MULTI-DIMENSIONAL INTEGRATED TRANSPORT POLICIES OPTIMIZATION BASED ON GENETIC ALGORITHM

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Abstract: Empirical experiences showed that improving the urban transport problems should rely on integrated multi-dimensional transport policies which can also soften the demand of infrastructure investment. However, to fully consider the multi-dimensional transport polices in transportation planning framework would be very difficult due to the factor that there would be too many possible policy combinations to be evaluated. Therefore, this study attempts to develop an analytic framework for evaluating urban integrated transport policies comprehensively, including strategies of investment, pricing, management and regulation. In particular, to deal with the difficulty of too many policy combinations, genetic algorithms will be employed to search for the optimal strategy combination for integrated transport policy. Finally, the relationships between quantified objectives, policy combinations, and assessment performances would be analyzed using the proposed model in this study. The results can also provide a reference to decision makers when drafting urban integrated transport policies.

Key Words: Public Transport, Performance Assessment, Genetic Algorithms.

1. INTRODUCTION

Urban transportation problems include several phases, such as congestion, accident, and pollution. To deal with those problems effectively and to develop the sustainable transport in cities, the integrated transport policy should be fully considered in conjunction with land-use, socio-economy, environmental impact, finance and sustainability rather than restricted to only a single policy element (May and Roberts, 1995; May et al., 2003; Jones et al., 2003, Lan et al., 2006).

Most of the constituent elements of these strategies are already available, but there is a serious lack of detailed understanding of the impacts of many of these policy instruments and of their transferability to different contexts (May et al., 2003). However, to fully consider the multi-dimensional transport polices in transportation planning framework would be very difficult due to the factor that there would be too many possible policy combinations to be evaluated.
Even more serious is the lack of understanding of how to design integrated strategies which most effectively combine infrastructure, management, regulation and pricing. Even where appropriately sustainable strategies are identified, there are serious barriers to their implementation (May et al., 2003). Therefore, only simplified policy combinations have been considered in the real world practices.

Thus, this study attempts to develop an analytic framework for evaluating urban integrated transport policies comprehensively, including strategies of investment, pricing, management and regulation. For more reliable and realistic applications the evaluation framework should consider many factors, which increase the complexity of the problem. They are considered with different emphasis and levels of detail at different stages in the whole evaluation process.

Hence, there is a need for a new optimization method which takes into account the interdependency between these four elements for various levels of the designed goal or subjects. In this study, genetic algorithm (GA) approach has been proposed to search for the optimal strategy combination for integrated transport policy.

This paper has been organized in a following way. In Section 2, review the related literature. In Section 3, dilate on the simulated steps of the evaluation framework. Then, discusses the policy instruments considered in addressing urban transport problems and the formulation of integrated transport policy alternatives. Section 4 outlines the optimal solution methods developed for the combined four different policy elements. Numerical analysis is also carried out here. Some conclusions for urban transport policy are drawn in Section 5.

2. LITERATURE REVIEW

To deal with the urban transportation problems effectively, we review the development of Integrated Transport Studies (ITS) which has expanded from England. Secondly, collect currently useful transport policy instruments in the world, and try to look for a systematic way to divide in several meaningful categories.

2.1 Integrated Transport Study

Integrated Transport Studies (ITS) are as a base for guiding the development of transport strategy from 1990s. The concept of ‘integrated transport’ has become an important guiding principle for transport policies’ institutional and structural development in many countries. Its purpose is “to provide access to goods, resources, and services, while reducing the need to travel, so that economic, environmental and social needs can be met efficiently and in an integrated manner” (Potter and Skinner, 2000).

May et al. (1995) have developed the resulting optimization procedure to evaluate the optimal integrated transport policy combinations. Later, Fowkes et al. (1998) modified the procedure to increase the efficiency and improved in Edinburgh case. Afterward, European Union had an OPTIMA project, for generating optimal transport strategies has been applied in nine European cities. The resulting optimization procedure is used to find out the optimal integrated transport policy combinations. Furthermore, the policy measures were tested using city-specific transportation models which had already been set up, calibrated and used by the city authorities before the star of the project (May et al., 2000; May et al., 2001; Timms et al., 2000).
Those researches bring up a new think way to update the traditional transport policy planning. According to different visions of urban developed plans, planners conferred on the best way to integrate transportation and land-use policy instruments. Then, broad quantification of representative scenarios for transport was required covering national and local factors so as to provide a focus for the appraisal of alternative transport strategies by area, corridor and mode (Jones et al., 1990). Through quantitative analytical framework, the synergy between each policy instruments would be clarified. Offering a substantial and feasible planning process is so different from the blueprint or white book.

