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碩士論文

社會福利最大化之大眾運輸補貼雙層數學規劃模式－考量生態足跡限制

Bi-level Transit Subsidy Programming Models toward Social Welfare Maximization under Ecological Footprint Constraint

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摘　　要

為了達到永續運輸及社會福利最大化之目的，本研究試圖建構一雙層數學規劃模式針對預算的分配來訂定最適之永續政策。上層是在有限的預算、運輸系統的容量及生態足跡的限制下，求得每個旅次的社會福利最大化，並對於大眾運輸使用者進行票價補貼、大眾運輸班次的虧損補貼及可取得的綠能地來消化運輸所產生的生態足跡。下層則是經由運具選擇模式決定每個旅次發生所使用的運具，並針對使用私人運具進行使用者均衡模式來決定旅次路線。根據這些假設，本研究發展出單一世代雙層數學規劃模式模式(SG)及跨世代雙層數學規劃模式(AG)。單一世代模式僅考量現在所擁有的資源及預算來決定最適之政策；而跨世代模式則是兩個世代之間的資源及預算交易來求得最適之結果。

為驗證模式的實用性，本研究建構一模擬路網進行模擬分析，單一世代模式結果顯示，增加大眾運輸使用者的票價補貼及大眾運輸的班次，會吸引許多使用者使用大眾運輸，並達到相同的社會福利水準，然而，後者會伴隨著產生大量的生態足跡對於生態環境帶來莫大的傷害。而跨世代模式結果則顯示，現在這個世代可以藉由移轉部分的預算給未來的世代以增加整體總效益並達到對兩個世代最佳之決策。

關鍵字：預算分配，雙層數學規劃，永續，生態足跡

Bi-level transit subsidy programming models toward social welfare maximization under ecological footprint constraint

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ABSTRACT

To achieve transportation sustainability and social welfare, bi-level budget allocation models are proposed, in which the upper level is to maximize the social welfare of trip makers under the constraints of government budget, capacity of transport system, and ecological footprint by allocating budget to subsidize bus users for increasing public transportation patronage and reducing usage of private vehicles and/or to acquire additional green land for accommodating excess footprint. The lower level is to determine the mode choice decisions of all trip makers and the route choice decisions of those who use of private vehicles. Two models are developed and compared: the single generation (SG) model and the across generation (AG) model. The SG model assumes these decisions are made under the consideration of the contemporary generation alone, while the AG model compromises these decisions with the following generation. To investigate the applicability of the model, a case study on an exemplified network is conducted. Results of the SG model show that the measure of bus fare discount and the measure of bus frequency increase can both attract remarkable percentage of bus usage and achieve almost the same social welfare, however, the latter will generate much larger footprint than that of bus fare discount due to the high emission characteristic of buses. The results of the AG model show that the optimal decision of the contemporary generation will compromise its total utility with that of the next generation by intentionally leaving part of budget to the next generation.

Keywords： budget allocation, bi-level programming model, ecological footprint.

誌　　謝

時光荏苒，兩年的北交生活，轉眼間，就在我人生中畫下一個完美的句點。過程中，有許多美好的景色停留，讓我總是捨不得告別這讓我成長許多、穩重許多的大家庭。

首先，謝謝邱裕鈞教授，在研究的過程中一路扶持著我成長，在一旁給予我建議及一直扮演指引我人生方向的燈塔，謝謝您，因為有您，讓我認為我毅然決然來到北交念書的決定是對的，我真的學到許多受用無窮且寶貴的人生經驗。

而在這即將離別的夜晚，總是讓我想起那一起跳舞表演、一起瘋狂想破頭怎麼把活動辦得有聲有色的所學會，會長泓均總是和我隨時討論活動細節、副會長秉宏總是排除萬難、不辭辛苦的帶我們練舞、美麗的祕書佩怡總是適時的聽我吐些莫名的苦水，但還是掛著那大家熟悉的微笑和我說加油，而和我同班六年的好兄弟醫仲和細心的千瑜則是負責盡職的總務，賢慧且總是幫我做手工藝的美工寶慧還有總是和我搶桌子的志偉，以及不管何時都沒任何怨言執行活動的好學長偉丞和朝偉，謝謝你們，總是配合我天馬行空的活動流程及企畫，過程總是把大家累得半死卻永遠是最支持我的好伙伴。

邱家的思豪、鎮篷、雅丹，也謝謝你們在我論文和工作忙不過來的同時，提供我許多資訊及幫助，讓我不會因此分不開身而忽略許多該注意的事項，不管時間過多久，邱家人，永遠是邱家人，對吧！

還記得，那一晚晚在計中工作的日子，身邊總是環繞著大家，每個人都在綻放著魅力及光芒述說著自己的未來以及心中遠大的夢想，那時的我們，是多麼的令人折服與嚮往，希望，不管過了多久，我們都不要忘了最初衷的自己，別遺棄了每晚我們共同一起看到攜手前往的未來，雖然我們在人生的道路上，暫時分離，但我相信，總有一天，我們一定會在某一個特定的時間、特定的地點，再一起聚首，再一次的創造並開啟屬於我們美好的人生故事，所以在這之前，我們每個人都要在自己所認定的藍天裡努力自在的翱翔，勇敢去追尋屬於我們的夢想。

然而，最後要感謝的，還是要謝謝我的家人們，謝謝媽媽總是在我人生重要道路上扮演著亦師亦友的角色，帶著我走過許多難關，也看著我逐漸成長茁壯，相信，換我讓媽媽過著幸福快樂且無憂無慮的日子，已經近在眼前了。

而來到台北念書，遇到一個讓我生命完全不一樣的一個人，不但給了我前所未有的希望與動力，讓我在處理任何事及面對任何難題，都能發揮超乎平常水準的能力，雖然，有些近乎嚴格的要求總是讓我們吵得不可開交，但靜下來後，卻又總是指引我整裝出發的明燈，謝謝你，讓我的人生有了不一樣的開端，謝謝你，讓我朝著自己的夢想奔去時，可以無後顧之憂的盡全力奔馳，因為你永遠是在背後最支持我，且會在我不小心跌倒、難過時，給予我最大的溫暖及擁抱的人，這個人大家都知道是誰，寶貝，謝謝你，陪伴著我分享人生種種成功的喜悅，我們還有許多未來，需要一起牽著手去面對，一起成長去體會。

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Content

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Motivations and background

Transportation plays an important role as a key chain of the social systems and ecosystems. Sustainable transport has drawn increasing worldwide attentions under the policies and initiatives of sustainable development provoked by the Brundtland Commission, formally the World Commission on Environment and Development (WCED) since 1987. The OECD (1996) defined environmentally sustainable transport as transportation that does not endanger public health or ecosystems and meets mobility needs consistent with use of renewable resources at below their rates of regeneration and use of non-renewable resources at below the rates of development of renewable substitutes. Pertaining to this concept, a number of earlier works attempted to address what the scope of transportation sustainability meant and what the directions and indicators of sustainable transportation were. For example, Black (1996) defined sustainable transport as "…satisfying current transport and mobility needs without compromising the ability of future generations to meet these needs." Whatever it is defined, most researchers have agreed that sustainable transport development is highly affected by such factors as spatial and land-use planning, government policy, economic forces, technology, and social and behavioral trends.

Towards transportation sustainability, it is essential to guide people to choose low- or zero-emission and energy conservation mode. However, people always choose the most economical and convenient mode depending upon their life styles. Use of private vehicles without paying the external pollution and congestion costs seems a popular choice worldwide, which also explains the rapid growth in the ownership and usage of cars and motorcycles. The greater usage of private vehicles will inevitably lead to a serious environmental disaster.

To control the usage of private vehicles and to encourage public transportation patronage is a classical "Carrot-and-Stick" policy to relieve such an environmental disaster. However, in most of demographic countries, the Stick-related policies are usually not appealing. Therefore, under government budget and ecological footprint constraints, how to provide adequate favorable incentives to encourage the ridership of public transportation deserve in-depth studies.

However, mode choice behaviors are significantly affected by level of service and travel cost of transport modes; while the level of service and travel cost determines the mode choices inversely. In addition, many stakeholders, such as passengers, transit operators, government, are involved during the decision process. The complexity of transport systems not only derives from the pluralism of infrastructures and vehicles, it also sources from the behaviors of people and organizations. Very few studies have employed quantitative methods that can satisfactorily elucidate the interactions among different transport systems under sustainability contexts, perhaps due to the complex nature of transport systems. Without an analytical framework or robust modeling, quantitative results of insightful directions and interactions among different sectors are barely obtained. Therefore, to propose policy towards transportation sustainability, it is necessary to develop an integrated model which can model such complex interactions among various modes and stakeholders and to clearly indicate the directions of effective policies.

In addition, “ecological footprint” is one of tools to measure what natural burdens and how sustainable an activity is, which is defined as the total area of productive land and water area required to provide support for that activity (Wackernagel and Rees, 1996). This tool is helpful to unify different units of resources used and environment burdened during the transportation process and to compare with the amount of natural resource which we enjoy.

1.2 Research objectivities

Based on the abovementioned motivations, the aims of this study are：

1. To review and summarize the studies related to “sustainable transportation”, “ecological footprint”, and “quality of life” to serve as the step stone of this study.
2. To develop a bi-level programming model to determine the optimal strategies for subsidizing public transportation toward Quality of Life maximization and Ecological Footprint minimization under the government budget constraint and lower-level model (user equilibrium model).
3. To validate the proposed model by an exemplified example.
4. To draw conclusions and to recommend the strategies through scenario analysis and sensitivity analysis.

1.3 Framework and organization

The research flowchart of this study is depicted in Figure 1.1.

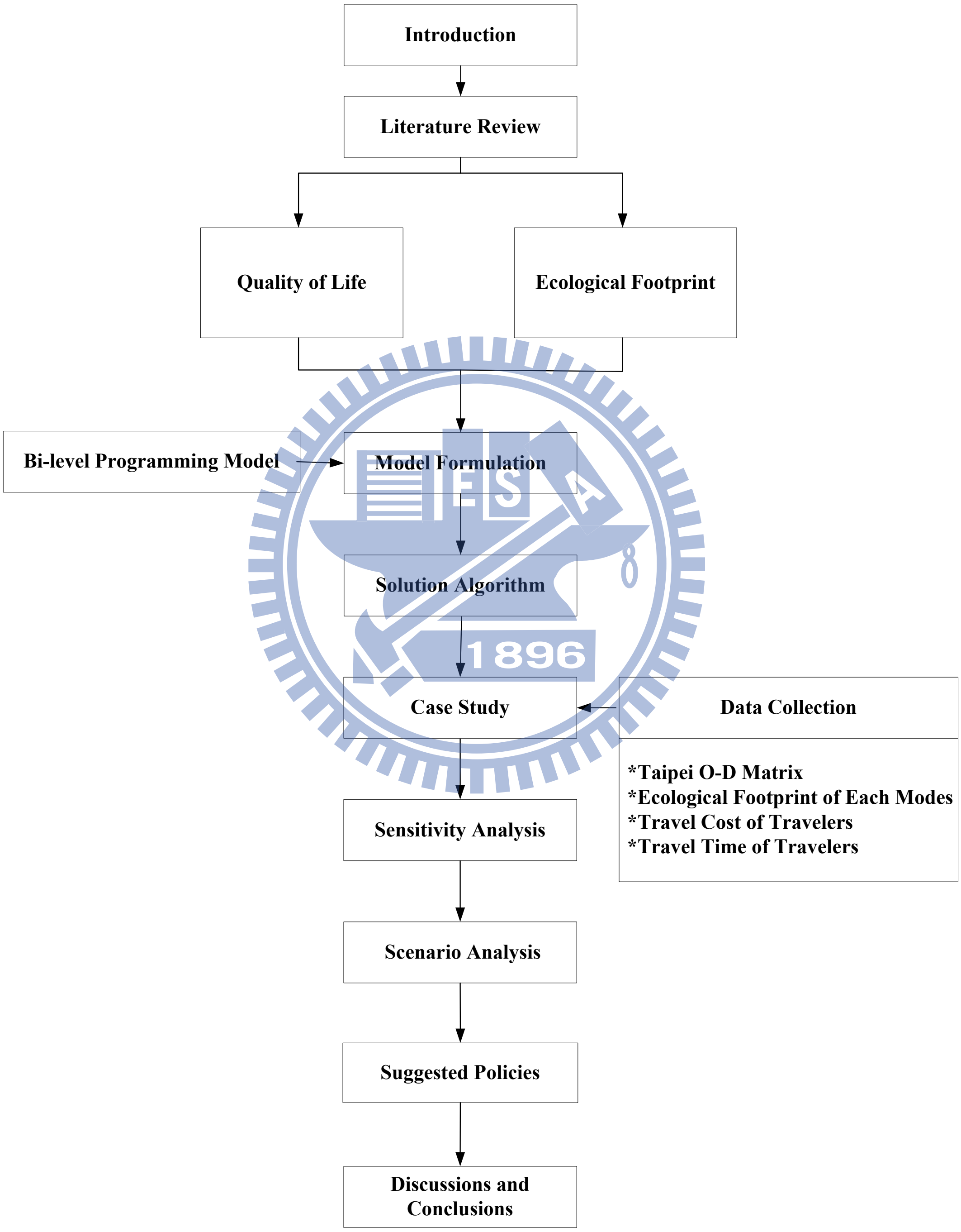


Figure 1.1 Research flowchart

1.4 Research procedure

Following the research objectives and the flowchart in Figure 1.1, the research procedure of this study is designed below：

1. Problem definition

Clearly define the research target and scope of this study and to confirm the objectivities of this study. Determine the potential methodologies and tools related to this research.

2. Literature review

Systematically review the studies related to sustainable transportation, ecological footprint, and quality of life for selecting the key indicators influence sustainability and quality of life.

3. Research framework

Due to the complexity of the transport systems, the proposed model will contain several sub-models. To clearly indicate the relationships among these sub-models, a research framework is developed.

4. Model formulation

The proposed bi-level programming model is formulated as：

I. Upper level：

The decision maker in upper level is government, which aims to determine an optimal strategies for subsidizing public transportation to maximize quality of life and minimize ecological footprint under the budget constraint.

II. Lower level：

There are two models in the lower level： a model choice model (Logit model) and an user equilibrium model. The decision maker in lower level is the users of the transportation system. Users attempt to make mode choice and route choice decisions to be better off.

5. Exemplified example

An exemplified example is designed validate the proposed model and to compare the performances of different subsidy strategies.

6. Sensitive analysis

This chapter presents the sensitive analysis of parameters in the proposed model, including changes in budget, mode choice coefficients, and ecological footprint coefficients.

7. Scenario analysis

To further investigate the effect of situation changes, three scenarios： optimistic, neutral, and pessimistic are respectively tested and compared.

8. Conclusion and suggestion

Based on the results of case study, effective strategies towards transportation sustainability are recommended. Suggestions for future studies are also indicated.

