P_i = \frac{n_i}{\sum_i n_i}$
MRT Accessibility	0.7565	0.85	0.60	0.37	0.63	0.10
MRT Affordability	0.0500	0.05	0.15	0.00	1	0.16
MRT Operator Profit	66.3379	20.00	150.00	0.36	0.64	0.11
Bus Accessibility	0.6867	0.85	0.60	0.65	0.35	0.06
Bus Affordability	0.0300	0.03	0.10	0.00	1	0.16
Bus Operator Profit	148.2754	200.00	50.00	0.34	0.66	0.11
Bus Mobility	0.7645	0.80	0.40	0.09	0.91	0.15
Bus Reliability	0.7301	0.85	0.65	0.60	0.40	0.07
Energy Consumption	35.3783	20.00	45.00	0.62	0.38	0.06
Emission	27.7931	15.00	30.00	0.85	0.15	0.02
				$\sum m_i =$ **3.89**	$H = -\sum P_i \ln P_i =$ **2.190**	

4.3.2 Single Objective Problem - Maximizing Transport Diversity

Secondly, the analytical results of maximizing transport diversity problem are expressed in Table 4-6. The summation of normalized gap decreases by 5.96% whereas the transport diversity increases to 2.2429 due to the investments, such as constructing bus exclusive lanes, extending bus operation routes, and reducing the bus headway. The satisfactions of bus accessibility, mobility and reliability are thus improved obviously because reducing average bus headway costing dearly improves the bus mobility and reliability simultaneously. Since the achievements of stakeholder needs distributed uniformly in the baseline alternative, restricted budgets allocated to raise equity become less efficient. Particularly, the achievement of bus operator profit performs poorly in comparison to the baseline alternative. Moreover, the need satisfactions derived from the most equitable resource allocation are inferior to that from the most efficient allocation except bus accessibility and bus reliability.

TABLE 4-6 Solution to the allocation model under a maximum diversity objective

Indicator	*Present Value*	*Goal Value*	*Threshold Value*	m_i	n_i	$P_i = \frac{n_i}{\sum_i n_i}$
MRT Accessibility	0.7565	0.85	0.60	0.37	0.63	0.12
MRT Affordability	0.0811	0.05	0.15	0.31	0.69	0.13
MRT Operator Profit	65.3247	20.00	150.00	0.35	0.65	0.12
Bus Accessibility	0.7075	0.85	0.60	0.57	0.43	0.08
Bus Affordability	0.0508	0.03	0.10	0.30	0.70	0.13
Bus Operator Profit	133.6368	200.00	50.00	0.44	0.56	0.11
Bus Mobility	0.6288	0.80	0.40	0.43	0.57	0.11
Bus Reliability	0.7513	0.85	0.65	0.49	0.51	0.10
Energy Consumption	35.5842	20.00	45.00	0.62	0.38	0.07
Emission	27.9494	15.00	30.00	0.86	0.14	0.03
				$\sum m_i =$ ***4.74***		$H = -\sum P_i \ln P_i =$ ***2.243***

4.3.3 Multi-Objective Problem

Traditionally, goal programming is often employed to solve problems with conflicting objectives such that an optimized solution may not exist. The principle idea is to convert the original multi-objectives into a single combined goal, and then to seek a compromised solution based on the relative importance of each objective. In fact, both proposed objectives in this study, normalized gap and transport diversity, simultaneously consider the setting and weighting of each goal, fuzzy multi-objectives programming is thus utilized.

According to the solution of each single objective shown in Table 4-5 and Table 4-6, the ideal and anti-ideal solution set refer to $I^* = \{3.89, 2.243\}$ and $I^\# = \{4.75, 2.190\}$, respectively. The multi-objectives problem can be transformed into a single objective problem maximizing λ using the ideal and anti-ideal solution set. Along with the equations mentioned in Section 3.4, the following two more constraints are added into the model.

$$\lambda \le (4.75 - W_1)/(4.75 - 3.89)$$
$$\lambda \le (W_2 - 2.190)/(2.243 - 2.190)$$

Table 4-7 reveals the analytical results of fuzzy multi-objectives programming in which the maximized compromise-grade generated within membership function equals to 0.4810. The optimal allocation indicates that all policy variables are variously invested except extending MRT lines and reducing average bus headway. Since manufacturing new infrastructures of MRT is costly, MRT accessibility is improved via extending feeder buses routes rather than lengthening MRT lines. Along with slightly raising bus mobility and reliability, building bus exclusive lanes avoids the severely negative impacts of reducing average bus headways on government finance and bus operator profit.

TABLE 4-7 Compromised solution to the fuzzy allocation model

Indicator	*Present Value*	*Goal Value*	*Threshold Value*	m_i	n_i	$P_i = \frac{n_i}{\sum_i n_i}$
MRT Accessibility	0.7716	0.85	0.60	0.31	0.69	0.12
MRT Affordability	0.0745	0.05	0.15	0.24	0.76	0.13
MRT Operator Profit	65.8027	20.00	150.00	0.35	0.65	0.11
Bus Accessibility	0.6969	0.85	0.60	0.61	0.39	0.07
Bus Affordability	0.0474	0.03	0.10	0.25	0.75	0.13
Bus Operator Profit	148.2331	200.00	50.00	0.35	0.65	0.12
Bus Mobility	0.7111	0.80	0.40	0.22	0.78	0.14
Bus Reliability	0.7462	0.85	0.65	0.52	0.48	0.08
Energy Consumption	35.4217	20.00	45.00	0.62	0.38	0.07
Emission	27.8308	15.00	30.00	0.86	0.14	0.03
				$\sum m_i =$ ***4.33***		$H = -\sum P_i \ln P_i =$ ***2.230***

The ideal transport diversity under the given 10 indicators values at 2.30 if the achievements of stakeholder needs follows a uniform distribution. Transport diversity in present situation reaching 2.268 confirms that the Taipei metropolitan area performed well under equitably satisfying public transit stakeholder needs. Accordingly, resources utilized to bridge 75% gaps in stakeholder needs bring transport diversity a mere 21.23% improvement. The compromised allocation elevates the satisfactions of stakeholder needs including MRT accessibility, MRT affordability, bus affordability, bus mobility and bus reliability to a remarkably high level. Besides, energy consumption and emissions are mitigated due to the increment of public transit trips.

After comparing the proposed Pareto based model to single objective strategies, most need achievements of the compromised model lie between single objective models excluding MRT accessibility. This manifests that investments allocated to improve MRT accessibility are favorable for the trade-off consideration between efficiency and equity but might be harmful to each single target. Additionally, with the exception of affordability achieving advantaged levels in present situation, satisfactions incline to better performance of each need. The Pareto based allocation contributes to a 14.14% improvement in normalized gaps in stakeholder needs, as well as to a 4.25% improvement in transport diversity. Consequently, the Pareto based approach evades inefficient and inequitable resource allocation.