2.2 Urban Transport Policy

Urban transport policy has a significant development of the last decade has been emergence of a much wider range of policy instruments available to the urban transport planner (May et al., 2003). How to effectively categorize urban transport policies and strategies is a big challenge. World Bank (1986) divided urban transport policies into four parts, which are transport demand management, traffic management, public transport management, and infrastructure. Besides, according to the project namely Knowledgebase on Sustainable Land Use and Transport (KonSULT) (Matthews et al. 2002), has been to categorize instruments by type of intervention, distinguishing between six types: land use policies; infrastructure provision; management and regulation; information provision; attitudinal and behavioral measures; and pricing (May et al., 2003). Jones et al. (2003) tried to evaluate and implement transport measures in a wider policy context, so that divided policy context into four parts, infrastructure, management, information and pricing. Through the review of urban transport policy discrimination, we obtain that infrastructure, pricing, management and regulation are important dimensions in urban transport policy.
3. EVALUATION

A good integrated transport policy should throng a completely evaluation process before it become a real action for implementation. Therefore, we construct a comprehensive evaluation framework based on the travel demand forecasting for appraising integrated transport policy alternatives. The comprehensive evaluation framework will be introduced detailed step by step. After that, focus on the empirical city- Kaohsiung, follow the urban long-term development plan, to define the context of the integrated transport policy alternatives, which those scenarios will be simulated the effects through the evaluation framework. Thirdly, apply the genetic algorithm in terms of the systematic and automatic solution. Finally, interpret the genetic algorithm parameters for the model application.

3.1 The Evaluation Framework

The evaluation framework was originally proposed by Chen et al. (2005). An integrated transport policy alternative has included four different policy dimensions, investment, pricing, regulation, and management as shown in Figure 1. The numbers of policy alternatives were limited because the whole process could not operate automatically in Chen et al. (2005). There are three to five different strategies or instruments in each policy dimension. Each strategy under different policy dimension is difficult to identify the truly quantitative content. For example, how to decide the parking fee per hour precisely is hard in pricing policy dimension, but it is an impartment simulation result to suggest the local authorities to carry out. Therefore, we modified the framework and applied GA optimization heuristic to deal with above shortcomings and try to find out more quantitative and specific integrated transport policy alternatives in this modified evaluation framework (as shown in Figure 1).

The modified framework was illustrated in Figure1 and starts with the vision of the urban (Step1). Public transportation is a sustainable form of urban transportation (World Bank, 1996), and serves as a promising solution to the problem of transportation demand in most urban cities around the world (Schmocker et al., 2003; Wong and Lam, 2006). Therefore, in order to solve urban transportation problems, the main goal is to encourage people to use public transportation more frequently. Then, an explicit objective is to raise the public transport market share (Step2). The next step is to construct a combination of investment, pricing, regulation, and management to generate some possible and reasonable policy alternatives. The combinations themselves allow the interactions between four categories to be assessed (Step3).

Then, each alternative needs to analyze its travel demand in the future predicted year by the traditional classic four-stages of trip generation, trip distribution, mode split, and trip assignment (Step4). According to the results of the travel demand analysis, we can calculate the number of trips made in each traffic zone, and the percentage of market share in each mode. From the steps of the transport policy alternatives selection, the travel demand analysis, to the step of the alternatives evaluation, genetic algorithm has been proposed to search for the optimal strategy combination automatically. This mechanism also has the feedback function to check the degree of the transport goal implementation. After the iterations, the optima integrated transport policy alternative can be appeared automatically (Step5).
3.2 Genetic Algorithm and model application

Genetic Algorithms (GA) was first introduced by Holland (1975). GA imitates the principles of natural evaluation for parameter optimization problems (Michalewicz, 1999). It is one kind of simulation nature heredity search principle, mainly is take simulates Darwin "the theory of evolution" as the calculation foundation. Using the nature heredity characteristic, GA contains several operators, reproduction, crossover, mutation and so on. Goldberg (1989) and Gen and Cheng (1997) elucidated applications of GA and attracted the growing interest of optimization problems. GA is also a family of adaptive search procedures that are loosely based on models of genetic changes in a population of individuals (Haldenbilen and Ceylan, 2005).

About the characteristics of GA, Goldberg (1989) states four important distinctions of GA over other search method: a) GA works with a coding of the parameter set, not the parameters themselves; b) GA searches from a population rather than a single point; c) GA uses payoff (objective function) information, not derivatives or other auxiliary knowledge; d) GA uses probabilities transition rules, not deterministic rules. Besides, Haldenbilen and Ceylan (2005) discuss the main advantage of GA is its ability to use accumulating information about initially unknown search space in order to bias subsequent searches into useful subspaces.

According to the comprehensive evaluation framework (Figure 1), Kaohsiung is selected as an empirical city of this research because it is the second biggest city in Taiwan and has the biggest international commercial harbor. To find out the optima integrated transport policy alternatives, the GA flow is developed to carry out the detailed step and various parameters hypothesis explanation as follows:

![Diagram](image-url)
Travel demand analysis

Genetic Algorithm Parameters Setting
- Generation
- Population
- Crossover rate
- Mutation rate

Design the upper and low bound of each gene

Produce chromosomes randomly
- Fitness function
- Ranking
- Elitist

Reproducing
Crossover
Mutation
Evaluation
Fitness Function

Converge Condition
- Yes
- No

Optimal Solution

Figure 2. The Genetic Algorithm Process

3.2.1 Coding and decoding

In order to optimize the objective function, we need to code the strategies with some precision. To present the entire integrated transport policy altogether, we design a chromosome $V_0$ to include four sections of genes $\{x_1, x_2, x_3, x_4\}$, separately expresses strategy of investment, pricing, regulation and management.