Chapter 2 Literature Review

2.1 The idea of sustainable transportation

Sustainable development should include three principles about fairness, sustainability and commonality. In society, we have to distribute the resource fairly to satisfy the need of contemporary and next generations. In economy, we have to develop economy in sustainable progress but protect the natural system of the earth. And in ecological, we look forward to coexist between human and the nature. This idea about sustainable development was proposed from the proposal about World Conservation Strategy by International Union for Conservation of Nature (IUCN), United Nations Environment Programme (UNEP) and World Wide Fund for Nature (WWF) in 1980s. And then, World Commission on Environment and Development of United Nations in 1987 (WCED) put forward the special project report of "our common future", commonly defined as development that meets the needs and aspirations of current generations while preserving the ability of future generations to meet their own needs and aspirations.

OECD (2000) declaimed the core concern of sustainability is in ensuring that while economic and social development continues, the natural and human environment is preserved, and the impacts of development and environmental management are equitably distributed. They also have clearly explanation about "sustainable transportation", and based on it to establish the sector of Environment Sustainable Transport (ESI). They set the goal of sustainable transportation to decline the pollution from the vehicles. The way is how do reduce the trips, how to develop and encourage public transport and how to improve the impact to environment from transportation by technique.

Steg and Gifford (2005) propose the principle of sustainable transportation about how to balance environment, society and economy by seeking and building up the important indicators. Government could take advantage of the effective sustainable goal to keep a watchful eye on the development of sustainable transportation by effective indicators. According to the study from Geurs and Van Wee (2000), they promote some criterions to evaluate CO_2, NO_x, particles emission and land use. And then, they present three different scenarios to evaluate sustainable transportation in different levels：high-technology scenario, mobility-change scenario and combination scenario. And we could know from that, if we want to reach the goal of sustainability, we have to make a breakthrough in technology and urgent to change the behavior of human and the style of economy. However, it also causes some problems about that if government always develops forward sustainability, whether it's accepted by population or not?

There are many different definitions about sustainable transportation in many references. However, they are talking about the same thing. That is how to get balance among economy, society and environment between different generations to reach the goal of sustainable transportation. And government could base on contemporary transportation system to develop sustainability in future, including the land use, pollution emissions, traffic safety, traffic noise, and healthy affection, the cost of emergency and accessibility (Steg and Gifford, 2005). And at the same time, governments also have to consider different strategies which will have different impacts on sustainability. Changing the transportations system in use would have other influences on any un-sustainability development. That is why the governments have to consider the levels of society, economy and environment when they do some policy making.

Different stakeholders meet their goals with widely different priorities to reach consensus on interim goals. In Amekudzi (2009)'s research, they present a model about sustainability footprint to assess the quality of life for society and the impact of natural environment of transportation system. As the result, constructing a useful and feasible tool to observe and develop sustainability is necessary. We can proof that by the idea from Acutt and Dodgson (1997), they consider transportation department should apply different economic strategies to incline the impact on environment from transportation system and assess the utility of all, including the tax on pollution, fuels and the usage of the vehicles.

Discussion

According to some studies, we could find out that if we want to develop forward sustainability, economic, environment and equity are the different levels what we have to find out the balance among those. There are also some studies discussing about how to use the different indicators or tools to evaluate the sustainability. Therefore, this study will summarize some tables to point out the difference among different tools which used by evaluating the transportation sustainability.

2.2 The tools of sustainable development

Because of economy improvement, the consumption of resources also increases rapidly. When earth reaches the limit of ecological capacity, there are also some crises for human being surviving. Therefore, the governments around the world have set the goals to solve the problems about sustainability and develop some programs and indicators to assess the system. The results are summarized in table 2.1.

Table 2.1 Comparable analysis of tools assessing sustainability

Tools	Contents	Factors
Sustainable development indicators	Solve the problem and assess sustainability by three levels of economy, society and environment.	● Economy factors ● Society factors ● Environment factors
Ecological footprint	Require how much land and water area to reduce the resources to consume and absorb its wastes under prevailing technology	● Fossil energy land ● Build up land ● Arable land ● Pasture ● Sea area ● Forest area
Environment space	Based on the environment space in 2010to assess the usage of environment resources and consider the problem of resources allocations.	● Energy usage and emission ● Reuse materials ● Land-use ● Forest ● Sea
Life recycle analysis	Assess the environment impacts of the process from extracts, production, usage and discards	● Materials ● Pollutions ● Discards
Ecological effective analysis	Use materials and energy more efficiency, and incline the cost of economy and impact of environment	● Materials density ● Energy density ● Poison spread ● Recyclable materials ● Re-use resources efficiency

		● Durable materials ● Service power

In this study, I take advantage of ecological footprint as the tool to evaluate the ecological environment. The characteristic of the ecological footprint is the concept by assessing the natural resources required by various human activities in terms of productive land. That is the productive land and water area required to provide support for that activity, and it is also a resource management tool that measures how much land and water area a human population required to produce the resources it consumes and absorb its wastes under prevailing technology.

Based on the concept of ecological footprint, this study applies it to evaluate sustainable transportation within some development indicators. And this paper uses this concept to measure the consumption of different resources among different vehicles. And we expect we could use this result to let people realize the idea of the transportation behaviors from each person will have heavy impacts on the environment of the earth. Therefore, people should choose the friendlier ways such as shifting the habits of transportation in order to improve the environment of the earth.

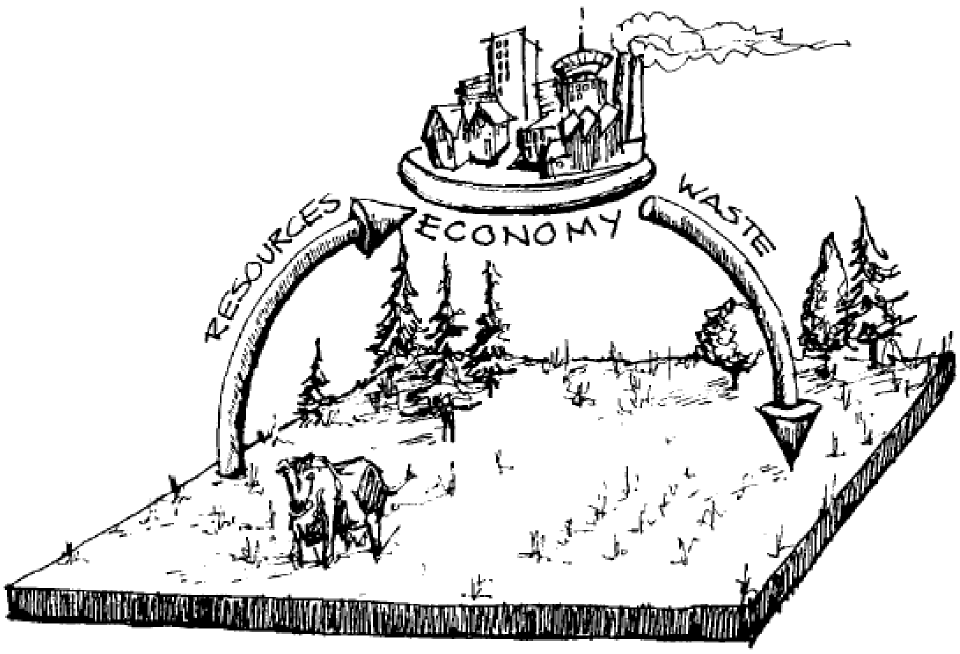


Figure 2.1 A city has an "industrial metabolism" to measure ecological footprint

Sources： Rees and Wackernagel, 1996

In other words, we can image the concept of ecological footprint as the metabolism of the city or the global world (Rees and Wackernagel, 1996). In this respect, it can be compared to a large animal grazing in its pasture. Just like the beast, the city consumes resources and all this energy and matter eventually passes through to the environment again. Thus, the footprint question becomes： "How large a pasture is necessary to support that city indefinitely-to produce all its 'feed' and to assimilate all its wastes sustainably"

In general, the consumption of ecological footprint produced by higher-development city is the much highest. As this result, higher-development city have to balance the ecological deficit with un-development or developing cites. Therefore, when we calculate the ecological footprint on the special area, we can forward to compare with ecological benchmark to realize the differences between each other.

Ecological benchmark means that the natural resources what people could use in the earth. The value will change by the real land productivity. If this value is much higher than the real one, we call it "ecological deficit". We could find out the reflection about how to use the natural capacity and the tradeoff happened by ecological deficit.

Before calculating the ecological benchmark, we have to classify the biological productivity of the different land use. And we can estimate what the alternative lands people can use from different lands and productivity. Biological productivity means the ability of regeneration. Let the productivity of the special land divided by total land area in this category. According to the research from Wackernagel et al. (1999), they separate it into six categories：

1. Arable land

   The most productivity land in ecological, people could cultivate the crop like wheat or rice. People have 0.25 hectare per person around the world.

2. Pasture

   People take advantage of it to graze cattle, sheep or cow there. People have 0.6 hectare per person around the world.

3. Forest area

   People could use it to cultivate or produce the natural woods. There are 34.4 hundred million hectare forest areas around the world. That equals to 0.6 hectare per person around the world.

4. Fossil energy land

   In theory, these areas are used to absorb and preserve CO_2. However, more lands have been developed in reality, couldn't use it to absorb CO_2. That means the consumption and the energy of fossil land couldn't absorb by these areas. We depend on the natural capital to survive now.

5. Build up land

People use it to construct or road building, however, if we continuously develop these area could have harmful damage for arable areas. People have 0.03 hectare per person around the world.

6. Sea area

Studies view sea areas as biological productivity land, because of that people could acquire food from sea. There are 366 hundred million hectare sea areas all over the world. That equals to that people have 6 hectare each person. However, the 95% ecological productivity of the sea only 0.5 hectare, that is the maximum production of the sea.

Summarize the total land areas of biological productivity： 0.25 hectare of arable area, 0.6 hectare of pasture area, 0.6 hectare of forest area, 0.03 hectare of build area and 0.5 hectare of sea. That means people have 2 hectare biological productivity land each person around the world. However, according to the report of the WCED, there are at least 12% ecological capacities preserved to protect biological diversity.

According to this result, people only could use 1.7 hectare area among it, the other 0.9 hectare have been used to protect the biological diversity. And we view this 1.7 hectare land area as “ecological benchmark” to compare with ecological footprint. Although ecological footprint is easier using to evaluate the environment protection and sustainability, there are some opposite opinions from some studies considering this concept is too easier to have the problems about that there may some gaps between theory and reality (Rees and Wackernagel, 1996). For example, the model is static, whereas both nature and the economy are dynamic systems. Therefore, ecological footprint cannot directly take into account such things as technological change or the adaptability of social systems. In fact, each analysis provides a snapshot of our current demands on nature, a portrait of how things stand right now under prevailing technology and social values. Therefore, we could view ecological footprint as a tool to estimate how much we have to reduce our consumption, improver our technology, or change our behavior to achieve sustainability. And if we add the factor of time, we also could find out the influence change by improvement technology and behavior change.

2.2.1 The foundation thesis and application of ecological footprint

The overall ecological footprint model should include the land-used directly and indirectly consumed from all the resource and energy. Because the manner of calculating the ecological footprint is set to list, when adding one assessment item into analysis will may increase the total footprint. That result in the ecological what we calculated is smaller and more conservation than the real world. There are two processes of the analysis and calculation about ecological footprint：At first, tracing and analyzing the overall consumption of resource and junk produced, and then transform it into the bio-productivity land area to provide and supply the function around the world.

In theory, ecological footprint model would calculate how much land and water area used for the consumption of resource. But the process is hard and complicated; there are some simplify way to calculate：

1. The land with productivity is sustainable in the assumption; however, it is not true in the reality, the consumption of the lands are usually faster than re-use it.
2. Only considering the basic service of naturals and focus on how to use the function by the activities directly and indirectly by human being, including the recycle

energy and disposable consumption, the absorption of the consumption, the building land area, available water using and some environmental pollution.

3. If there are more than two services or activities in the same land area, not calculating the consumption of ecological doubly, only calculate which use more ecological footprint.

4. Simplify the manner of classification about bio-productivity to make it easier to calculate and analyze. E.g. separate ecological system into eight land categories.

Simplifying will underestimate the needs for land by human being. But if continuously tracing the development, the indicators of ecological footprint are just like camera that could display each step about the needs of human being. Ecological footprint presents the other thought to evaluate the problem of environment. It not only emphasizes the analyst of ecological physical, but also promotes the development and expansions of economy are all limited by the ecological carrying capacity. The consumption of resource and energy from human being also has to consider the limitation from the ecological system.

The major strength of ecological footprint analysis is its conceptual simplicity. This method provides an intuitive and visually graphic tool for communicating the sustainability dilemma, which is one of the most important dimensions in sustainability. It not only aggregates the ecological flows associated with consumption and translates them into appropriated land area, but is an indicator that anyone can understand it. Then, the ecological footprint of population can be compared with the available supply of productive land. Individuals can contrast their personal footprints with their ecological "fair Earth shares". National footprints can be compared to domestic territories, and the aggregate human footprint can be compared to the productive capacity of the entire planet.

In case that the ecological footprint is significantly larger than a secure supply of productive land, the difference represents a "sustainability gap" and "ecological deficit" (Rees, 1996). This is the amount by which consumption must be reduced for long term ecological sustainability. Thus, unlike ordinary measures of total resource use, ecological footprint analysis provides secondary indices that can be used as policy targets. And then the questions appears：How large is our ecological deficit and what must be done to reduce it？

Although acknowledging its power to communicate a fundamental message, some commentators have suggested that the footprint concept is too simplistic. For example, the model is static, whereas both nature and the economy are dynamic systems. Ecological footprinting therefore cannot directly take into account such things as technological change or the adaptability of social systems.

Footprint analysis is not dynamic modeling and has no predictive capability. However, prediction was never our intent. Ecological footprinting acts, in effect, as an ecological camera－each analysis provides a snapshot of our current demands on nature, a portrait of how things stand right now under prevailing technology and social values. Ecological footprinting also estimates how much we have to reduce our consumption, improve our technology, or change our behavior to achieve sustainability.

2.2.2 The meaning and definition of ecological footprint

Ecological footprint analysis illustrates the fact that as a result of the enormous increase in per capita energy and material consumption made possible by technology, and universally increasing dependencies on trade, the ecological locations of high-density human settlements no longer coincide with their geographic locations. So far, our Ecological Footprint calculations are based on five major categories of consumption－food, housing, transportation, consumer goods and services－and on eight major land-use categories as Table 2.2.

Table 2.2 Eight major land-use categories and categories

(1) Energy land	a. "Transformed land" by fossil energy	Energy or the land of CO_2
(2) Consumed land	b. Build up land	Deteriorated land
(3) Available land	c. Garden	Recuperated build-up land
	d. Arable land	Arable system
	e. Pasture	Adjusted system
	f. Cultivated forest	
(4) Limited undeveloped land	g. Uncultivated forest	Productivity ecosystem
	h. Unavailable land	Desert; Ice cap

Source： Wackernagel *et al.* (1999)

However, we have examined only one class of waste flow in detail. We account for carbon dioxide emissions from fossil energy consumption by estimating the area of average carbon-sink forest that would be required to sequester them

[carbon emissions/capita] / [carbon assimilation/hectare],

on the assumption that atmospheric stability is a prerequisite of sustainability.