CHAPTER 5 DISCUSSION

The purpose of this chapter is to discuss the issues related to the definition of transport diversity proposed in Chapter 2, the methodologies presented in Chapter 3 and the empirical findings demonstrated in Chapter 4. The connections among sustainability, quality of life and transport diversity are discussed in Section 5.1. The determination of stakeholder needs and the spatiotemporal development of transport diversity are shown in Section 5.2 and Section 5.3, respectively. The confounding effects are presented in Section 5.4, followed by the issues of resource allocation.

5.1 Connection among Sustainability, Quality of Life and Transport Diversity

The study proposes a conceptual framework that integrates diverse stakeholder needs to evaluate transport diversity based on sustainability and quality of life. This study defines transport diversity as the level of satisfaction of stakeholder needs and measures it as the gap between the targets for stakeholder needs and current achievement of those needs in the form of the Shannon-Weaver Index, or namely the Entropy.

Transportation planning attempts to maximize diversity to comprehensively and equitably satisfy needs. The evaluation of transport diversity is involved in the process of sustainability assessment to confirm the sustainable targets and the basic level of quality of life to satisfy the stakeholder needs more equitably. Additionally, this study presents covered many but not all contents of sustainability and quality of life. The contents are utilized as the needs of stakeholders for evaluation of transport diversity. Failure to satisfy basic stakeholder needs may negatively impact quality of life.

Accordingly, diversity can assist planners in resource allocation to promote quality of life in two ways. First, quality of life should be improved in areas with the least diversity. Second, the infrastructure or service could be invested based on the need with the largest gap between target and present value, i.e. that with the least achievement. Planners can propose appropriate transportations systems, i.e. determine the basic quality of life standard and the expected sustainable target by setting goals and threshold values. Consequently, the city following transport diversity principle can benefit by comparing improvements in quality of life and sustainability strategies for resource allocation. Such an evaluation could help policy-makers determine which plans would maximize transport diversity to satisfy stakeholder needs, which plans would produce a more equitable and sustainable development and quality of life.

Therefore, the assessment of transport diversity should be considered at the commencement planning and policy making. Moreover, diversity is useful for assessing the improvement in quality of life and resource allocation. The investments could be allocated to reduce any gap in needs. This investigation found that urban requirements may vary according to the dynamics of a city such as the level and distribution of income, urbanization, and the target for sustainable urban development. Furthermore, goal values and threshold values indicating the expected satisfaction and acceptable quality of life of needs, respectively, may differ according to the dynamics of a city.

The contents of quality of life could be tailored to fit different sustainable development targets. Transport diversity represents the equitable achievement of rich stakeholder needs which are identified from the daily life. Transport diversity is thus the necessary condition for quality of life and sustainability. Improving the sustainability and quality of life with regard to transportation requires the support of transport diversity.

5.2 Spatiotemporal Development of Transport Diversity

An empirically spatiotemporal study for transport diversity in the Taipei metropolitan area is discussed after the most important stakeholder needs are determined. Temporal analysis could demonstrate the tendencies of transport diversity indicated by the gap between the expected goals and present values of needs and assist policy-makers in reviewing the effects of historical strategies. Meanwhile, spatial analysis indicated the distribution of transport diversity in urban space and help policy-makers understand what infrastructure or services have to be improved and where and then decide the resource allocation strategies to promote the equitable transport diversity.

Accordingly, the study proposes an indicator framework integrated with sustainable transportation to evaluate the transport diversity in spatiotemporal perspectives. Indicators referring to emission, safety, accessibility, mobility, reliability, affordability, economic health, level of universal design and energy consumption are established. The result of temporal analysis shows that the summation of normalized gaps between goal and present value of stakeholder needs reduces by 28.1% in 5 years while the diversity increases by 16.74%. This reveals that the stakeholder needs in 2005 had been satisfied more equitably than that in 2000. In addition, the finding of spatial analysis indicates that the gaps between the goals and present values of needs are increasing from urban core to suburban area while the transport diversity reduces gradually. Moreover, lower transport diversity relates to which numerous indicators fail to achieve the threshold. Therefore, any stakeholder needs should not be neglected. Although the diversity has been improved in the Taipei metropolitan area, the emission and the accident rate have to be mitigated to make the urban transportation system more sustainable.

5.3 Confounding Effects in Causality Analysis

Traditionally, there have been little discussion of transportation system behavior and decision-makers lack specific and operational methods for clearly representing of what-if scenarios in urban transportation system behavior. A hybrid model is introduced to help decision-makers obtain a comprehensive understanding of transportation system behavior and for investigating the influence of resource allocation policies on transport diversity, representing the degree to which different stakeholder needs are satisfied. The proposed system-simulated decision support model integrating system dynamics, a quantitative method, cognitive maps, a qualitative approach, and sensitivity model, a semi-quantitative tool, provides a practical solution for dealing with the complex relations among variables. The relations are determined via expert meetings in which planners, professionals, government and scholars consult to establish a consensus and test possible policy outcomes.

Different algorithms are applied to the relationships between factors in a holistic system to establish a decision support model that addresses realistic and complex behavior despite the simplicity of the equations. The constructed model provides the planner with a convenient and effective tool for the process of public participation and consensus, a key element of the implementation of sustainable development. It provides planners with information about the roles of system variables for the purpose of policy formulation. Besides, scenario simulations are carried out according to different combinations of system parameters and manifest the model flexibility and applicability. The model application is illustrated through an empirical study to enhance the managerial implications in the Taipei metropolitan area. The results of sensitivity analysis reveal that the increase in private vehicle trips reduces transport diversity due to the increased energy consumption, emissions and accident rate. However, tuning policy delays does not significantly impact system performance through managerial choices of resource allocation in Taipei.

This study contributes to systems research on transportation by establishing a practical model for formulating and evaluating policies designed to improve system performance. Moreover, the simulation results indicate that the gaps in stakeholder needs are generally opposite to transport diversity and positive proportion to private vehicle trips. This verifies that incremental public transit trips help the system bridge the gap between user satisfactions of stakeholder needs.

5.4 Relationship between Resource Allocation and Transport Diversity

An optimizing model to allocate resource in terms of transport diversity is constructed considering the appropriate indicators referring to the stakeholder needs which are much critical via the former study. Because the setting of each goal including maximized transport diversity and minimized normalized gaps considers a goal programming evaluation, fuzzy multi-objectives programming is employed in this study, which combines fuzzy set theory and multi-criteria decision-making methods to solve multi-objectives problems. The objective functions are represented via a fuzzy set, and the decision rule is used to select the solution with the highest membership of the decision sets.

The model seeks to determine the resource allocation for public transportation infrastructures and services so as to maximize the transport diversity and as to minimize gaps of stakeholder needs simultaneously. This model evaluates both the investments of transportation infrastructures and services to support the urban public transit stakeholder needs equitably, as well as gaps to sustainable targets of needs in order to make recommendations on efficient resource allocation. The developed multi-objectives model based on Pareto optimization leads to acceptable compromised solutions.