From Table 2.3, we could find out that most highly urbanized industrial countries run an ecological deficit about an order of magnitude larger than the sustainable natural income generated by the ecologically productive land within their political territories. However, ecological footprint analysis illustrates the fact that as a result of the enormous increase in per capita energy and material consumption made possible by technology, and universally increasing dependencies on trade, the ecological locations of high-density human settlements no longer coincide with their geographic locations. Cities necessarily appropriate the ecological output and life support functions of distant regions all over the world through commercial trade and natural biogeochemical cycles. Perhaps the most important insight from this result is that no city or urban region can achieve sustainability on its own. Regardless of local land use and environmental policies, a prerequisite for sustainable cities is sustainable use of the global hinterland.

Table 2.3 Compared ecological footprint of different major countries around the world

Country	Population (thousand people)	Ecological footprint (ha/capita)	Country	Population (thousand people)	Ecological footprint (ha/capita)
Iceland	274	9.91	Poland	38521	3.35
New Zealand	3654	9.83	Israel	5854	3.05
America	268189	8.36	Thailand	60046	2.77
Australia	18550	8.11	Hong Kong	5913	2.66
Canada	30101	6.99	Malaysia	21018	2.66
Ireland	3577	6.57	South Africa	43325	2.6
Finland	5149	6.33	Venezuela	22777	2.6
Japan	125672	6.25	Brazil	167046	2.57
C.I.S.	146381	5.98	Costa Rica	3575	2.52
Sweden	8862	5.82	Hungary	10037	2.46
Denmark	5194	5.75	World average	5892480	2.34

France	58433	5.68	Mexico	97245	2.27
Norway	4375	5.68	Philippines	70375	2.17
Austria	8053	5.39	South Korea	45864	1.99
Singapore	2899	5.29	Turkey	64293	1.89
Portugal	9814	5.05	Peru	24691	1.73
Belgium	10174	5.03	Columbia	36200	1.72
Switzerland	7332	5.00	Nigeria	118369	1.69
Netherlands	15697	4.66	Indonesia	203.631	1.58
Argentina	35405	4.64	Jordan	203631	1.54
Germany	81845	4.61	China	1247315	1.18
England	58587	4.6	Egypt	65445	1.15
Italy	57247	4.51	Ethiopia	58414	0.99
Czech Republic	10311	4.2	Pakistan	148686	0.84
Spain	39729	4.18	India	970230	0.81
Greece	10512	3.91	Bangladesh	125898	0.73
Chile	14691	3.46			

Source： Wackernagel *et al.* (1999)

2.2.3 The steps and calculation of ecological footprint

The calculation of ecological footprint includes the steps below：

1. Calculate annual per capita consumption of major consumption items (c_i)

   First, we estimate the annual per capita consumption of major consumption items from aggregate regional or national data by dividing total consumption by population size. Much of the data needed for preliminary assessments is readily available from national statistical tables on, for example, energy, food, or forest production and consumption. For many categories, national statistics provide both production and trade figures from which trade-corrected consumption can be assessed：

$$\textit{Trade-corrected consumption} = \textit{production} + \textit{imports} - \textit{exports}$$

2. Transform major consumption items into land area (aa_i)

Estimate the land area appropriated per capita for the production of each consumption item by dividing average annual consumption of that item (c_i; kg/capita) by its average annual productivity or yield (p; kg/ha).

Land area appropriated per capita for the production of each consumption item

$$\boldsymbol{(aa_i) = c_i/p}$$

Form this formulation; we could summary the total ecological area of annual per capita consumption and service (n). That is total average per capita ecological footprint (ef).

Total average per capita ecological footprint：

$$(ef) = \sum_{i=1}^{n} aa_i$$

3. Calculate total ecological footprint by multiplying the total average per capita footprint by population size (N), then obtaining the ecological footprint (EF_p)

$$\boldsymbol{EF_p = N \times ef}$$

According to the idea of ecological footprint, this study applies this concept to transportation, trying to definite the ecological footprint of transport system. That means "To sum up the population who using the transport system, the productivity land area are needed by the consumption of energy and junk produced." It also produced the burden to the environment when people use the transport system.

Reference and suppose There is 15 million hectare of road area, car using is the major. The car owner ratio is 1/1.75 (car/capita) Suppose there are 230 work days a year

Suppose one bicycle rider needs 900 KJ foods by 10 kilometer riding.

Environment Canada points out that there is 98.4% car using in the traffic urgent time, however, only loading 62% commuter. As this result, we can make the conclusion about that one bus rider only occupied 2.6% road area of car driver.

（0.016/0.38）/（0.984/0.62）=0.026

Calculation

Bicycle：Bicycle driver needs 900KJ foods to support the 10 kilometer trip back and forth. Suppose that additional energy comes from the sweet corn of breakfast. And sweet corns need land to produce and energy to manufacture. The needs of land are used to cultivate agriculture product and used to manufacture food is the same. Therefore, the land used above is double than cultivation area. Suppose we neglect the road area of bicycle, per kilogram sweet corns include 13000KJ energy and average productivity per hectare per year 2600 kilogram of the sweet corns around the world.

$$\frac{900(KJ/year)\times 230(day.year)\times 2}{1300(KJ/kg)\times 2600(kg/ha/year)}=0.0122\ hectare\ or\ each\ rider\ need\ 122\ square\ meters$$

Car：Average consumption of petrol by car in America approximately 12 liter each 100 kilometers. The manufacturers of car indirectly consume carbon dioxide and road maintenance about 45 %. And per liter petro include approximately 35 million J of energy. Therefore, the footprint of fossil fuels by car commuters is

$$\frac{1.45\times 12(L/kg)\times 0.035(hundred\ milion\ J/L)\times 10(kg/day)\times 230(wrok\ day/year)}{100(km)\times 100(hundred\ million\ J/ha/year)}$$

= 0.14 (ha/capita) = 1500 (m^2/capita)

In other side, car needs the road space, the car space of each American is

$$\frac{15,000,000(ha)}{250,000,000(capita)} = 0.06(ha.capita) = 600(m^2 / capita)$$

Cars using about 97.4% road space, commuting 10 km every day occupied about 1/8 of average car using rate each year. However, each car using represents 7.15 capita, so per unit per capita needs （0.974x1/8x600/1.75）＝42（m^2）road space when commuting 10 km. As this result, the footprint of one commuting car is 1442 m^2.

Bus：Short distance bus needs 0.9 MJ/capita/km energy, and have to plus additional 45% (the same with the car) for the indirectly needs for road, bus and cost of maintenance.

$$\frac{1.45 \times 0.0009(hundred\ million\ J / capita / km) \times 230(work\ day / year) \times 10(km)}{100(MJ / ha / year)}$$

= 0.03 (ha/capita) = 300 (m^2/capita)

Bus also needs the road space, as suppose above, the road space needed by a bus user is 2.6% the same distance by a car driver. That is （42 m^2x 2.6%）＝1.092（m^2）. Therefore, the total needs of land area by bus user who have to commute 10 km every day is 301 m^2

Discussion

Based on the statements above, this study summaries some key points about ecological footprint below：

1. It can help us to notice the ecological limit when systems running.
2. Avoiding over consumption and helping government to do the right policy making.
3. A way to help assess both current reality and alternative "what if" scenarios on the road to sustainability.
4. How to strongly share the productive land and water area around the world.
5. Distributing productivity and resource equitably by ecological footprint.

This study compares the purposes and the disadvantages in the table below：

Table 2.4 The purposes and disadvantages of ecological footprint

Purposes and characteristics	Limits and disadvantages
The indicators of sustainable development： Display the relationship with the consumption of human and natural environment by quantification indicators.	It's hard to reflect the sustainable goal among different generations in reality.
The observation tool of sustainable development： Help strategy maker to analyze and execute that the development is on the right way to goal.	It hard to quantification about the consumption of natural environment.
Continuously trace the ecological environment： Observe the difference between people and development by the change of ecological footprint every year.	Lack biological diversity and the capability and demand of all ecological system.

This study summaries the idea of sustainability and the concept of the ecological footprint in the table 2.5 below：

Table 2.5 literature review about sustainable transportation

Authors/year	Research Objectives	National wide / City	Research Approach
Whitelegg（1983）	To decrease using less motorized transport for sustainable outcome	City level（Europe）	● Momo effect analysis ● Time valued conception ● Leisure life promotion
Rees and Wackernagel（1996）	To evaluate the effect of ecological system influenced by human activities	National wide	Ecological footprint analysis
Acutt and Dodgson（1997）	To decrease the environmental effect and influence of transport modes	National wide	Indicator proposed： ● Emission regulations ● Fuel taxes ● Vehicle use restrictions
Linster（1999）	To compare different transport modes to different effect of environment	National wide	Comparative table
Geurs and Van Wee（2000）	To develop different sustainability by different transport scenario	National wide	● Scenario analysis ● High-technology scenario ● Mobility-change scenario ● Combination scenario
Steg and Gifford（2005）	To find the balance of environment, society and economy.	City level（Dutch）	Indicator proposed： 22 indicators to measure sustainability
Amekudzi（2009）	To analyze the effect of transport systems to society and natural	City level（Atlanta and Chicago）	Sustainability footprint model

2.3 The concept of the quality of life

In the study from Steg and Gifford (2005), we find out that, in order to develop sustainability, behavioral and technological strategies not only differ in the extent to which they may improve different sustainability aspects, but probably also in the extent to which they affect the quality of life of citizens. In general, people prefer technological solutions much more than behavior changing, because the latter is perceived as more strongly reducing the freedom to move and convenience. For example, reducing car use implies that we need to adjust our lifestyle, which may evoke resistance because it requires effort and reduces freedom, comfort and convenience. And many people believe that technological measures require few behavioral changes. For example, an energy-efficient car allows individuals to drive as much as the used to do, thereby significantly reducing adverse environmental impacts. However, technical measures generally require initial investments, and therefore often rather expensive, especially for low-income groups (Steg and Gifford, 2005).

Therefore, how to reduce the volume of car use are needed to manage the problems caused by traffic and transport. As this result, drivers agree that car use should be reduced, but they are not in favor of measures that restrict their own car use. We find out the truth about that there are some conflict between individual benefit and sustainability transportation. How to use the balance function to choose an acceptable sustainable transport system is a very important task to be dealt with.

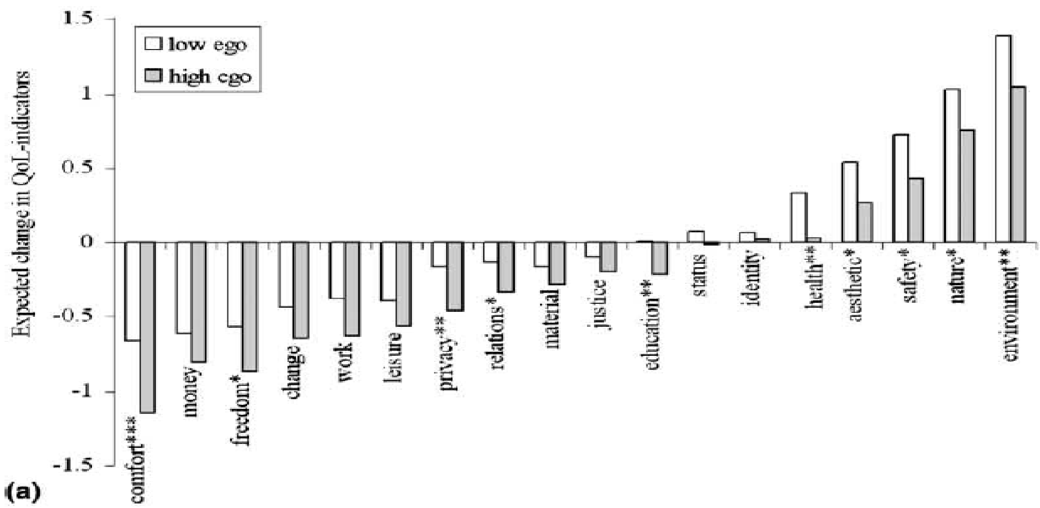
Quality of life is a multi-dimensional construct; there are some different definitions about quality of life from some references. Diener (1984) considers that quality of life is individuals' cognitive and affective evaluations of their lives and is a cognitive judgmental process of how satisfied people are with their current state of affairs. And Vemuri and Costanza (2006) think about the participation and the number of times in leisure activities is the decisive indicator of quality of life. The frequency and duration of engagement in leisure activities is an important objective determinant of quality of life. They further separate it into place-centered leisure activities and people-centered leisure activities to examine the relative importance of each for self reported quality of life. Place-centered leisure activities are focus on the special facilities and activities and dependent upon location specific activities, e.g. bowling golfing. And people-centered leisure activities are dependent upon social contact specific activities, e.g. socializing, playing cards. While Spinney (2009) purports people-centered leisure activities tend to have the most positive influence on quality of life. Therefore, in my study, the interaction of place-centered and people-centered factors both contribute to quality of life.

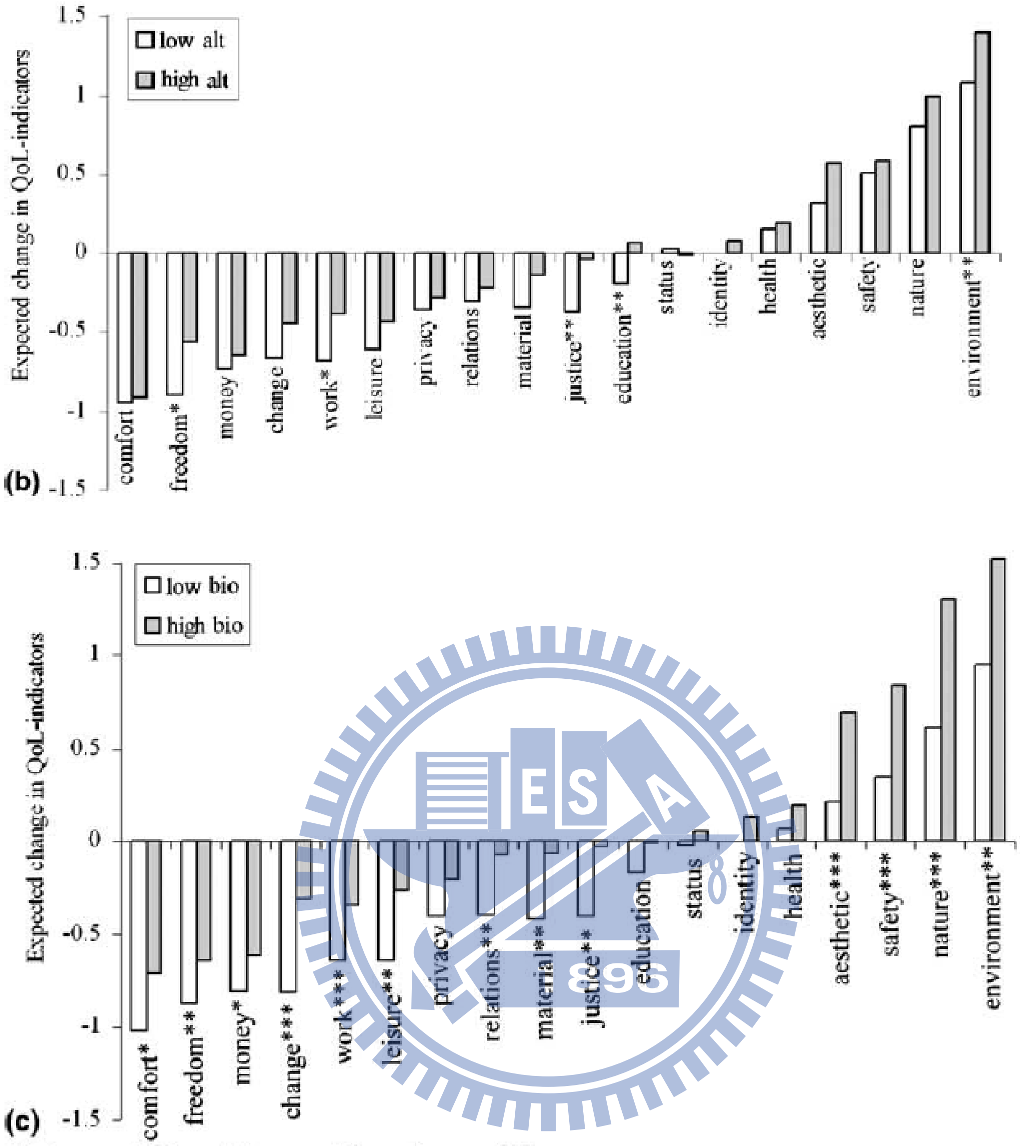
Eck et al. (2005) analyze what impact configurations on the quality of life of different population categories. They propose that individuals take participant in the activities in the special time and the potential action space. Calculate it by the distance from origin to destination, available time space, the ratio of travel time and the speed of the principal vehicle. And they use the following three indicators to evaluate quality of life： trip feasibility, efficiency of travel time and efficiency of travel distance. And we could find out the truth based on the study that the higher urbanization city will have much more shorter travel distance. And travel time will influence by traffic congestions and limit parking space due to higher urbanization cites. However, in higher urbanization cities, there are also some higher percentages to use public transport system, bicycle and walking. Available parking areas also have the limitation and the negative influences on the private car owner. As result, how to build up the sustainable transportation strategies by the characteristic of urbanization is also a challenge that the policy maker has to realize deeper.