To illustrate the approach, this study presents an empirical example where the resource allocation model is developed for an urban public transit system from the Taipei metropolitan area. Specifically, the statistical framework and expert consensus are utilized to estimate quantitative and qualitative relationships, respectively, among variables in urban public transit systems. Since individual parameters and behaviors are unavailable, the experiments are carried out on average valued instances. Moreover, the interactions between public transit and private vehicle systems are assumed as constant, along with the ignored pedestrian, bicycle and land use patterns. Conclusions are limited by the purposeful simplification of the model compared to actual systems and incomplete validation. Despite the preliminary nature of work, two interesting results suggest changes for public transportation management practice and future research.

First, the result of single-objective optimization shows that policies allocated to minimizing the gaps of stakeholder needs give decision-makers a totally false impression of moving systems towards sustainability. The inequitable supplies, disregarding the needs of certain disadvantaged minorities with which they could travel without deficiencies, aggravate the disparity between satisfactions of demands. This recommends against the common perception that the most increase of need achievements is an effective policy to reach sustainability because some improved needs are relatively more sustainable. Resources could be allocated to improve lower satisfied needs impacting daily travel behaviors prior to those needs with relative higher satisfaction. The result implies that decision-makers could seek to identify appropriate target and basic level of satisfaction to each stakeholder need.

Second, analytical outcomes show that recent investments allocated to public transit system considered equitable stakeholder satisfactions both of MRT and bus, as well as promoted transport diversity in the Taipei metropolitan area. Although bus accessibility, mobility and reliability performed relatively poorly in public transit system, variation in satisfactions of considered stakeholder needs was slight so that most public transit stakeholders achieve their fundamental transportation quality in daily life. This is rational to the Taipei metropolitan area with the most faultless mass transit systems. The outcomes recommend that future investments could be allocated to improve the levels of bus services in order to prevent limited resource from a biased and inefficient MRT-oriented allocation. Besides, empirical results seem to show that Pareto based approach is superior to single objective strategies since multi-objectives model generates a compromised efficient solution with higher cardinality and better diversity along the Pareto frontier.

CHAPTER 6 CONCLUSION AND RECOMMENDATION

The objectives of this research are to propose a conceptual framework for identifying transport diversity and exploring their characteristics, to propose an approach for determining stakeholder needs involved in transport diversity and importance related to each need, to propose an approach for examining the causalities in urban transportation, and to propose an approach for optimizing resource allocation within transport diversity. The summary of the work performed in this research is described in Section 6.1. Recommendations for further research are drawn in Section 6.2.

6.1 Conclusion

In this study, transport diversity and causal relationships in urban transportation systems are examined by analyzing stakeholder needs derived from spatiotemporal databases. The contributions and findings related to methodologies in this study are summarized in the following points:

1. Taking advantage of the Entropy, this study constructs a conceptual framework which could effectively examine the distribution of stakeholder need satisfactions from diversity perspective. In particular, the evaluation of transport diversity is involved in the process of sustainability assessment to confirm the sustainable targets and the basic level of quality of life to satisfy the stakeholder needs more equitably. Transport diversity can assist planners in resource allocation to promote quality of life in two ways. First, quality of life should be improved in areas with the least diversity. Second, the infrastructure or service could be invested based on the need with the largest gap between target and present value, i.e. that with the least achievement. Accordingly, failure to satisfy basic stakeholder needs may negatively impact quality of life. Transport diversity is thus the necessary condition for quality of life and sustainability.
2. System thinking about the development of sustainable transportation is applied in the analysis by a hybrid model consisting of quantitative system dynamics, qualitative cognitive maps and semi-quantitative sensitivity model. The application of proposed model to causality for diversity in urban transportation is a very positive experience for Taiwan. The tool raises the accessibility of local residents and interest groups to development policy for urban transportation system. It brings the people together who are concerned with sustainable development and provides them with a convenient tool to share their view and test the possible policy outcomes.
3. A hybrid systematic simulation approach integrating quantitative, qualitative and semi-quantitative approaches is introduced to tackle the complexity and feedback loops in urban transportation systems. Along with precise relationships, causalities determined by participant consensus either via expert cognitions or through accurate ordinal pattern recognition perform well in illustrating transportation system behaviors and assessing system performance. This confirms that capturing all the modeling details of complicated systems is a challenging task. However, this study demonstrated that the task is by far feasible.
4. From the perspective of equity, the primary focus is to achieve transportation stakeholder need equitably. But from the perspective of efficiency, to minimize the gap between the sustainable target and the present value for each stakeholder needs is eager to be devised. Because the setting of each goal

including maximized transport diversity and minimized normalized gaps considers a goal programming evaluation, fuzzy multi-objectives programming is employed in this study, which combines fuzzy set theory and multi-criteria decision-making methods to solve multi-objectives problems. The objective functions are represented via a fuzzy set, and the decision rule is used to select the solution with the highest membership of the decision sets. Therefore, compromised solution for avoiding inefficient or inequitable allocation can be advantageous.

This study mainly examines the characteristics of urban transportation system in the Taipei metropolitan area. The findings are summed up in the following points:

1. This investigation found that urban requirements may vary according to the dynamics of a city such as the level and distribution of income, urbanization, and the target for sustainable urban development. Furthermore, goal values and threshold values indicating the expected satisfaction and acceptable quality of life of needs, respectively, may differ according to the dynamics of a city.
2. The results of the spatiotemporal analysis reveal that transport diversity is improved from 2000 to 2005 in the Taipei metropolitan area. In fact, the transportation system has progressed in the satisfactions of safety and reliability. However, the achievements of emission, accessibility and level of universal design perform poorly. Decision-makers could understand better resource allocation policies according to the analytical results for improving transport diversity referring to system performance in the future to bridge the gaps induced by the past inequitable investments. In particular, deficient quality of life for disable users could be improved effectively and efficiently.
3. Moreover, the improvements of urban transportation infrastructures and services are mostly allocated in urban core area, in which stakeholder needs achieved a relatively higher satisfaction level, rather than sub-urban areas. The priorities of ongoing policies could be redesign to reach an equitable quality of life, as well as to move whole urban transportation system towards sustainability.
4. The result of sensitivity analysis reveals that the increment of private vehicle trips reduces transport diversity due to the increase of energy consumption, emission and accident rate. However, tuning policy delays does not significantly impact system performance through managerial choices of resource allocation in Taipei. Moreover, the simulation results indicate that the gaps in stakeholder needs are generally opposite to transport diversity and positive proportion to private vehicle trips. This verifies that increasing public transit trips helps the system bridge the gap between satisfactions of stakeholder needs.
5. The result of single-objective optimization shows that policies allocated for minimizing the gaps in stakeholder needs give decision-makers a totally false impression of moving systems towards sustainability. The variation between achievements of different stakeholder needs is enlarged from 0.04 (in the baseline alternative) to 0.09 due to the inequitable allocation disregarding the needs of certain disadvantaged minorities with which they could travel without deficiencies. Resources could be allocated to improve lower satisfied needs impacting daily travel behaviors prior to those needs with relative higher satisfaction. The result implies that decision-makers could seek to identify appropriate target and basic level of satisfaction to each stakeholder need.