In the study of Steg and Gifford (2005), they use the questionnaires and the definition by compensatory decision-making model. The studies reveal that deteriorations in specific quality of life indicators may be compensated for by improvements in other dimension. Clearly, sustainable scenarios typically threaten individual quality of life indicators such as comfort, freedom and privacy, while quality of life indicators that refer to collective qualities such as environmental quality and nature and biodiversity would improve. For example, most current drivers choose to act in their own interest by continuing to drive, especially because cars are be lived to have many advantages over other modes of transport, such as public transport or bicycles.

However, changes typically are resisted at first, because these may have negative consequences. As long as individual are unsure of the consequences, they prefer the status quo (Steg et al., 2005). For example, Gifford et al. (2002) revealed that attitudes toward bus riding improved and bus riding increased after a policy change, because individuals perceive that the problem is being solved. Therefore, clear description of proposed changes in the transport system is important for helping respondents think through possible consequences of the plans for them personally. This may result in better and more acceptable sustainable transport plans.

Table 2.4 reveals that most quality of life indicators are considered to be very important to people's lives. That means quality of life indicators refer to important needs and values. There are 22 indicators about different levels below. Policy-makers should especially consider possible impacts on the most important quality of life indicators when designing and implementing sustainable transport policies. De Groot and Steg (2006) use these indicators to examine relationships between value orientations and perceived quality of life-changes when the cost of car use is doubled. Three general value orientations should be distinguished when studying pro-environmental behavior： an egoistic value orientation (in which people will especially consider costs and benefits for them personally); an altruistic value orientation (in which people will focus on perceived costs and benefits for other people); and, a biospheric value orientation (in which people will consider costs and benefits for the ecosystem and biosphere). Different respondents will have different situations depend on the government's policies, which changes in quality of life respondents would expect from future economic and environmental improvements or deteriorations. But in overall, when government doubled the price of car use would have more disadvantages than advantages and, thus reduce the perceived quality of life. Respondents indicated that environmental quality, nature/biodiversity and safety were believed to improve if the government would implement this policy (Table 2.4 and Figure 2.2).





***$p < .001$ **$p < .01$ *$p < .05$

Figure 2.2 Expected changes in quality of life indicators by different situations

Source： De Groot and Steg（2006）

Quality of life is a personal goals and experiences of life. Therefore, policy makers should especially consider possible impacts on the most important quality of life indicators when designing and implementing sustainable transport policies, because the public will especially oppose measures that negatively affect these quality of life indicators. Governments should look for other ways to achieve sustainable transport that would affect these quality of life indicators in ales negative, or even a positive way. One may also look for possible ways to compensate the expected negative effects (Steg and Gifford, 2005). In general, sustainable strategies will deteriorate individuals' indicators of quality of life, but will improve public quality of life. That is prove the truth about that the benefit conflicts between individuals and public is exist, especially when individual car users are asked to significantly adapt their lifestyles and transport behavior.

Therefore, knowing how specific quality of life aspects may be influenced positively may enhance policy acceptability. This will facilitate the implementation of sustainability policies and guarantee effective and efficient decision making. And different countries will have different national conditions and cultures, the sustainable strategies are also different by different countries. However, some studies also reveal the truth about that change in transport may influence quality of life initially, but as individuals usually adapt soon, no significant changes in quality of life may occur in the long term. Therefore, this study looks forward to construct an assessment model to evaluate the change of quality of life.

This study creates the relationship with the concept of ecological footprint and quality of life, considering that the change of quality of life will have influence on the development of sustainable transportation. Dominguez and Robin (1992) also propose three different strategies to reduce ecological footprint while not compromising our quality of life：

1. Increase nature's productivity per unit of land, e.g. terraces on mountain slopes, solar collectors on unused roof areas or less wasteful agricultural systems (Pimentel et.al 1996).

2. Do the same with less through the better use of the harvested resources, e.g. eco-efficient technology such as smart lamps or heat-pumps;

3. Consume less by be fewer people and consuming less per capita, e.g. by avoiding car-ownership and disposable products. This simpler and less expensive life-style may buy people more leisure time and be less harsh on their health (Dominguez and Robin, 1992).

Amekudzi (2009) proposed the sustainability footprint model, including the concept of ecological footprint and quality of life, to assess development impacts of transportation systems. They take advantage those sustainable development paradigms for addressing civil infrastructure systems have framed the core issues using the tripartite framework of impacts on the economy, environment and society. The model in their studies calculated the change of quality of life to assess and evaluate whether the development sustainability or not.

Discussion

Quality of life is the concept including many different levels. In our opinions, the best situation and the ideal sustainable development is that improve public quality of life, but no change even reduce ecological footprint. Therefore, how to evaluate the rate of change of quality of life to compare different stakeholders in different economic development is much more meaningful about sustainability. Based on the study of Wackernagel, how to choose the indicators what we're concerned to evaluate quality of life, not considering all of the indicators to make the decision of the strategy. Therefore, the problem what we have to resolve is how to maximum the value of the indicators what you choose, but not decline other indicators in different levels.

Table 2.6 Description of importance ratings and mean scores of expected change of 22 quality-of-life indicators

Indicators	Description	Important rating	Expected change
Health	Being in good health. Have access to adequate health care	4.9	0.2
Partner and family	Having an intimate relationship. Having a stable family life and good family relationships	4.7	-0.1
Social justice	Having equal opportunities and the same possibilities and rights as others. Being treated in a just manner	4.7	-0.2
Freedom	Freedom and control over the course of one's life, to be able to decide for yourself, what you will do, when and how	4.5	-0.7
Safety	Being safe at home and in the streets. Being able to avoid accidents and protected against criminality	4.5	0.6
Education	Having the opportunity to get a good education and to develop one's general knowledge	4.3	-0.1
Identity/self-respect	Having sufficient self-respect and being able to develop one's own identity	4.2	0.0
Privacy	Having the opportunity to be yourself, to do your own things and to have place of your own	4.2	-0.3
Environmental quality	Having access to clean air, water and soil. Having and maintaining good environmental quality	4.2	1.2
Social relations	Having good relationships with friends, colleagues and neighbors. Being able to maintain contacts and to make new ones	4.2	-0.3
Work	Having or being able to find a job and being able to fulfill it as pleasantly as possible	4.2	-0.5
Security	Feeling attended to and cared for by others	4.1	0.2
Nature/biodiversity	Being able to enjoy natural landscapes, parks and forests. Assurance of the continued existence of plants and animals and maintaining biodiversity	4.1	0.9
Leisure time	Having enough time after work and household work and being able to spend this time satisfactorily	4.0	-0.5
Money/income	Having enough money to buy and to do the things that are necessary and pleasing	3.6	-0.7

Comfort	Having a comfortable and easy daily life	3.5	-0.9
Aesthetic beauty	Being able to enjoy the beauty of nature and culture	3.5	0.4
Change/variation	Having a varied life. Experiencing as many things as possible	3.3	-0.6
Challenge/excitement	Having challenges and experiencing pleasant and exciting things	3.2	-0.2
Status/recognition	Being appreciated and respected by others	3.0	0.0
Spirituality/religion	Being able to live a life with the emphasis on spirituality and/or with your own religious persuasion	2.9	0.1
Material beauty	Having nice possessions in and around the house	2.6	-0.2

Source： De Groot and Steg（2006）

This study summaries the concept of quality of life in the table 2.7 below：

Table 2.7 literature review about quality of life

Authors/year	Research Objectives	National wide /City	Research approach
Diener（1984）	Quality of life is a cognitive judgmental process of how satisfied people		
Dominguez and Robin（1992）	To take advantage of the change of lifestyle to decrease ecological footprint.	National wide	Footprint model analysis
Pimentel(1996)	To increase nature's productivity per unit of land	National wide	Approaches proposed： ● Terraces on mountain slopes ● Solar collectors on unused roof areas ● Less wasteful agricultural systems
Steg and Gifford（2005）	To establish the important indicators to evaluate sustainable development	City level（Dutch）	Questionnaire ● Propose 22 important indicators of quality of life
Eck et al.（2005）	To analyze what impact configurations on the quality of life of different population categories	City level（Dutch）	MASTIC model ● The feasibility of carrying out desired activities ● Travel time efficiency ● Travel distance efficiency
Vemuri and Costanza	To measure the frequency and duration of engagement in leisure activities	National wide	Regression model Revise regression model

（2006）			
De Groot and Steg（2006）	To examine relationships between value orientations and perceived quality of life-changes when the cost of car use is doubled.	City level： 1. Austria, 2. Czech Republic, 3. Italy, 4. The Netherlands, 5. Sweden	Questionnaire Three groups analyze： ● Egoistic value orientation ● Altruistic value orientation ● Biospheric value orientation
Amekudzi（2009）	To evaluate and discuss the study whether development sustainability or not	City level（Atlanta and Chicago）	Sustainability footprint model
Spinney et al.（2009）	To quantify the impacts of transport mobility and investigate their impacts on the quality of life	City level（Canada）	Questionnaire ● Psychological benefits ● Exercise benefits ● Community-helping ● Community-socializing

2.4 The application of bi-level programming model

Bi-level programming model decides *x* from upper level, and according to the different set *x* to decide the decision variable about *y* from upper level. The attributes are as follows (Bials and Karwan, 1984;Wen and Hsu,1991)：

1. There is an obvious hierarchical structure among different decision makers.
2. The decision makers decide the strategies in upper level, and then, the decision makers in lower level follow it to decide the strategies for their own.
3. The decision units achieve their goal of optimal their own objective function independence, however, the strategies they decided doesn't influence each others.
4. The external effects from different decision problem will effect their own objective function and feasible solution.

In the applications of transportation with bi-level programming model, there are some literatures below：

Chen (2004) takes advantage of the conception about bi-level programming model to construct the dynamic signal control system. Upper level is minimum total travel time, lower level is user equilibrium model to get the information about signal variables.

Cao and Chen (2006) promote the model to construct the mathematical model to do the location choice. There are two different decision levels. The decision maker in upper level is primary company and the objection function is how to minimum cost of opening stations and opportunity cost of available capacity. The decision maker in lower level is each station and objection function is how to minimum the operational cost.

Brotcoren et al.(2000) use bi-level programming model in to the problems of setting freight fares. Upper level has a group of competitive freight carriers, and the profit comes from total fares. Lower level is a specific freight consignor and achieve the goal of how to minimum ship cost.

Huang et al.(2006) take advantage of genetic algorithm and geographic information system (GIS) to solve the multi objective traveling salesman problem. The TSP problem in past, only consider minimum travel cost, travel distance and travel time. However, Huang et al.(2006) take advantage the route planning about tourism, and the route is planned by four traveler business in specific area. And the route planning includes four criteria： travel time, the cost of vehicle operational, safety and the quality of the sightseeing. And upper level decides the weight of each criterion; lower level decides the optimal tourism route by the weight from upper level. And four criterions furthermore quantitative by GIS and evaluate the cost of each route link to find the optimal solution.

Table 2.8 literature review about bi-level programming model

Authors/year	Research Objectives	Models	Algorithm solution
Brotcoren (2000)	International freight shipping	● Upper level： Maximum the benefit from freight shipping of freight company ● Lower level： Minimum the shipping cost from freight consignor	Heuristics algorithms
Chen H.K. (2004)	Dynamic signal control system	● Upper level Minimum system travel time ● Lower level User equilibrium model with Variational Inequalities	● Sensitive analysis with Variational Inequalities ● Generalized Inverse Approach
Cao and Chen (2006)	Location choice	● Upper level Minimum cost of opening stations and opportunity cost of available capacity. ● Lower level Minimum the operational cost.	● Bi-level → single-level ● non-linearity→ linearity
Huang *et al.* (2006)	Multi-objective travel salesman problem	● Upper level Decide the weight of each criterion ● Lower level Decide optimal tourism route	● Generic algorithm ● Geographic information system

Chapter 3 Methodology

3.1 The theory and application of bi-level programming model

The bi-level programming model considered here can be represented as a leader-follower, or Stackelberg, game where the regulator is the leader, and the users are the followers. It is assumed that the regulator can influence, but cannot control, the users' mode and route choice behavior through subsidy strategies. This interaction game can be represented as the following bi-level programming problem (Yang and Yagar, 1994, 1995)：

$$\begin{aligned} &\mathit{Min} \quad F(u, v(u)) \\ &\mathit{Subject\ to} \quad G(u, v(u)) \leq 0 \end{aligned} \tag{1}$$

Where v (u) is implicitly defined by

$$\begin{aligned} &\mathit{Min} \quad f(u, v) \\ &\mathit{Subject\ to} \quad g(u, v) \leq 0 \end{aligned} \tag{2}$$

Where, u and v are vectors of decision variables in the upper level and lower level, respectively. F(u, v (u)) and G(u, v(u)) are the objective function and constraints of the upper level. f(u, v) and g(u, v) are the objective function and constraints of the lower level.

3.2 The framework of bi-level programming model

The framework of the proposed model is depicted in Figure 3.1. The upper level is a budget allocation model while the lower level contains mode choice and route choice models. The model is to maximize total utility under the constraints of budget, capacity of transport system and available land area in terms of ecological footprint.