6. The analytical results of maximizing transport diversity problem express that the summation of normalized gap decreases by 5.96% whereas the transport diversity increases only 0.70%. This indicates that recent investments allocated to public transit system considered equitable stakeholder satisfactions both of MRT and bus with a slight variation 0.04 so that most public transit stakeholders achieve their fundamental transportation quality in daily life, as well as promoted transport diversity in the Taipei metropolitan area. This recommends that future investments could be allocated to improve the levels of bus services in order to prevent limited resource from a biased and inefficient MRT-oriented allocation.

6.2 Recommendation

Although this study has taken a step forward in the direction of examining transport diversity and transportation system causality from stakeholder perspective, some limitations should be noticed to point to opportunities for future research and findings are worth further studies.

1. The contents of diversity based on quality of life could be tailored to fit different sustainable development targets. The developed diversity evaluation framework focusing on urban transportation system considers managerial implications as an essential composition. Further research applying the concepts of stakeholder need satisfaction as diversity assessment could elaborate on the extent to which important needs in daily life. Moreover, distinct requirements of specific users are neglected in this study. Particularly, the deficient quantitative data of level of universal design may lead to inequitable resource allocation for disadvantaged minorities.

2. For detailed illustrations of the interactions between stakeholder needs and system behaviors, sustainability could be decomposed into three dimensions including economic efficiency, social equity and environmental impact for simultaneously clarifying the relationships among investments, allocation policies, as well as satisfaction level improvement of each stakeholder need and overcoming the diverse issues from sustainability.

3. This hybrid approach provides a practical solution for dealing with the complicated relations among variables. However, the specification of the interlink function for each pair of variables requires a great deal of consultancy work. For example, the impact of a bus exclusive lane can be assessed to determine how it would affect mobility and accessibility in an urban area and transportation. A causal system can help policy-makers assess which investments achieve the greatest improvements in sustainability and quality of life.

4. In the proposed hybrid systematic simulation model, the assumed impacts of certain subsystems including pedestrian, bicycle, paratransit (taxi and demand response transportation), parking and trip generation related to land use patterns as constants could be released. Additionally, the detailed interactions among the compositions in those subsystems could be determined to complete an entire urban transportation system and to illustrate the complex system behaviors.

5. Several features of the current work that limit conclusions point to opportunities for future research, including its focus on only one dimension of performance (transport diversity) and model assumptions. Stakeholder needs and related policies are likely to be impacted by other such factors as the effect of resource allocation in specific spaces. Further research replicated the outlined approach is recommended

to simultaneously consider temporal and spatial resource allocation policies, and to improve for reflecting additional aspects of a entire transportation system in practice.

6. In terms of future work, it would be interesting to analyze a richer data set and a private vehicle involved system in order to develop improved, practical and portable resource allocation model. In particular, having data for more than five years as well as more stakeholder participation in the consensus building meetings may lead to model capturing reliable effects.

Additionally, the approaches outlined in this study could be replicated in different collaborative groups, as well as in diverse spatial scope to establish a typology for the number and type of indicators that could be involved and the processes necessary for transport diversity.

REFERENCES

Alberts H. C., Alberts R. M., Bloom, M. F., LaFlamme, A. D. and Teerikangas, S. (2004). “The three Gorges dam project from a systems viewpoint.” *System Research and Behavioral Science*, 21(6), 585-602.

Aldaihani, M. M., Quadrifoglio, L., Dessouky, M. M. and Hall, R. (2004). “Network design for a grid hybrid transit service.” *Transportation Research Part A: Policy and Practice*, 38(7), 511-530.

Allen, T. F. H. and Hoekstra, T. W. (1994). “Toward a definition of sustainability.” *Sustainable Ecological Systems: Implementing an Ecological Approach to Land Management*. W. W. Covington and L. DeBano, eds., Rocky Mountain Forest and Range Experiment Station, Colorado.

Alterkawi, M. M. (2006). “A computer simulation analysis for optimizing bus stops spacing: The case of Riyadh, Saudi Arabia.” *Habitat International*, 30(3), 500-508.

Altiparmak, F. and Karaoglan, I. (2008). “An adaptive tabu-simulated annealing for concave cost transportation problems.” *Journal of the Operational Research Society*, 59(3), 331-341.

American Association of State Highway and Transportation Officials (1994). *A Policy on Geometric Design of Highways and Streets*, AASHTO, Washington, D.C.

Barlas, Y. and Yasarcan, H. (2006). “Goal setting, evaluation, learning and revision: A dynamic modeling approach.” *Evaluation and Program Planning*, 29(1), 79-87.

Belfares, L., Klibi, W., Lo, N. and Guitouni, A. (2007). “Multi-objectives Tabu Search based algorithm for progressive resource allocation.” *European Journal of Operational Research*, 177(3), 1779-1799.

Beirao, G. and Cabral, J. A. S. (2007). “Understanding attitudes towards public transport and private car: a qualitative study.” *Transport Policy*, 14(6), 478-489.

Bhattacharya, U., Rao, J. R. and Tiwari, R.N. (1992). “Fuzzy multi-criteria facility location problem.” *Fuzzy Sets and Systems*, 51(3), 277-287.

Bigotte, J. F. and Antunes, A. P. (2007). “Social infrastructure planning: A location model and solution methods.” *Computer-Aided Civil and Infrastructure Engineering*, 22(8), 570-583.

Bit, A. K., Biswal, M. P. and Alam, S .S. (1992). "Fuzzy programming approach to multicriteria decision making transportation problem." *Fuzzy Sets and Systems,* 50(2), 135-141.

Bit, A. K., Biswal, M. P. and Alam, S .S. (1993). "Fuzzy programming approach to multiobjective solid transportation problem." *Fuzzy Sets and Systems*, 57(2), 183-194.

Blunden, W. R., and Black, J. A. (1984). *The Land-use Transport System*, 2nd ed., Pergamon Press, Sydney.

Burns, L. D. (1979). *Transportation, Temporal, and Spatial Components of Accessibility*, Lexington Books, Massachusetts.

Carbonara, N. and Scozzi, B. (2006). "Cognitive maps to analyze new product development processes: A case study." *Technovation*, 26(11), 1233-1243.

Carman, J. M. (1990). "Consumer perceptions of service quality: An assessment of the SERVQUAL dimensions." *Journal of Retailing,* 66(1), 33-35.

Carr, C. L. (2007). "The FAIRSERV model: Consumer reactions to services based on a multidimensional evaluation if service fairness." *Decision Sciences*, 38(1), 107-130.

Ceder, A. and Wilson, N. H. M. (1986). "Bus network design." *Transportation Research Part B: Methodological*, 20(4), 331-344.

Centre for Sustainable Transportation (1997). *Definition and Vision of Sustainable Transportation,* Centre for Sustainable Transportation, Toronto.

Ceselli, A., Gatto, M., Lübbecke, M. E., Nunkesser, M. and Schilling, H. (2008). "Optimizing the cargo express service of Swiss federal railways." *Transportation Science*, 42(4), 450-465.

Chan, S. L. and Huang, S. L. (2004). "A systems approach for the development of a sustainable community - the application of the sensitivity model (SM)." *Journal of Environmental Management,* 72(3), 133-147.

Chang, C. T. (2007). "Binary fuzzy goal programming." *European Journal of Operational Research*, 180(1), 29-37.

Chen, F. Y. and Chang, Y. H. (2005). "Examining airline service quality from a process perspective." *Journal of Air Transport Management*, 11(2), 79-87.

Chu, C. Y. and Durango-Cohen, P. L. (2008). "Incorporating maintenance effectiveness in the estimation of dynamic infrastructure performance models." *Computer-Aided Civil and Infrastructure Engineering,* 23(3), 174-188.

Commission of the European Communities (2002). *Communication from the commission on impact assessment* - COM(2002) 276 final, Commission of the European Communities, Brussels.

Conrad, K. (2000). "An econometric model of production with endogenous improvement in energy efficiency, 1970-1995." *Applied Economics*, 32(9), 1153-1160.

Das, I. and Dennis, J. E. (1997). "A closer look at drawbacks of minimizing weighted sums of objectives for

Pareto set generation in multicriteria optimization problems." *Structural Optimization*, 14(1), 63-69.

de Cea, J., Fernandez, J. E. and de Grange, L. (2008). "Combined models with hierarchical demand choices: A multi-objective Entropy optimization approach." *Transport Reviews*, 28(4), 415-438.

de Vasconcellos, E. A. (2005). "Transport metabolism, social diversity and equity: the case of Sao Paulo, Brazil." *Journal of Transport Geography*, 13(4), 329-339.

Deng, W. (2007). "Using a revised importance-performance analysis approach: The case of Taiwanese hot springs tourism." *Tourism Management*, 28(5), 1274-1284.

Diener, E., Suh, E. M., Lucas, R. E., and Smith, H. L. (1999). "Subjective wellbeing: three decades of process." *Psychological Bulletin*, 125(2), 276-302.

Eckton, G. D. C. (2003). "Road-user charging and the Lake District National Park." *Journal of Transport Geography*, 11(4), 307-317.

Eden, C. and Ackermann, F. (2004). "Cognitive mapping expert views for policy analysis in the public sector." *European Journal of Operational Research*, 152(3), 615-630.

European Commission (2006). *Mid-term Review of White Paper: European Transport Policy for 2010 [COM (2001) 0370]*, European Commission, Dessau.

Fankhauser, S. and Tepic, S. (2007). "Can poor consumers pay for energy and water? An affordability analysis for transition countries." *Energy Policy,* 35(2), 1038-1049.

Feng, C. M. and Hsieh, C. H. (2009). "Implications of transport diversity for quality of life." *Journal of Urban Planning and Development*, 135(1), 13-18.

Ferguson, B. K. (1996). "The maintenance of landscape health in the midst of land use change." *Journal of Environmental Management*, 48(4), 387-395.

Gao, Z., Sun, H. and Shan, L. L. (2004). "A continuous equilibrium network design model and algorithm for transit systems." *Transportation Research Part B: Methodological*, 38(3), 235-250.

Gilbert, R., and Tanguay, H. (2000). *Sustainable Transportation Performance Indicators Project*, Centre for Sustainable Transportation, Toronto.

George C. (2001). "Sustainability appraisal for sustainable development: integrating everything from jobs to climate change." *Impact Assessment and Project Appraisal*, 19(1), 95-106.

Georgopoulos, V. C., Malandraki, G. A. and Stylios, C. D. (2003). "A fuzzy cognitive map approach to differential diagnosis of specific language impairment." *Artificial Intelligence in Medicine*, 29(3), 261-278.

Gilbert, D. and Wong, K. C. (2003). "Passenger expectations and airline services: A Hong Kong based study." *Tourism Management*, 24(5), 519-532.

Gorman, M. F. (2008). "Evaluating the public investment mix in US freight transportation infrastructure."

Transportation Research Part A: Policy and Practice, 42(1), 1-14.

Gronroos, C. (1984). “A service quality model and its marketing implications.” *European Journal of Marketing*, 18(4), 36-44.

Gursoy, D., Chen, M. H. and Kim, H. J. (2005). “The US airlines relative positioning based on attributes of service quality.” *Tourism Management*, 26(1), 57-67.

Hamilton, A. J. (2005). “Species diversity or biodiversity?” *Journal of Environmental Management*, 75(1), 89-92.

Hansen, W. (1959). “How accessibility shapes land use.” *Journal of the American Planning Association*, 25(2), 73-76.

Hensher, D. A., Stopher, P. and Bullock, P. (2003). “Service quality - developing a service quality index in the provision of commercial bus contracts.” *Transportation Research Part A: Policy and Practice*, 37(6), 499-517.

Hunter, M. L., Jr. (1990). *Wildlife, Forests, and Forestry: Principles of Managing Forests for Biological Diversity*, Prentice-Hall, Inc., New Jersey.

Ingram, D. R. (1971). “The concept of accessibility: A search for an operational form.” *Regional Studies*, 5(2), 101-107.

Institute of Transportation (2002). *Quantitative Indicators of Sustainable Transportation* (in Chinese), the Institute of Transportation, Taipei

Islam, S. and Roy, T. K. (2006). “A new fuzzy multi-objective programming: Entropy based geometric programming and its application of transportation problems.” *European Journal of Operational Research*, 173(2), 387-404.

Jeon, C. M., Amekudzi, A. A., and Vanegas, J. (2006). “Transportation system sustainability issues in high-, middle-, and low-income economics: Case studies from Georgia (U.S.), South Korea, Colombia, and Ghana.” *Journal of Urban Planning and Development - ASCE*, 132(3), 172-186.

Jha, M. K., Schonfeld, P. and Samanta S. (2007). “Optimizing rail transit routes with genetic algorithms and geographic information system.” *Journal of Urban Planning and Development*, 133(3), 161-171.

Jiang, J. J., Klein, G. and Crampton, S. M. (2000). “A note on SERVQUAL reliability and validity in information system service quality measurement.” *Decision Sciences*, 31(3), 725-744.

Kang, K. M. and Jae, M. (2005). “A quantitative assessment of LCOs for operations using system dynamics.” *Reliability Engineering and System Safety*, 87(2), 211-222.

Kang, I., Lee, S. and Choi, J. (2004). “Using fuzzy cognitive map for the relationship management in airline service.” *Expert Systems with Applications*, 26(4), 545-555.