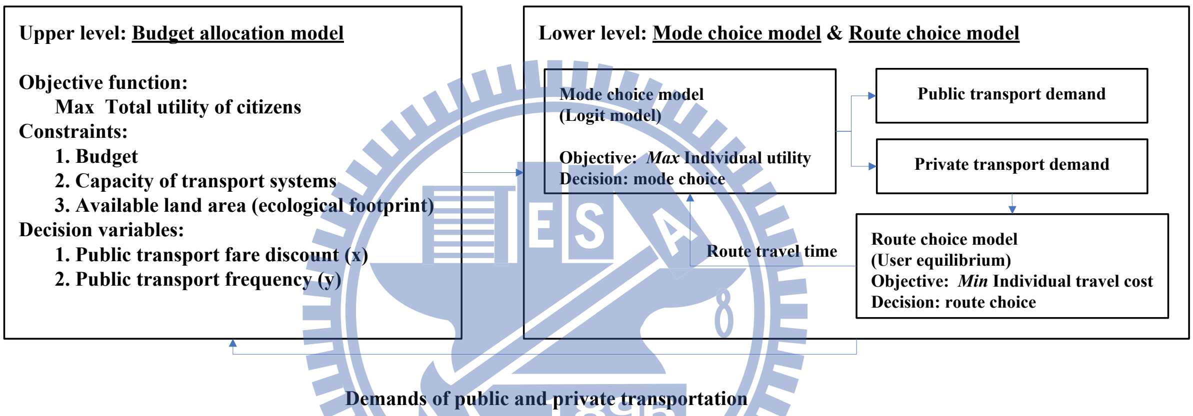


Figure 3.1 Framework of the proposed model

In Figure 3.1, there are three sub-models, the first is the budget allocation model, and the second and third are mode choice and route choice models. The upper level is to optimally determine the values of x, y, and z; however, its objective function is an aggregated sum of individual mode choice utility affected by the lower level. In contrast, the lower level is to determine the mode and route choice behaviors based on the given values of x, y, and z. It is the reason that both levels can not be solved separately.

3.3 Model formulation

This study proposed the bi-level programming model as following. The goal in upper level is that how to maximum quality of life, combining the government budget as the constraint of upper level. And in lower level where using user equilibrium model and logit model to solve the problem. First, using user equilibrium model to calculate the travel time of the network, and then put this travel time into the logit model in lower level to get newly consequence of mode choice. This newly travel time will have influence on the travel time again until balance. Therefore, government could take advantage of this value in this network to develop ideal sustainability strategies.

3.3.1 The SG model

The SG model is to determine the optimal decisions associated with Figure 3.1 based on the best interest of the contemporary generation, which can be expressed as：

[Upper level]

$$Max \quad U^T = \sum_{rs\in N} q^{rs}\,\mathrm{Pr}_c^{rs}\,U_c^{rs} + \sum_{rs\in N} q^{rs}\,\mathrm{Pr}_b^{rs}\,U_b^{rs} \tag{3}$$

Subject to

$$(\sum_{rs\in N} q^{rs}\,\mathrm{Pr}_b^{rs})x + SD + (GL)z \le B \tag{4}$$

$$EF \le A + z \tag{5}$$

$$SD = \begin{cases} (\sum_{k\in R_b} d_k y)FC - (\sum_{rs\in N} q^{rs}\,\mathrm{Pr}_b^{rs})TC_b, & \text{if } (\sum_{k\in R_b} d_k y)FC \ge (\sum_{rs\in N} q^{rs}\,\mathrm{Pr}_b^{rs})TC_b \\ 0, & \text{else} \end{cases} \tag{6}$$

$$EF = \left(\frac{\sum_{a \in L} d_a v_a}{F_c} + \frac{\sum_{k \in R_b} r_k y}{F_b} \right) \frac{EC}{EL} \tag{7}$$

[Lower level]

$$Min \quad \sum_{a \in L} \int_0^{v_a} t_a \left\{ 1.0 + 0.15 \left(\frac{v_a}{C_a} \right) \right\}^4 dv_a \tag{8}$$

Subject to

$$\sum_{k \in K_{rs}} f_k = \frac{q^{rs} \Pr_c^{rs}}{l_c} \quad \text{for} \quad r,s \in N \tag{9}$$

$$v_a = \sum_{r,s \in N} \sum_{k \in K^{rs}} f_k \delta_{ak}^{rs} \tag{10}$$

$$q^{rs} \Pr_b^{rs} \le l_b y \quad \text{for} \quad r,s \in N \quad \text{and } r \ne s \tag{11}$$

$$\Pr_j^{rs} = \frac{e^{U_j^{rs}}}{e^{U_b^{rs}} + e^{U_c^{rs}}} \quad \text{for } j=b,\ c \tag{12}$$

$$U_j^{rs} = \alpha IT_j^{rs} + \beta OT_j^{rs} + \gamma TC_j^{rs} \quad \text{for} \quad r,s \in N \quad \text{and } j=b,\ c \tag{13}$$

$$OT_b = \frac{30}{y} \tag{14}$$

$$f_k \ge 0, \text{ for } \ k \in K^{rs} \tag{15}$$

Where, U^T is the total utility which sums up utilities of all trip makers. q^{rs} is the trip demand from origin *r* to destination *s* (i.e. the OD pair *rs*). Pr_b^{rs} is the market share of public transportation (hereafter, bus) of OD pair *rs*. Pr_c^{rs} is the market share of private transportation (hereafter, car) of OD pair *rs*. U_c^{rs} is the utility of a trip maker choosing cars of OD pair *rs*. U_b^{rs} is the utility of a trip maker choosing buses of OD pair *rs*. *SD* is the financial deficit of the bus operator defined by Eq. (6). *GL* is the acquired cost of a hectare of green land area (NT dollars), including land purchase cost (or land rent cost) and tree planting cost. B is the government budget for the generation (NT dollars). N is a set of nodes of the network. L is a set of links of the network. A is the original green land area in terms of ecological footprints (ha) of the study network. EF is the ecological footprints produced by private and public transportation defined by Eq. (7). FC is the bus unit operating cost (NT dollars/bus-km). TC_b and TC_c the travel costs of bus (i.e. fare) and car (i.e. fuel cost and car depreciation cost). R_b is a set of bus routes. d_a is the distance of link a (km). v_a is the traffic volume of link a (pcu/hr). r_k is the distance of bus route k (km). F_c and F_b are fuel efficiency of cars and buses, respectively (km/l). EC is CO_2 emission coefficient of fossil fuel (ton/l). EL is an energy-to-land ratio, which is used to convert emitted CO_2 into land area (ton/ha). There are three decision variables： x, y, and z. x is the fare discount for each of bus passengers (NT dollars). y is the bus frequency (bus journey/hour). z is the amount of acquired green land area (ha).

In the lower level, t_a is the free-flow travel time of link a. C_a is the capacity of link a. l_c is the load factor of cars (persons/car). l_b is the capacity of buses (persons/bus). $\delta_{a,k}^{rs}$ is an indicator with the value of 1 representing that route k contains link a and 0 else of OD pair rs. K^{rs} is a set of routes connecting OD pair rs. f_k is the traffic volume of route k. IT_j and OT_j represent in-vehicle travel time and out-of-vehicle travel time, respectively. $j=b, c$. α, β and γ are the coefficients of the mode choice model (Logit model) associated with in-vehicle travel time, out-of-vehicle travel time and travel cost.

Eq. (4) expresses the budget constraint. Three terms of left hand side are the total amount of fare subsidy, total amount of deficit subsidy and total amount of green land acquisition cost. Eq. (5) restraints the total transportation footprints should be less than the original green land (A) and additionally acquired green land (z). Eqs. (6) and (7) are definitional equations used to determine the SD and EF. In Eq. (6), the financial deficit of the bus company equals to the total operating cost minus total fare box revenue. SD is set as zero in case that there is a positive profit (no need to provide deficit subsidy). Eqs. (8)~(10) constitute a user equilibrium model. Eq. (11) represents the capacity of bus system. A logit mode choice model is expressed by Eqs. (12)~(13). Eq. (14) assumes the waiting time of bus passengers equals to a half of bus inter-arrival time ($=1/2\times60/y=30/y$).

3.3.2 The AG model

As to the abovementioned SG model, the regulator simply determines an optimal budget allocation plan for the contemporary generation. Without consideration of the interest of the next generation, the contemporary generation tends to use up all budget and leave as much as footprint to the next generation. The core logic is obviously against the concept of sustainability. Accordingly, the proposed AG model further considers the opportunity cost of budget at the point of view of the next generation, which can be expressed as follows：

{***Contemporary generation***}

[Upper level]

$$Max \quad f = U^T - s_B(B-\Delta B) = \sum_{rs} q^{rs}\,\mathrm{Pr}_c^{rs}\,U_c^{rs} + \sum_{rs} q^{rs}\,\mathrm{Pr}_b^{rs}\,U_b^{rs} - s_B(B-\Delta B) \tag{16}$$

Subject to

$$(\sum_{rs\in N} q^{rs}\,\mathrm{Pr}_b^{rs})x + SD + (GL)z \le B \tag{17}$$

$$EF \le A + z \tag{18}$$

$$SD = \begin{cases} (\sum_{k \in R_b} d_k y)FC - (\sum_{rs \in N} q^{rs} \Pr_b^{rs})TC_b, & \text{if } (\sum_{k \in R_b} d_k y)FC \ge (\sum_{rs \in N} q^{rs} \Pr_b^{rs})TC_b \\ 0, & \text{else} \end{cases} \tag{19}$$

$$EF = \left(\frac{\sum_{a \in L} d_a v_a}{F_c} + \frac{\sum_{k \in R_b} r_k y}{F_b} \right) \frac{EC}{EL} \tag{20}$$

$$\Delta B = B - \left\{ \sum_{rs} q^{rs} \cdot \Pr_B + EF \cdot z + \left[\sum_{a} l_a \cdot FC \cdot y - \sum_{rs} q^{rs} \cdot \Pr_B \cdot \left(TC_B - x \right) \right] \right\} \tag{21}$$

[Lower level]

Eqs. (8)~(15).

{***Next generation***}

[Upper level]

$$Max \quad U^T = \sum_{rs} q^{rs} \cdot \Pr_c \cdot U_c + \sum_{rs} q^{rs} \cdot \Pr_B \cdot U_B \tag{22}$$

Subject to

$$(\sum_{rs} q^{rs} \cdot \Pr_B) \cdot x + SD + (GL)z \le B_t + \Delta B_{t-1} \tag{23}$$

$$EF \le A + z \tag{24}$$

$$SD = \begin{cases} (\sum_{k \in R_b} d_k y)FC - (\sum_{rs \in N} q^{rs} \Pr_b^{rs})TC_b, & \text{if } (\sum_{k \in R_b} d_k y)FC \ge (\sum_{rs \in N} q^{rs} \Pr_b^{rs})TC_b \\ 0, & \text{else} \end{cases} \tag{25}$$

$$EF = \left(\frac{\sum_{a \in L} d_a v_a}{F_c} + \frac{\sum_{k \in R_b} r_k y}{F_b} \right) \frac{EC}{EL} \tag{26}$$

$$\Delta B_{t-1} = B - \left\{ \sum_{rs} q^{rs} \cdot \Pr_B + EF \cdot z + \left[\sum_{a} l_a \cdot FC \cdot y - \sum_{rs} q^{rs} \cdot \Pr_B \cdot \left(TC_B - x \right) \right] \right\} \tag{27}$$

[Lower level]

Eqs. (8)~(15).

Where, s_B is the shadow price of the budget constraint of the next generation, which means that the every dollar of the budget left to the next generation will increase how much total utility of the next generation. According to Eq. (16), the more budget used in the contemporary generation will increase the total utility of the contemporary generation (U^T) but reduce the total utility of the next generation [s_B (B- ΔB)]. It should be noted that the value s_B of budget used will vary depending upon how much budget is remained to the next generation. As the shadow price increases, the remained budget (ΔB) will be larger, vice versa. In other words, an iterative solution algorithm is used to solve the contemporary and the next generations iteratively till the shadow price (s_B) remains unchanged.

3.4 Solution algorithms

3.4.1 Solution algorithm of the SG model

This paper employs genetic algorithms (GAs) to solve the SG model. The decision variables of x, y, z are directly encoded by three consecutive genes with value of 0~9, implying the values of three decision variables range from 0~999. A penalty is subtracted from the total utility once the solution violates constraints. The max-min-arithmetical crossover and the non-uniform mutation in Chiou and Lan (2005) is used. A brief description is given below.

(1) Max-min-arithmetical crossover

Let $G_w^t = \{ g_{w1}^t, \ldots, g_{wk}^t, \ldots, g_{wK}^t \}$ and $G_v^t = \{ g_{v1}^t, \ldots, g_{vk}^t, \ldots, g_{vK}^t \}$ be two chromosomes selected for crossover, the following four offsprings will be generated：

$$G_1^{t+1} = aG_w^t + (1-a)G_v^t \quad (27)$$

$$G_2^{t+1} = aG_v^t + (1-a)G_w^t \quad (28)$$

$$G_3^{t+1} \text{ with } g_{3k}^{t+1} = \min\{g_{wk}^t, g_{vk}^t\} \quad (29)$$

$$G_4^{t+1} \text{ with } g_{4k}^{t+1} = \max\{g_{wk}^t, g_{vk}^t\} \quad (30)$$

where a is a parameter ($0 < a < 1$) and t is the number of generations.

(2) Non-uniform mutation

Let $G_t = \{ g_1^t, \ldots, g_k^t, \ldots, g_K^t \}$ be a chromosome and the gene g_k^t be selected for mutation (the domain of g_k^t is $[g_k^l, g_k^u]$), the value of g_k^{t+1} after mutation can be computed as follows：

$$g_k^{t+1} = \begin{cases} g_k^{\ t} + \Delta(t, g_k^u - g_k^{\ t}) & if \quad b = 0 \\ g_k^{\ t} - \Delta(t, g_k^{\ t} - g_k^l) & if \quad b = 1 \end{cases} \tag{31}$$

where b randomly takes a binary value of 0 or 1. The function $\Delta(t, V)$ returns a value in the range of $[0, V]$ such that the probability of $\Delta(t, V)$ approaches to 0 as t increases：

$$\Delta(t, V) = V(1 - r^{(1-t/T)^h}) \tag{32}$$

where r is a random number in the interval $[0,1]$, T is the maximum number of generations and h is a given constant. In Eq. (32), the value returned by $\Delta(t, V)$ will gradually decrease as the evolution progresses.

The solution algorithm of the AG model is stated as follows：

Step 0： **Initialization.** Generate an initial population with p chromosomes. Each gene randomly takes one integer from [0, 9]. Let's IT_{ji}^{rs}=the in-vehicle travel time of the shortest path for all O-D pairs under free-flow traffic condition. i=1.

Step 1： **Fitness calculation.** For each of chromosomes, calculate its fitness value by solving the following sub-steps：

Step 1-1： **Mode choice**. Based on the values of x, y, z given by the chromosome and IT_{ji}^{rs}, use of the Logit model in Eqs. (12) and (13) to compute the choice probabilities of cars and buses of all O-D pairs (i.e. Pr_b^{rs} and Pr_c^{rs}).

Step 1-2： **Route choice.** Based on the choice probabilities of cars, use of traffic assignment algorithm of Chiou and Lai (2008) to determine the link flow and to updated the travel time IT_{ji+1}^{rs}.