Kano, N., Seraku, N., Takahashi, F, and Tsuji, S. (1984). “Attractive quality and must-be quality.” *Quality*, 14(2), 39-48.

Kapp, C. (2003). “WHO acts on road safety to reverse accident trends.” *The Lancet,* 362(9390), 1125-1125.

Kasemir, B., Jäger, J., Jaeger, C. C., and Gardner, M. T. (2003). *Public Participation in Sustainability Science*, Cambridge University Press, Cambridge.

Kettinger, W. J. and Lee, C. C. (2005). “Zones of tolerance: Alternative scales for measuring information systems service quality.” *MIS Quarterly*, 29(4), 607-621.

Koontz, T. M. (2003). “The farmer, the planner, and the local citizen in the dell: how collaborative groups plan for farmland preservation.” *Landscape and Urban Planning,* 66(1), 19-34.

Kuhn, K. D. and Madanat, S. M. (2006). “Robust maintenance policies for Markovian systems under model uncertainty.” *Computer-Aided Civil and Infrastructure Engineering,* 21(3), 171-178.

Kwahk, K. Y. and Kim, Y. G. (1999). “Supporting business process redesign using cognitive maps.” *Decision Support Systems*, 25(2), 155-178.

Lane, D. C. (2000). “Should system dynamics be described as a ‘hard’ or ‘deterministic’ systems approach?” *Systems Research and Behavioral Science*, 17(1), 3-22.

Lee, E. S. and Li, R. J. (1993). “Fuzzy multiple objective programming and compromise programming with Pareto optimum.” *Fuzzy Sets and Systems,* 53(3), 275-288.

Lee S. M. and Moore L. J. (1973). “Optimizing transportation problems with multiple objectives.” *IEE Transactions,* 5(4), 333-338.

Lee, Z. W., Ford, D. N. and Joglekar, N. (2007). “Effects of resource allocation policies for reducing project durations: A systems modelling approach.” *Systems Research and Behavioral Science*, 24(6), 551-566.

Levine, J., and Garb, Y. (2002). “Congestion pricing conditional promise: promotion of accessibility or mobility?” *Transport Policy*, 9(3), 179-188.

Levinson, D. (2003). “Perspectives on efficiency in transportation.” *International Journal of Transport Management*, 1(3), 145-155.

Li, R. J. and Lee, E. S. (1990). “Fuzzy approaches to multicriteria de novo programs.” *Journal of Mathematical Analysis and Applications*, 153(1), 97-111.

Liang, T. F. (2008). “Interactive multi-objective transportation planning decisions using fuzzy linear programming.” *Asia-Pacific Journal of Operational Research,* 25(1), 11-31.

Liou, J. H. and Tzeng, G.. H. (2007). “A non-additive model for evaluating airlines service quality.” *Journal of Air Transport Management*, 13(3), 131-138.

Loo, B. P. Y. and Chow, S. Y. (2006), “Sustainable urban transportation: Concepts, policies, and methodologies.” *Journal of Urban Planning and Development - ASCE*, 132(2), 76-79.

Maclaren, V. W. (1996). “Urban sustainability reporting.” *Journal of the American Planning Association*, 62(2), 184-202.

Malizia, E. E. and Ke, S. (1993). “The influence of economic diversity on unemployment and stability.” *Journal of Regional Science*, 33(2), 221-235.

Martellato, D., Reggiani, A., and Nijkamp, P. (1998). “Measurement and measures of network accessibility - economic perspectives.” *Transport Networks in Europe; Concepts, Analysis and Policies*, K. Button, P. Nijkamp and H. Priemus, eds., Edward Elgar, London.

Martins, C. L. and Vaz Pato, M. (1998). “Search strategies for the feeder bus network design problem.” *European Journal of Operational Research*, 106(2-3), 425-440.

Martinson, F. K. (1993). “Fuzzy vs. minmax weighted multiobjective linear programming illustrative comparisons.” *Decision Sciences*, 24(4), 809-824.

May, R. M. (1976). *Theoretical Ecology: Principle and Applications*, Blackwell, Oxford.

McGillvray, R., and Kirby, R. (1979). “Financing public transportation.” *Public Transportation: Planning, Operations, and Management*, G. Gray and L. Hoel, eds., Prentice-Hall, New Jersey.

McMahon, S. K. (2002). “The development of quality of life indicators - a case study from the City of Bristol, UK.” *Ecological Indicators*, 2(1-2), 177-185.

Muller, F. (1998). “Gradients in ecological systems.” *Ecological Modelling*, 108(1-3), 3-21.

Munasinghe, M. (1993). *Environmental Economics and Sustainable Development*, the World Bank, Washington, D.C.

Nathanail, E. (2008). “Measuring the quality of service for passengers on the hellenic railways.” *Transportation Research Part A: Policy and Practice*, 42(1), 48-66.

Ness, B., Urbel-Piirsalu, E., Anderberg, S., and Olsson, L. (2007). “Categorising tools for sustainability assessment.” *Ecological Economics*, 60(3), 498-508.

Nguyen, L. D. and Ogunlana, S. O. (2005). “Modeling the dynamics of an infrastructure project.” *Computer-Aided Civil and Infrastructure Engineering*, 20(4), 265-279.

Odum, E. P. (1993). *Ecology and Our Endangered Life-Support System*, Sinaure Associate, Massachusetts.

Odum, H. T. (1983). *Systems Ecology*, John Wiley and Sons, New York.

Organization for Economic Cooperation and Development (2001). *OECD Environmental Indicators: Towards Sustainable Development*, OECD Publications Service, Paris.

Organization for Economic Cooperation and Development (2004). *Measuring Sustainable Development: Integrated Economic, Environmental and Social Frameworks*, OECD Publications Service, Paris.

Pakdil, F. and Aydm, O. (2007). “Expectations and perceptions in airline service: An analysis using weighted SERVQUAL scores.” *Journal of Air Transport Management*, 13(4), 229-237.

Park, J. W. (2007). “Passenger perceptions of service quality: Korean and Australian case studies.” *Journal of Air Transport Management*, 13(4), 238-242.

Phillis, Y. A. and Andriantiatsaholiniaina, L. A. (2001). “Sustainability: an ill-defined concept and its assessment using fuzzy logic.” *Ecological Economics*, 37(3), 435-456.

Pidd, M. (1996). *Tools for Thinking Modeling Management Science*, John Wiley & Sons, Chicheste.

Point, S. and Singh, V. (2003). “Defining and dimensionalising diversity: evidence from corporate websites across Europe.” *European Management Journal*, 21(6), 750-761.

Pope, J., Annandale, D., and Morrison-Saunders, A. (2004). “Conceptualising sustainability assessment.” *Environmental Impact Assessment Review*, 24(6), 595-616.

Rammel, C. and van den Bergh, J. (2003). “An evolutionary perspective on sustainable development policies: adaptive flexibility and risk minimizing.” *Ecological Economics*, 47(2-3), 121-133.

Reeves, D. (2005). *Planning for Diversity: Policy and Planning in a World of Difference*, Routledge, Oxon.

Rhoades, D. L. and Waguespack Jr, B. (2000). “Judging a book by it’s cover: The relationship between service and safety quality in US national and regional airlines.” *Journal of Air Transport Management*, 6(2), 87-94.

Sanchez-Silva, M., Daniels, M., Lleras, G., and Patino, D. (2005), “A transport network reliability model for the efficient assignment of resources.” *Transportation Research Part B: Methodological*, 39(1), 47-63.

Sasaki, M., Gen, M. and Yamashiro, M. (1995). “A method for solving fuzzy de novo programming problem by genetic algorithms.” *Computers & Industrial Engineering*, 29(1-4), 507-511.

Segnestam, L. (1999). *Environmental Performance Indicators: A Second Edition Note* - Environment Economics Series Paper No. 71, the World Bank, Washington, D.C.

Shafer, C. S., Lee, B. K., and Turner, S., (2000). “A tale of three greenway trails: user perceptions related to quality of life.” *Landscape and Urban Planning*, 49(3-4), 163-178.

Shohet, I. M. and Perelstein, E. (2004). “Decision support model for the allocation of resources in rehabilitation projects.” *Journal of Construction Engineering and Management - ASCE*, 130(2), 249-257.

Simon, H. (1996). *The Sciences of the Artificial*, MIT Press, Cambridge.

Sohail, M., Maunder, D. A. C., and Cavill, S. (2006). “Effective regulation for sustainable public transport in developing countries.” *Transport Policy*, 13(3), 177-190.

Soltani, A. and Allan, A. (2006). “Analyzing the impact of microscale urban attributes on travel: Evidence from Suburban Adelaide, Australia.” *Journal of Urban Planning and Development - ASCE*, 132(3), 132-137.

Steg, L. and Gifford, R. (2005). “Sustainable transportation and quality of life.” *Journal of Transport Geography*, 13(1), 59-69.

Sterman J. D. (2000). *Business Dynamics, System Thinking and Modeling for a Complex World*, Irwin McGraw-Hill, New York.

Stylios, C. D. and Groumpos, P. P. (2000). “Fuzzy cognitive naps in modeling supervisory control systems.” *Journal of Intelligent and Fuzzy Systems*, 8(1), 83-98.

Templet, P. H. (1999). “Energy, diversity and development in economic systems; an empirical analysis.” *Ecological Economics*, 30(2), 223-233.

Tong, C., Song, G. B., Chen, B. R. and Ye, W. H. (2008). “Macroeconomic efficiency of use of non-renewable resources in the industrial economy during a period of rapid economic growth in China.” *Resource, Conservation and Recycling*, 52(5), 737-746.

Topolski, T. D., Edwards, T. C., and Patrick, D. L. (2004). “Toward youth self-report of health and quality of life in population monitoring.” *Ambulatory Pediatrics*, 4(4), 387-394.

Transportation Research Board (2000). *Highway Capacity Manual*, National Research Council, Washington, D.C.

Triplett, J. L., Yau, O. H. M and Neal, C. (1994). “Assessing the reliability and validity of SERVQUAL in a longitudinal study: The experience of an Australian organization”. *Asia Pacific Journal of Marketing and Logistics*, 6(1-2), 41-62.

Tsaur, S. H., Chang, T. Y. and Yen, C. H. (2002). “The evaluation of airline service quality by Fuzzy MCDM.” *Tourism Management*, 23(2), 107-115.

Udwadia, F. E., von Bremen, H. F., Kumar, R. and Hosseini, M. (2003). “Time delayed control of structural systems.” *Earthquake Engineering and Structural Dynamics*, 32(4), 495-535.

van Kamp, I., Leidelmeijer, K., and Marsman, G. (2003). “Urban environmental quality and human well-being towards a conceptual framework and demarcation of concepts; a literature study.” *Landscape and Urban Planning*, 65(1-2), 5-18.

van Nes, R. and Bovy, P. H. L. (2000). “Importance of objectives in urban transit-network design.” *Transportation Research Record*, 1735(1), 25-34.

Vester, F and von Hesler, A. (1982). *Sensitivity Model*, Umlandverband Frankfurt am Main, Frankfurt.

Wachs, M., and Koenig, J. G. (1979). “Behavioral modeling, accessibility, mobility and travel needs.” *Behavioural Travel Modelling*. D. A. Hensher and P. R. Stopher, eds., Croom Helm, London.

Wale, R. (2000). “Development of environmental indicators systems: experiences from Germany.” *Environmental Management*, 25(6), 613-623.

Wall, G. and McDonald, M. (2007). “Improving bus service quality and information in Winchester.” *Transport Policy*, *14*(2), 165-179.

Wang, K. J., Wang, S. M. and Yang, S. J. (2007). “A resource portfolio model for equipment investment and allocation of semiconductor testing industry.” *European Journal of Operational Research*, 179(2), 390-403.

Wang, R. T. (2007). “Improving service quality using quality function deployment: The air cargo sector of

China airlines.” *Journal of Air Transport Management*, 13(4), 221-228.

Withanachchi, N., Uchida, Y., Nanayakkara, S., Samaranayake, D. and Okitsu, A. (2007). “Resource allocation in public hospitals: Is it effective?” *Health Policy*, 80(2), 308-313.

World Commission on Environment and Development (1987). *Our Common Future*, Oxford University Press, Oxford.

World Health Organization Quality of Life Group (1998). ”The world health organization quality of life assessment (WHOQOL): development and general psychometric properties.” *Social Science and Medicine*, 46(12), 1569-1585.

Yang, Z. (2002). “Microanalysis of shopping center location in terms of retail supply quality and environmental impact.” *Journal of Urban Planning and Development - ASCE*, 128(3), 139-149.

Yeh, S. C., Wang, C. A. and Yu, H. C. (2006). “Simulation of soil erosion and nutrient impact using an integrated system dynamics model in a watershed in Taiwan.” *Environmental Modelling & Software*, 21(7), 937-948.

Zeithaml, V. A., Parasuraman, A. and Berry, L. L. (1990). *Developing Quality Service: Balancing Customer Perceptions and Expectations*. The Free Press, New York.

Zimmermann, H. J. (1978). “Fuzzy programming and linear programming with several objective functions.” *Fuzzy Sets and Systems*, 1(1), 45-55.