Step 1-3： **Convergence test.** If $\left| IT_{c,i+1}^{rs} - IT_{c,i}^{rs} \right| \le \varepsilon$ for all O-D pairs, then compute the total utility by Eq. (3) and set it as the fitness value of the chromosome. Otherwise, let i=i+1 and go back to Step 1-1.

Step 2： **Selection.**

Step 3： **Crossover.**

Step 4： **Mutation.**

Step 5： **Stop condition test.** If the stop condition is satisfied, the incumbent solution is the optimal solution. If not, go back to Step 3.

3.4.2 Solution algorithm of the AG model

Since the value of shadow price of budget (s_B) for the next generation will vary depending upon how much budget is left by the contemporary generation. An iterative solution algorithm is required to solve the budget allocation problems of the contemporary and next generations iteratively until the shadow price (s_B) remains unchanged (becomes stable) as depicted in Fig.2.

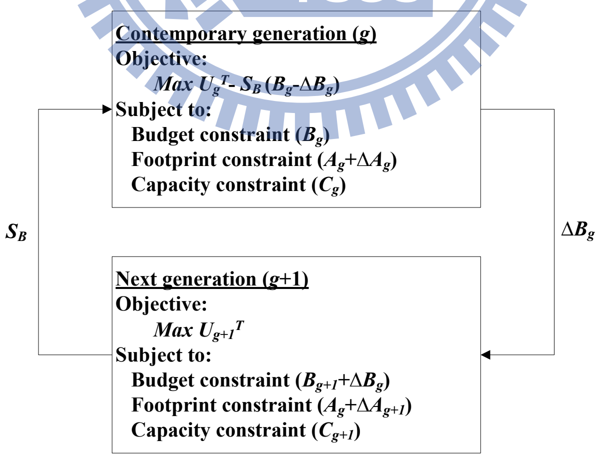


Figure 3.2 The iterative solution algorithm of the AG model

The solution algorithm is stated below：

{Contemporary generation}

Step 0： Let S_B^k=0 and k=1.

Step 1-0： **Initialization.**

Step 1-1： **Fitness calculation.** For each of chromosomes, calculate its fitness value by solving the following sub-steps：

Step 1-1-1： **Mode choice**.

Step 1-2-1： **Route choice.**

Step 1-3-1： **Convergence test.** If yes, then compute the fitness value by Eq. (16) (instead of Eq. (3)). Otherwise, let i=i+1 and go back to Step 1-1-1.

Step 1-2： **Selection.**

Step 1-3： **Crossover.**

Step 1-4： **Mutation.**

Step 1-5： **Stop condition test.** If the stop condition is satisfied, compute ΔB, go to Step 6. Otherwise, go back to Step 1-3.

{Next generation}

Step 2-0： **Initialization.**

Step 2-1： **Fitness calculation.** For each of chromosomes, calculate its fitness value by solving the following sub-steps：

Step 2-1-1： **Mode choice**.

Step 2-1-2： **Route choice.**

Step 2-1-3： **Convergence test.** If yes, then compute the fitness value by Eq. (22) (the same as Eq. (3)). Otherwise, let i=i+1 and go back to Step 2-1-1.

Step 2-2： **Selection.**

Step 2-3： **Crossover.**

Step 2-4： **Mutation.**

Step 2-5： **Stop condition test.** If the stop condition is satisfied, compute the shadow price of budget (S_B^{k+1}). If not, go back to Step 2-3.

Step 3： **Convergence test.** If $\left|S_B^{k+1} - S_B^k\right| \leq \varepsilon$, then terminate. The incumbent solutions of the contemporary and next generations are the optimal. Otherwise, let k=k+1 and go back to Step 1-0.

Chapter 4 Computational experiments and analyses

4.1 Simplified example analyses

To investigate the applicability of the proposed models and analyze the effects of parameters, a case study on an exemplified example in Yang and Lam (1996) is conducted. The details of the network and results of the budget allocation are delineated below.

The network contains six nodes and seven links as depicted in Figure 4.1. The free-flow travel time, capacity and distance of links are shown in Table 1. The trip demands of four OD pairs of 13 and 24 are all set as 200 trip/hour. Assume there is only one type of public transportation service： bus and one type of private vehicle：car. Four bus routes are operated： Bus route 1 (BR1) from Node 1 to Node 3 through Link 1, BR2 from Node 1 to Node 3 through Links 3, 4, and 6, BR 3 from Node 2 to Node 4 through Links 5, 4, 7 and BR 4 from Node 2 to Node 4 through Link 2.

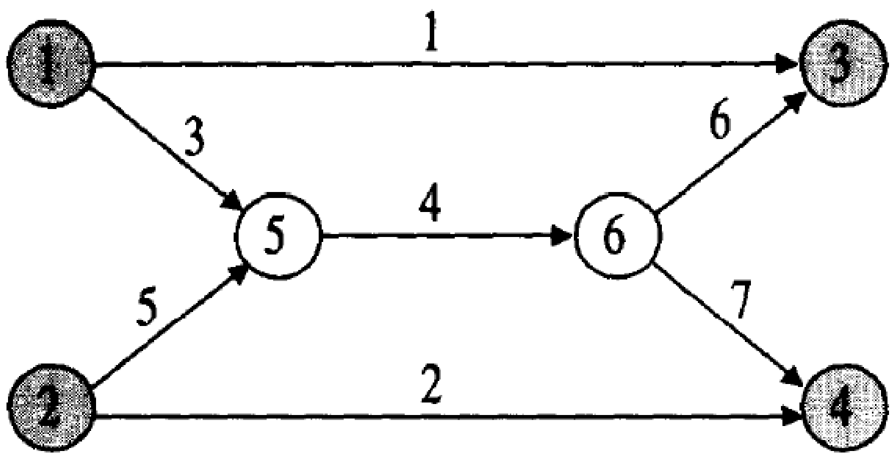


Figure 4.1 Transport network of the simplified example

Source： Hai Yan, William H. K. Lam (1996)

Table 4.1 Input data of the simplified example

Link a	1	2	3	4	5	6	7
t_a (min)	8	9	2	6	3	3	4
C_a (veh/hr)	20	20	20	40	20	25	25
d_a (km)	8	9	2	6	3	3	4

Unit：t (minutes)；C (travel trips each hour)

Source： Yang and Lam (1996)

4.2 The definition of the parameters

In order to simplify the scope of this research, this study only considers private car using as private transportation mode and bus as public transportation mode. Therefore, there are two mode choices for commuters in this transportation network. Suppose there are 200 travel demands of total commuter trips in each rush hour. The travel distance of network presented as figure above. And suppose the speed of private car limited by 60 km in free flow speed, which is also the most economic drive speed. And IVTT (in vehicle travel time) decided by the user equilibrium of this transportation network.

This study based on the research of Su, C.W. *et al.* (2005) to get the out of vehicle travel time (OTj) about the distance between home and vehicle and vehicle to work place. Waiting time of the bus in this study has some relationship with crowded level of frequency, where F represented the frequency of bus. And in other side, in vehicle travel time is decided by user equilibrium model. Capability of the different transportation mode is decided by the research of Feng, C.M. *et al.* (2001) and Institute of Transportation. The capability of the private care is 1.5 per capita per vehicle, public transport bus is 30 per capita per vehicle, as show in Table 4.2.

Table 4.2 Parameter settings of the models

Item	Parameter	Value
Budget (million NT dollars)	B	100
Original green land area (ha)	A	50
Energy-to-land ratio (ton/ha)	EL	6.6 [b.]
CO_2 emission coefficient	EC	2.24 [a.]
Green land cost (NT dollars/ha)	GL	60000 [a.]
Parameter of IT_j	α	0.2 [c.]
Parameter of OT_j	β	0.216 [c.]
Parameter of TC_j	γ	0.0803 [c.]

Sources： [a.] Lin, S.J. *et al.* (2001); [b.] Wackernagel *et al.*(1999); [c.] Chiou et al. (2009).

Table 4.3 Parameter settings associated with bus and car

Item	Parameter	Mode	
		Car	Bus
Out-of-vehicle time (min)	Walking time	2.16 [a.]	7.58 [a.]
	Parking time	7.87 [a.]	-
	Waiting time	-	$30/y$ [a.]
	Subtotal (OT_j)	10.03 [a.]	$7.58+30/y$ [a.]
Load factor/Capacity (person/car; person/bus)	l_j	1.5 [b.]	30 [b.]
Fuel efficiency (km/l)	F_j	11 [b.]	2.88 [b.]
Travel cost (NT dollar)	TC_j	30	45

Sources： [a.] Su, C.W. *et al.* (2005); [b.] Feng, C.M. *et al.* (2001)

4.3 Results of the Single Generation model

According to the formulation of the SG model, there are three policy variables: bus fare discount (x), bus frequency increase (y), and green land acquisition (z).

1. Transit Fare Discount Subsidy (x)

Control the price discount to attract more people to use public transportation or not. It influence the travel cost of each network user in the logit model to decide their mode choice.

2. Transit Deficit Subsidy (y)

Frequency will change by different budget. It influences the out of vehicle travel time of the public transportation mode. If there are more and more frequencies increasing, attracting more people to use public transportation but also more pollution and higher cost of carrier. Therefore, we have find out the optimal balance between this trade-off.

3. Cost of Tree Planting (z)

Cultivate the green land use to assimilate produced ecological footprint from human activities. It influence the liability of across generation model to decide the shadow price in the future generation.

To analyze the effects of different combinations of these policy decisions, four strategies are proposed and compared:

Strategy 0 (S0): Do nothing. (given x=0, y=5 and z=0)

Strategy 1 (S1): bus fare discount (x) + green land acquisition (z) (given y=5)

Strategy 2 (S2): bus frequency increase (y) + green land acquisition (z) (given x=0)

Strategy 3 (S3): bus fare discount (x) + bus frequency increase (y) + green land acquisition (*z*)

To solve the performances of these three strategies, we simply don't encode that decision variables into genes and substitute its fixed value into the computations. Table 4.4 gives the comparisons.

Table 4.4 Comparisons of four strategies

Strategy	Decision variable			Budget allocation			Market share		*EF*	U^T
	x	*y*	*z*	*x*	*y*	*z*	Car	Bus		
S0	0	5	0	0%	0%	0%	87.78%	12.22%	884.08	-13542
S1	34	5	104	81%	8%	11%	31.89%	68.11%	466.71	-2786
S2	0	12	327	0%	24%	20%	77.12%	22.88%	1141.38	-11283
S3	33	6	112	82%	10%	8%	29.02%	70.98%	492.13	-2694

As noted from Table 4.4, in comparing to do nothing strategy (S0), the total utility and ecological footprint is largely curtailed. It is interesting to note that both S1 and S2 can achieve almost the same total utility and mode choice share, but S1 can produce much less footprint than S2, because S1 uses of bus fare discount (34 NT dollars subsidy for each bus passenger, which accounts for 76% of the full fare of 45 NT dollars) to increase bus patronage, while S2 largely increases bus frequency (from 5bus journeys per hour to 12 bus journeys) to attract bus passengers but results into much footprint due to the high emission characteristic of buses. The most flexible strategy (S3) can achieve the highest total utility and keep footprint at a relatively low level.

4.4 Results of the Across Generation model

To further consider the welfare of the next generation, the AG model introduces the shadow price of budget into the objective function. Table 4.5 gives the results of the AG model. As noted from the table, the total utility of the contemporary generation will be lowered down in comparing to that of the SG model, since a total of 24,104,730 NT dollars is left to the next generation with consideration of the shadow price of 74.829 (for one million NT dollars). Although the total utility of the next generation is higher than the contemporary generation, the total utility will be lowered down once the next generation considers the welfare of the following generation. Note that the budget allocated to bus frequency (deficit subsidy) for the contemporary generation equals to zero, since the fare box revenue exceeds the operating cost. Most of budget still goes to the fare discount subsidy, similar to the results of the SG model.

Table 4.5 Results of the AG model

Variable	Contemporary generation		Next generation	
	Value	Percentage	Value	Percentage
x	22	47%	34	76%
y	10	17%	9	14%
z	202	12%	188	10%
B-ΔB (NT dollars)	75,895,270	75.9%	124,104,730	100%
ΔB (NT dollars)	24,104,730	24.1%	0	0
U^T		-3904		-2456
S_B		0.0000074829		

4.5 Sensitive analysis

This chapter constructs the sensitive analysis of this bi-level programming model. And further defines the results of the sensitive analysis to do the strategy management. To identify the effect of corresponding parameters to the optimal budget allocation plan, sensitivity analyses on some key parameters of the AG model are conducted.

4.5.1 Available budget

This section presents the optimal budget allocation plan under various amounts of available budget, as Table 4.6 and from Figure 4.2 to Figure 4.4 following below. Figure 4.2 and Figure 4.3 reveal the truth about increasing budget will make ecological footprint decrease but quality of life increase. As this result, increasing the budget which doesn't consider other elements any more, we could foresee that the percentage of the private car using will transfer to public transit mode.

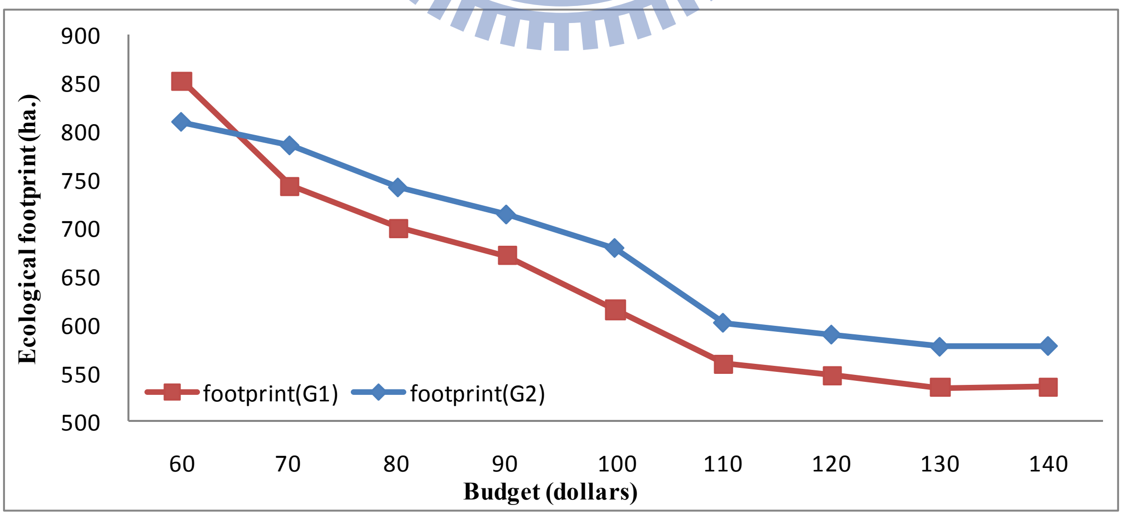


Figure 4.2 footprint under various amounts of available budget.

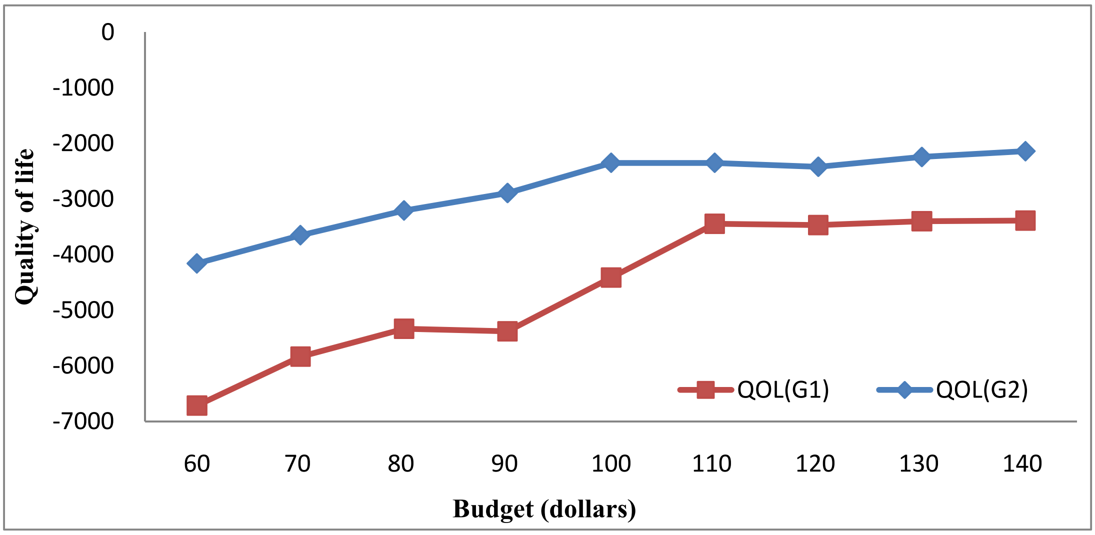


Figure 4.3 QOL under various amounts of available budget.

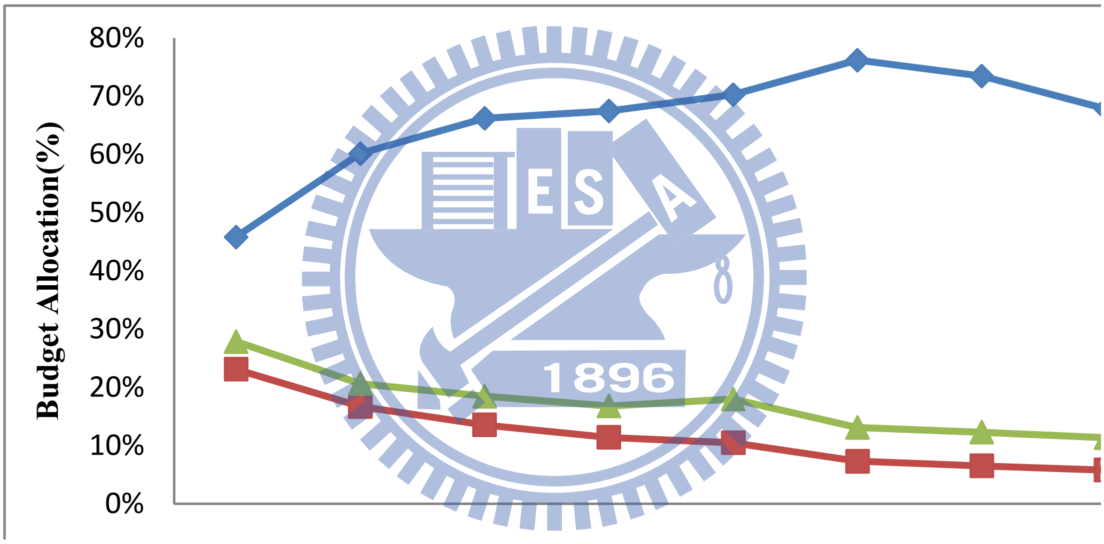


Figure 4.4 Optimal budget allocation plan under various amounts of available budget.

Figure 4.4 presents the optimal budget allocation plan under various amounts of available budget. Most of budget goes to the fare discount subsidy to attract more people use public transportation, which is also the reason why quality of life increases. Table 4.6 presents the result of the sensitive analysis, set 100 million dollars as the bench mark, increase (and decrease) 10%, 20%, 30% and 40% to realize the influence among public transit subsidy, quality of life and ecological footprint under various amount of available budget.

Table 4.6 The result of the sensitive analysis under various amounts of available budget.

Budget	**x (NT dollars)**	**y (Frequency)**	**z (hectare)**	**Budget (NT dollars)**			**Market Share**			**Footprint (ha.)**		
				Price discount	**Deficit subsidy**	**Green land**	**Private**	**Public**	**Total Utility**	**Private**	**Public**	**Total**
60	16	10	231	46%	28%	23%	51%	49%	-6715	388.39	296.28	684.67
70	21	9	195	60%	21%	17%	43%	57%	-5833	343.72	296.28	640.00
80	22	9	181	66%	18%	14%	37%	63%	-5332	300.20	296.28	596.48
90	22	9	171	67%	17%	11%	33%	67%	-5377	272.03	338.60	610.63
100	28	10	126	70%	18%	12%	28%	72%	-2528	70.27	423.25	493.52
110	32	8	134	76%	13%	7%	25%	75%	-3445	206.88	296.28	503.16
120	33	8	130	73%	12%	7%	24%	76%	-3466	184.36	338.60	522.96
130	33	8	126	68%	11%	6%	24%	76%	-3397	162.67	338.60	501.28
140	34	8	126	66%	11%	5%	22%	78%	-3385	142.89	338.60	481.49

4.5.2 Various values of *α* associated with in-vehicle travel time

This section presents the optimal budget allocation plan under various values of α associated with in-vehicle travel time. Figure reveals the truth about increasing α will make ecological footprint increase but quality of life decrease, as Table 4.7 and from Figure 4.5 to Figure 4.6 following below.. That is because if the value of α increase, it means the weight of the in-vehicle travel time increase. Therefore, some users will transfer from public transportation into private car using to decrease their time wasting. However, in this situation, public transportation has to satisfy the needs of the users, frequency still not change any more. Therefore, ecological footprint will increase because of the private car using increasing.

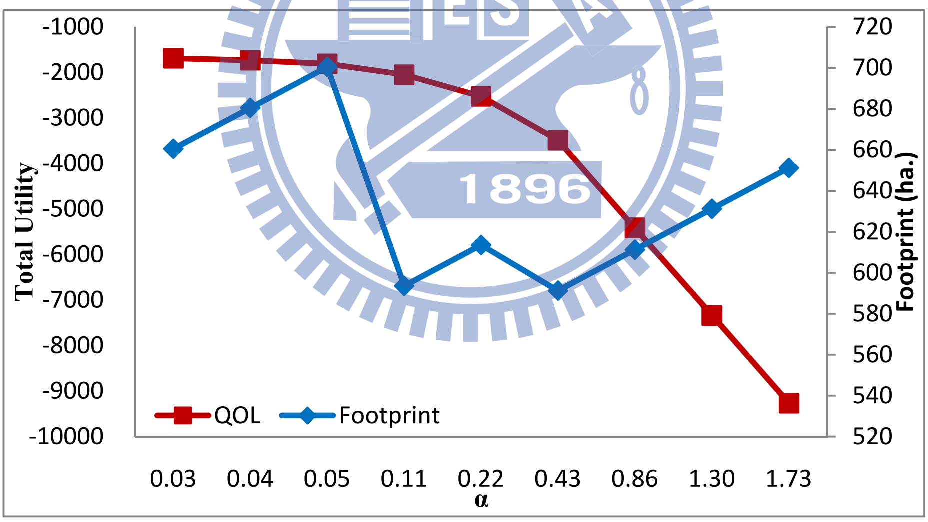


Figure 4.5 QOL and footprint under various values of α

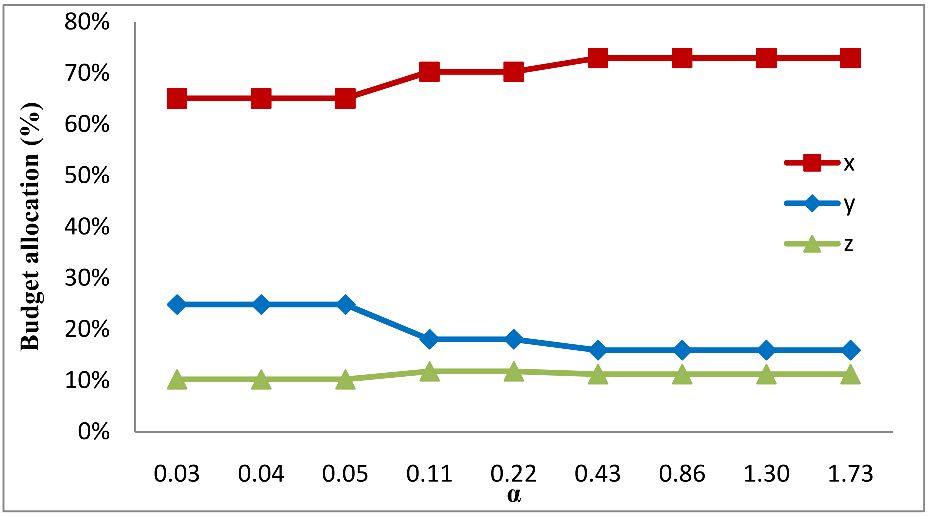


Figure 4.6 Optimal budget allocation plan under various values of α

Figure 4.6 presents the optimal budget allocation plan under various values of α. Most of budget goes to the fare discount subsidy. We could find out the truth about the most amount of budget allocation into price discount, and the remained budget into deficit subsidy and green land acquired. And we also could figure out if the weight of in-vehicle travel time increases will make more people choice private car using. It results in quality of life and bus frequency decreases.

Table 4.7 presents the result of the sensitive analysis, set α = 0.216 as the bench mark, times (and divided by) 2, 4, 6 and 8 to realize the influence among public transit subsidy, quality of life and ecological footprint under various amount of available budget.

Table 4.7 The results of the sensitive analysis under various amounts of α

α	**x (NT dollars)**	**y (Frequency)**	**z (hectare)**	**Budget (NT dollars)**			**Market Share**			**Footprint (ha.)**		
				Price discount	**Deficit subsidy**	**Green land**	**Private**	**Public**	**Total Utility**	**Private**	**Public**	**Total**
0.027	26	13	168	65%	25%	10%	29%	71%	-1690	110.27	550.23	660.50
0.036	26	13	168	65%	25%	10%	29%	71%	-1730	130.27	550.23	660.50
0.054	26	13	168	65%	25%	10%	29%	71%	-1810	150.27	550.23	660.50
0.108	28	10	126	70%	18%	12%	28%	72%	-2047	170.27	423.25	533.53
0.216	28	10	126	70%	18%	12%	28%	72%	-2528	70.27	423.25	493.52
0.432	29	9	112	73%	16%	11%	28%	72%	-3488	210.27	380.93	491.20
0.864	29	9	112	73%	16%	11%	28%	72%	-5414	230.27	380.93	491.20
1.296	29	9	112	73%	16%	11%	28%	72%	-7339	250.27	380.93	491.20
1.728	29	9	112	73%	16%	11%	28%	72%	-9265	270.27	380.93	491.20

4.5.3 Various values of β associated with out-of-vehicle travel time

This section presents the optimal budget allocation plan under various values of β associated with out-of-vehicle travel time. Figure reveals the truth about increasing β will make ecological footprint increase but quality of life decrease, as Table 4.8 and from Figure 4.7 to Figure 4.8 following below. That is because if the value of β increases, it means the weight of the out-of-vehicle travel time increase. Therefore, bus frequency will increase in order to decrease user's time wasting. On the other side, ecological footprint will increase which depends on the frequency of bus change.

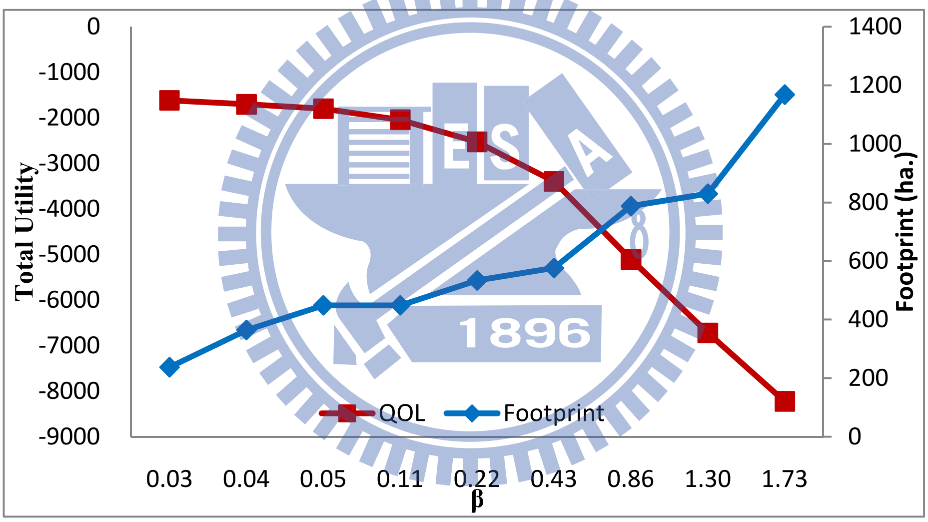


Figure 4.7 QOL and footprint under various values of β

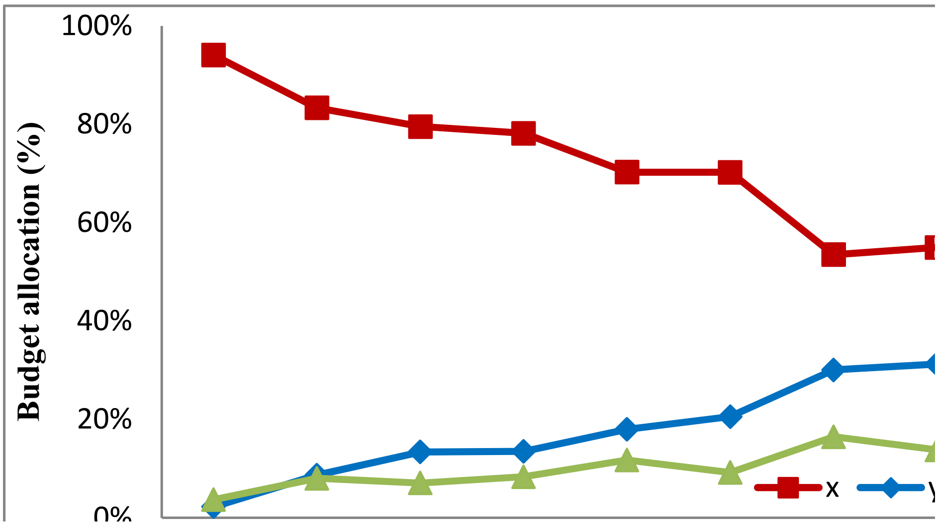


Figure 4.8 Optimal budget allocation plan under various values of β

Figure 4.8 presents the optimal budget allocation plan under various values of β. Most of budget goes to the fare discount subsidy; however, it also decreases gradually depending on the weight of out-of-vehicle travel time increases. We could find out that the budget allocation transfer from price discount to increase bus frequency, that is also the reason why ecological footprint increases but quality of life decreases.