APPENDIX A: NOTATION TABLE

Variable	Description
Suffix	
0	the existent value of transportation infrastructure and service for each variable as a constant
i	the determination of species
j	the concerned link
r	the strategy for resource allocation in the fuzzy multi-objectives programming, $r = 1, 2, \cdots, 7$
q	the concerned individual
s	the evaluation criteria used in the fuzzy multi-objectives programming, $s = 1, 2$
t	the time period
x	the concerned zone in divided space
y	the identified stakeholder need in urban transportation system including emission, safety, accessibility, mobility, reliability, affordability, resource over-utilization, operator profit and level of universal design
z	the divided spatial zone except the concerned one
Emi	the analysis for the need externality in the substitute emission
AR	the analysis for the need safety in the substitute accident rate
Ac	the analysis for the need accessibility
M	the analysis for the need mobility
rel	the analysis for the need reliability
Af	the analysis for the need affordability
$EnCs$	the analysis for the need resource over-utilization in the substitute energy over-consumption
R	the analysis for the need operator profit
UD	the analysis for the need level of universal design
Ab	the analysis for the ability taking modes
$\overline{Ab}$	the filtered ability calculated via a S-curve threshold function
Cr	the user restrictions caused by crowdedness of transit system
Superscript	
m	the modes, such as MRT, bus, feeder bus, passenger car and motorcycle
k	the stations of transit system including MRT and bus
$*$	the ideal situation in the fuzzy multi-objectives programming
$\#$	the anti-ideal situation in the fuzzy multi-objectives programming
H	the value of diversity
P_i	the proportion of the population of species i to the total population
n_i	the number of individuals belonging to species i
m_y	the normalized gap of the indicator referring to stakeholder need y
O_y^{goal}	the expected goal of need y
$O_y^{threshold}$	the minimum threshold of need y
V_y	the present value of need y
n_y	the positive remainder of the gap namely the achievement of need y
w_i	the weight of species i
T_x^m	the monthly trip amount for mode m in zone x
α_y^m	the average coefficient for need y

Variable	Description
N_x	the number of accident casualties in zone x
RV_x	the number of registered motor vehicles in zone x
P_x	the total population in zone x
p_x^k	the resident population in service area station k in zone x
γ_x	the number of links in zone x
nd_x	the number of nodes in zone x
L_j	the length of link j
A_j	the effective pavement width of link j
S_j	the average travel speed on link j
$TT_{xz}^{private}$	the ideal travel time (by private vehicle) from zone x to zone z in minutes
TT_{xz}^{bus}	the actual bus travel time from zone x to zone z in minutes
$Freq_{xz}$	the service frequency in departures from zone x to zone z per hour per direction
$\overline{TT}^{bus}$	the average bus waiting time
h^{bus}	the average headway of buses
$\hat{T}_q^m$	the monthly trip amount for individual q taking mode m
F^m	the average travel cost paid by user and the fare box revenue of operator per trip for mode m
Inc	the average monthly disposable income
C^m	the average operational cost for mode m
u^m	the amount of barrier-free facilities for mode m
Fac^m	the amount of total facilities for mode m
$f_y^m(V_y^m)$	the adjustment function of need y on mode m trips
T_t^m	the trips of mode m at time t
W_s	the solutions under the criterion s in the fuzzy multi-objectives programming
$DS_s(W_s)$	the membership function related to the solutions in the fuzzy multi-objectives programming
λ	the compromise-grade referring to overall satisfaction of the optimization in the fuzzy multi-objectives programming
x_r	the decision variables in the fuzzy multi-objectives programming

APPENDIX B: COEFFICIENTS OF RESOURCE ALLOCATION MODEL

TABLE B-1 Constant coefficients

Item	Applied in	Estimation	Unit	Source
α_1	Eqn. 3-28	7.32	liter oil-equivalent/vehicle-km	Taipei Rapid Transit Corporation
α_2	Eqn. 3-28	0.45	liter oil-equivalent/vehicle-km	Taipei City Department of Transportation
α_3	Eqn. 3-28	0.16	liter oil-equivalent/vehicle-km	Bureau of Energy, MOEA
α_4	Eqn. 3-29	0.1248	kg/vehicle-km	Environmental Protection Administration
α_5	Eqn. 3-29	0.5956	kg/vehicle-km	Environmental Protection Administration

TABLE B-2 Coefficient formulation sourced by regression

Coefficient	Applied in	Formulation	Unit of x_i	R-squared
$g_1(x)$	Eqn. 3-20	$-3375.2+1140.7\ln(L_0^{MRT}+x_1)$	km	0.92
$g_2(x)$	Eqn. 3-20	$-22193+3901.4\ln(L_0^{f-bus}+x_2)$	km	0.95
$g_3(x)$	Eqn. 3-23	$-12716+2263.7\ln(L_0^{bus}+x_3)$	km	0.94
$g_4(x)$	Eqn. 3-31	$33.869-6.2806\ln(L_0^{BEL}+x_7)$	km	0.88
$g_5(x)$	Eqn. 3-32	$33.048-7.155\ln(h_0^{bus}-x_6)$	minute	0.89

TABLE B-3 Consentaneous impact function via expert discussion meeting

Coefficient	Applied in	Formulation
$f_1(V_y)$	Eqn. 3-33	$\dfrac{1.05}{1+e^{-9(V_{Ac\,MRT}-0.35)}}$
$f_2(V_y)$	Eqn. 3-33	$1-\dfrac{1}{1+e^{-20(V_{Af\,MRT}-0.25)}}$
$f_3(V_y)$	Eqn. 3-34	$1.05\times(1-e^{-5V_{Ac\,bus}})$
$f_4(V_y)$	Eqn. 3-34	$1-\dfrac{1}{1+e^{-20(V_{Af\,bus}-0.25)}}$
$f_5(V_y)$	Eqn. 3-34	$\dfrac{1.05}{1+e^{-4(V_{M\,bus})}}$
$f_6(V_y)$	Eqn. 3-34	$\dfrac{1.07}{1+e^{-10(V_{rel\,bus}-0.5)}}$

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

☑ 達成目標

□ 未達成目標（請說明，以 100 字為限）

□ 實驗失敗

□ 因故實驗中斷

□ 其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：☑已發表□未發表之文稿 □撰寫中 □無

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3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

本計畫主要目的係回顧多樣性、生活品質與永續性之相關文獻，進行多樣性、生活品質與永續性之間相關性等議題之探討，彙整評估運輸多樣性所應分析之重要因素，並探究其影響以及可能因應之情況，根據前述重要結論，構建運輸多樣性評估之概念架構，建立都市運輸系統中各項因果關係與回饋。內容元素包括權益關係人需求、運輸系統行為與運輸政策等，並據以建立整合系統動態模型、認知圖法與感受性模型演算方式之決策支援模式，用以評估各項策略對於同時考量多元與公平之運輸多樣性指標的影響及該決策支援系統所提供之資訊，根據前述重要結論，分析系統模擬方法應用之限制及運輸多樣性評估之要件。研究成果部份已投稿至 *Journal of Urban Planning and Development* (SSCI)、*Computer-Aided Civil and Infrastructure Engineering* (SCI)、*運輸學刊* (TSSCI)、*Sustainability* 及 *Journal of the Eastern Asia Society for Transportation Studies* 並獲接受刊登。