Table 4.8 presents the result of the sensitive analysis, set β = 0.216 as the bench mark, times (and divided by) 2, 4, 6 and 8 to realize the influence among public transit subsidy, quality of life and ecological footprint under various amount of available budget.

Table 4.8 The results of the sensitive analysis under various amounts of β

β	x (NT dollars)	y (Frequency)	z (hectare)	Budget (NT dollars)			Market Share			Footprint (ha.)		
				Price discount	Deficit subsidy	Green land	Private	Public	Total Utility	Private	Public	Total
0.027	34	3	28	94%	2%	4%	21%	79%	-1617	110.27	126.98	237.25
0.036	31	6	70	83%	9%	8%	23%	77%	-1705	100.27	253.95	354.22
0.054	30	8	98	80%	13%	7%	24%	76%	-1800	90.27	338.60	428.87
0.108	30	8	98	78%	14%	8%	26%	74%	-2043	80.27	338.60	418.87
0.216	28	10	126	70%	18%	12%	28%	72%	-2528	70.27	423.25	493.52
0.432	28	11	140	70%	21%	9%	28%	72%	-3395	70.27	465.58	535.85
0.864	21	16	210	53%	30%	16%	27%	73%	-5108	70.27	677.20	747.47
1.296	20	17	224	55%	31%	14%	22%	78%	-6722	65.27	719.53	784.80
1.728	11	25	336	33%	46%	21%	14%	86%	-8225	55.27	1058.13	1113.40

4.5.4 Various values of γ associated with travel cost

This section presents the optimal budget allocation plan under various values of γ associated with travel cost. Figures reveal the truth about increasing γ will make ecological footprint increase but quality of life decrease, as Table 4.9 and from Figure 4.9 to Figure 4.10 following below. That is because if the value of γ increases, it means the weight of the travel cost increase. Therefore, government will increase the percentage of price discount in order to attract more people use public transportation. However, quality of life and bus frequency are both decrease.

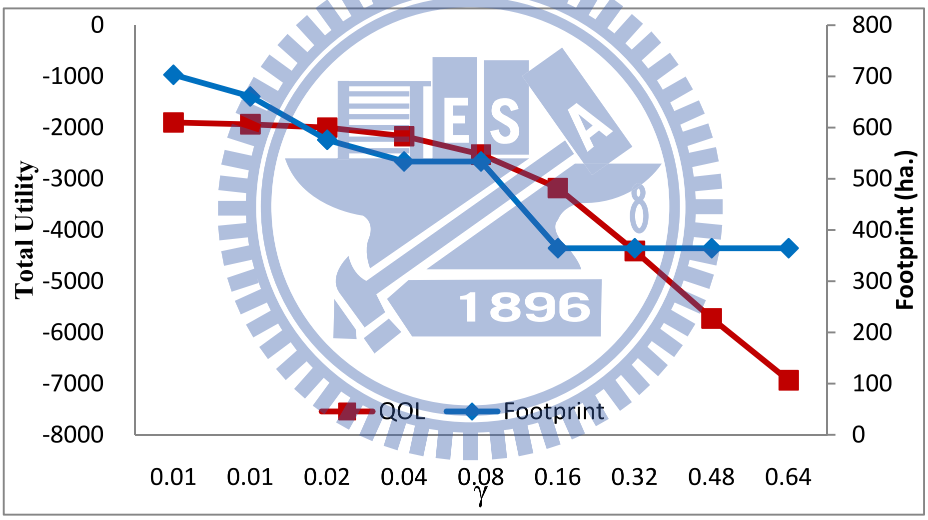


Figure 4.9 QOL and footprint under various values of γ

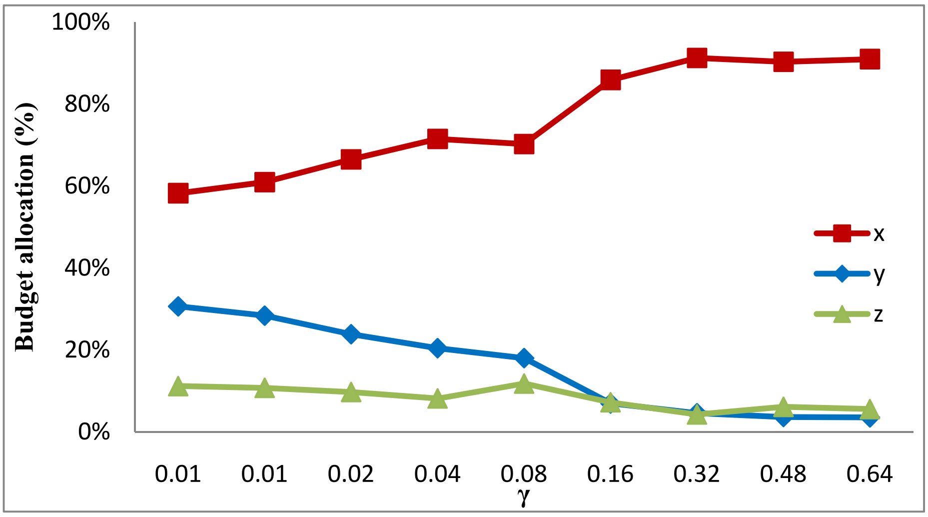


Figure 4.10 Optimal budget allocation plans under various values of γ

Figure 4.10 presents the optimal budget allocation plan under various values of γ. Most of budget goes to the fare discount subsidy in order to attract more people use public transportation. However, bus frequency decreasing results in the quality of life and ecological footprint decreases.

Table 4.9 presents the result of the sensitive analysis, set γ = 0.0803 as the bench mark, times (and divided by) 2, 4, 6 and 8 to realize the influence among public transit subsidy, quality of life and ecological footprint under various amount of available budget.

Table 4.9 The results of the sensitive analysis under various amounts of γ

γ	x (NT dollars)	y (Frequency)	z (hectare)	Budget (NT dollars)			Market Share			Footprint (ha.)		
				Price discount	Deficit subsidy	Green land	Private	Public	Total Utility	Private	Public	Total
0.010038	30	14	182	58%	31%	11%	35%	65%	-1902	110.27	592.55	702.83
0.013383	31	13	168	61%	28%	11%	32%	68%	-1935	100.27	550.23	650.50
0.020075	33	11	140	66%	24%	10%	30%	70%	-2001	90.27	465.58	555.85
0.04015	32	10	126	71%	20%	8%	29%	71%	-2168	80.27	423.25	503.53
0.0803	28	10	126	70%	18%	12%	28%	72%	-2528	70.27	423.25	493.52
0.1606	29	6	70	86%	7%	7%	26%	74%	-3183	60.27	253.95	314.23
0.3212	27	6	70	91%	5%	4%	24%	76%	-4409	50.27	253.95	304.23
0.4818	26	6	70	90%	4%	6%	24%	76%	-5728	40.27	253.95	294.23
0.6424	26	6	70	91%	4%	6%	23%	77%	-6936	30.27	253.95	284.23

Chapter 5　Conclusion and Suggestion

5.1 Conclusion

This paper develops two bi-level programming models – the SG model and the AG model -- to maximize total utility (a proxy of social welfare) under constraints of budget, capacity of transport system and ecological footprint. Three policy measures are considered here: bus fare discount, bus frequency increase, and green land acquisition. The former two measures aim to increase the attractiveness of bus, while the last one is simply to accommodate the excess footprint. To investigate the applicability of the model, a case study on an exemplified network is conducted. Results of the SG model show that the measure of bus fare discount and the measure of bus frequency increase can both attract remarkable percentage of bus usage and achieve almost the same social welfare, however, the latter will generate much larger footprint than that of bus fare discount due to the high emission characteristic of buses. The results of the AG model show that the optimal decision of the contemporary generation will compromise its total utility with that of the next generation by intentionally leaving part of budget to the next generation.

(1) The results in the SG model, government allocates 82% budget into price discount for the users of the public transportation, 10% budget into deficit subsidy and 8% budget into green land acquired. The percentage of private and public transportation mode using are separately 29.02% and 70.98%.

(2) The results in the AG model, in contemporary generation, government allocates 47% budget into price discount, 17% budget into deficit subsidy 12% budget into

green land acquired and remaining 24 % budget to future generation. As this result, future generation have more budget power to make decision. The results reveal that 76% into price discount, 14% into deficit subsidy and 10% into green land acquired.

5.2 Suggestion

Some directions for future studies can be identified. For simplicity, this study only considers one type of public transportation -- bus and one type of private vehicle – car. Other modes, such as air transportation, railway, motorcycle, and bicycle, can be considered. In addition, other government tools, such as transportation infrastructure construction plan, congestion toll, parking fee, can be further introduced. Last but not least, it is worth to apply the proposed models to a field case so that more fruitful and practical policy suggestions can be provided.

Reference

Acutt, M. Z. & Dodgson, J. S., 1997. Controlling the Environmental Impacts of Transport： Matching Instruments to Objectives. Transportation Research Part D, 2(1), 17-33.

Amekudzi, A. A., Jotin Khisty, C. & Meleckidzedeck, K., 2009. Using the sustainability footprint model to assess development impacts of transportation systems. Transportation Research Part A, 43, 339-348.

Brotcoren, L., Labbe, M., Marcotte, P., and Savard, G., 2000, "A bi-level model pand solution algorithm for a freight tariff-setting Problem," Transportation Science, Vol. 34, pp. 289-302.

Cao, D., and Chen, M., 2006, "Capacitated plant selection in a decentralizedmanufacturing environment： a bi-level optimization approach, *European Journal of Operational Research*, Vol. 169, pp.97-110.

Chen, H.K., Chou, C.Y. and Tai, C.T., 2004, "A bi-level dynamic signal timingoptimization problem," 2004 IEEE. International Conference on Networking Sensing and Control, pp.856-861.

Chiou, Y.C. and Lai, Y.H. , 2008, "An integrated multi-objective model to determine the optimal rescue path and traffic controlled arcs for disaster relief operations under uncertainty environments," Journal of Advanced Transportation, Vol.42, pp.493-519.

Chiou, Y.C., Lan, L.W., and Chang, K.L., 2010 , "Sustainable consumption, production and infrastructure construction for operating and planning intercity passenger transport systems," submitted to Journal of Cleaner Production.

De Groot, J. I. M. & Steg, L., 2006. The role of value orientations in evaluating quality of life consequences of a transport pricing policy. Transportation Research Part D, 11, 160-165.

Diener, E., 1984. Subjective well-being. Psychological Bulletin, 95（3）, 542–575.

Dominguez, J. & Robin, V., 1992. Your Money or Your Life. pp.350.

Eck, J. R. V., Burghouwt, G. & Dijst, M., 2005. Lifestyles, spatial configurations and quality of life in daily travel： an explorative simulation study. Journal of Transport Geography, 13, 123-134.

Feng, C.M., Shyu, R.B., 2001, "Exploring Travel Patterns in Taipei Metropolitan Area with Socioeconomic and Land Use Factors", Institute of Transportation Ministry of Transportation Communications

Geurs, K. T. & Van Wee, G. P., 2000. Environmentally Sustainable Transport： Implementation and Impacts for the Netherlands for 2030, Rijksinstituut voor Volksgezondheid en Milieu RIVM.

Go¨ Ssling, S., Borgstro¨M Hansson, C., Ho¨Rstmeier, O. & Sagge, S., 2002. Ecological footprint analysis as a tool to assess tourism sustainability. Ecological Economics, 43, 199-211.

Hai Yan, William H. K. Lam, 1996, Optimal Road Tolls under Conditions of Queuing and Congestion, Transportation Research Part A, Vol. 30, No. 5, pp. 319-332

Holden, E. & Høyer, K. G., 2005. The ecological footprints of fuels. Transportation Research Part D, 10, 395–403.

Huang, B., Yao, L. and Raguraman, K., 2006, "Bi-level GA and GIS formulti-objective TSP route planning," Transportation Planning and Technology, Vol. 29, No. 2, pp. 105-124

Lee, W.K., Lin, C.Y. and Kuo, F.Y. , 2008, "Developing a sustainability evaluation

system in Taiwan to support infrastructure investment decisions," International Journal of Sustainable Transportation, Vol.2, pp.194-212.
Lin, S.J., Shih, N.C., 2001, "The characteric analysis of energy consumption and SOx、NOx、CO2 road transportation sector in Taiwan", Bureau of Energy, Ministry of Economic Affairs
Linster, M., 1999. Bakground facts and figures. Transport Policy and the Environment, 9-45.
Loo, B. P. Y. & Lam, W. W. Y., Indicators of socially sustainable urban transport： A space-time accessibility approach. Transportation and Management Science, 187-195.
OECD, 2001. Guidelines towards Environmentally Sustainable Transport.
OECD,1996, *Environmental Criteria for Sustainable Transport,* Document OECD/GD, 136.
Pimentel, D. & Pimentel, M., 1996. Food, Energy and Society. University Press of Colorado.
Rees, W. & Wackernagei, M., 1996. Urban Ecological Footprints： Why Cities Cannot Be Sustainable And Why They Are A Key To Sustainability. 223-248.
Richardson, B.C. ,2005, "Sustainable transport: analysis frameworks," *Journal of Transport Geography,* Vol.13, pp.29-39
Shiftan Y, Kaplan S, and Hakkert S. ,2003, "Scenario building as a tool for planning a sustainable transportation system," *Transportation Research Part D*, Vol.8, pp.323-342.
Spinney, J. E. L., Scott, D. & Newbold, K. B., 2009. Transport mobility benefits and quality of life： Atime-use perspective of elderlyCanadians. Transport Policy, 16, 1-11.
Steg, L. & Gifford, R., 2005. Sustainable transportation and quality of life. Journal of Transport Geography, 13, 59–69.
Su, C.W., Chang, C.W. Leu, H.M. Chang, S.Y., Yang, Y.W., 2004, "The Demand Model of Intercity Transportation Systems under National Sustainable Development in Taiwan", Institute of Transportation Ministry of Transportation Communications
Tam, M. L. & Lam, W. H. K., 2000. Maximum car ownership under constraints of road capacity and parking space. Transportation Research Part A, 34, 145-170.
United Nations, 1987, *Report of the World Commission on Environment and Development*, General Assembly Resolution 42/187.
Vemuri, A. W. & Costanza, R., 2006. Theroleofhuman,social,built,andnatural capital inexplaininglifesatisfactionatthecountrylevel ： towardaNational Well-BeingIndex(NWI). EcologicalEconomics, 58, 119-133.
Wackernagel, M., Onisto, L., Bello, P., Linares, A. C., Lo´Pez Falfa´N, I. S., Me´Ndez Garcı´a, J., Sua´Rez Guerrero, A. I. & Sua´Rez Guerrero, M. G., 1999. National natural capital accounting with the ecological footprint concept. Ecological Economics, 29, 375-390.
Wilhelm, A. and Posch, K.H. ,2003, "Mobility management strategies for the next decades: findings and recommendations from largest European mobility management project," *Transportation Research Record*, No.1839, pp.173-181.
Whitelegg, J., 1993. Transport for a sustainable future - the case of Europe. Belhaven Press London and New York.
Yang, H. and Lam, W.H.K. ,1996, "Optimal road tolls under conditions of queuing and congestion," Transportation Research Part A, Vol.30, pp.319-332.