The investment policy dimension $\{x_1\}$ designs five different public transport networks according to the long-term planning of Kaohsiung city government, including exist road network; additionally constructs the MRT line; additionally constructs the LRT line; increase bus system; and reduces the headway of bus system.

The pricing policy dimension $\{x_2\}$ is presented by different level of parking fee because Kaohsiung city has a serious parking problem by road side. The charge for parking fee may differently divide five kinds, because rest on the different characteristics of traffic zones. The ordinary roadside-parking fee is 30 NTD per hour according to the Kaohsiung City Transportation Bureau (KCTB) at present the parking charge standard. Some parking spaces are charged in increasing way, for example, the first hour is 50 NTD, and from the second hours increase to 100 NTD. Therefore, this research design the parking for automobile each hour is from 20 to 50 NTD, and the motorcycle is from 0 to 25 NTD. The simulation range takes every 5 NTD as a unit.
The management policy dimension \(x_3\) has many qualitative strategies, such as tax, toll, and out-of-pocket cost. Those strategies may be summed up in the traveling cost per kilometer by different modes. The traveling cost per kilometer is according to officially report published by the Ministry of Transportation and Communication for “the road vehicles driving cost investigation” (MOTC, 1990). Using the investigation results of Kaohsiung County vehicle owners pay each driving cost statistics as a foundation. This research design the traveling cost of vehicle owner for each kilometer is from 2 to 9 NTD and the motorcycle for each kilometer is 1 to 2.5 NTD. Sampling for simulation will take every 0.2 NTD as a unit.

The regulation policy dimension \(x_4\) accounts the time for searching a parking space and walking to the destination. Five different kinds of time specifications are designed because each traffic zone has different parking space provision. The automobile searching time is 0 to 10 minutes and the walking time 0 to 10 minutes. The motorcycle searching time is 0 to 10 minutes and the walking time 0 to 10 minutes. Sampling for simulation will take each minute as a unit.

If try to simulate all of the combinations, there are more than thousands combinations need to try to find out the optima one. That’s the reason for applied GA to raise the simulation efficiency.

3.2.2 Initial Population

The initial population is the first generation of chromosomes. Two general common kinds to generate, one is randomly production that may retain the biggest variation. The other is randomly coordinate the heuristic procedure for the principle to produce If considers to have for the feasible solution, also may. A good initial population is helpful to the search efficiency, guarantees the result to be able fast to converge. This research produces the initial population randomly and each generation has 20 chromosomes.

3.2.3 Fitness Function

The fitness function plays the role of the environment, rating potential solution in terms of their fitness. In order to strive for the simplification, this research designed "the market share of public transport" thorough the travel demand analysis to take the fitness function, evaluates fit and unfit quality of the chromosome. Because the travel demand analysis needs to simulation in another transport specific software, the design of fitness function is different as common as an equation form or objective function, instead of a percentage numeric.

3.2.4 Elitist Model

For guarantee best individual of every generation can come down course evolved to participate in through choosing to continue protecting in mechanism, eliminate every generation worse individual at the same time, in order to improve whole average adaptation degree of ethnicity, so there is formulation of the elite way. Its method is to keep the first best individual while taking the place of, eliminate from generation this worst individual is it evolve constantly towards kind direction go on to so as to ensure, used to improve the efficiency of making mathematical calculations.
3.2.5 Selection and Reproduction

Selection process is to select of a new population with respect to the probability distribution based on the fitness values. A roulette wheel with slots sized according to fitness is common used.

3.2.6 Crossover

Now we are ready to apply the recombination operator, crossover, to the individuals in the new population. The probability of crossover, \( p_c \) is one of the parameters of a genetic system. This probability presents the expected number \( (p_c \times \text{pop-size}) \) of chromosomes which undergo the crossover operation.

3.2.7 Mutation

Mutation is performed on a bit-by-bit basis. Probability of mutation, \( p_m \), another parameter of the genetic system, is used to calculate the expected number of mutated bits.

The model is performed with the following GA parameters:
- Population size \( (n) \) 20
- Generation number \( (t) \) 100
- Probability of crossover \( (p_c) \) 0.5
- Probability of mutation \( (p_m) \) 0.01

The solution algorithm of the GA in this study follows the following procedure:

1. **Step1** GA parameter setting. The important parameters of genetic system are population size, generations, probability of crossover and mutation.
2. **Step2** Design the upper and lower bond of each gene. For given lower and upper bound of the different strategy, represent the parameters as binary strings to form a chromosome.
3. **Step3** Generate the initial random population of the model parameters and set \( t=1 \).
4. **Step4** Decode all weighting variable to map the chromosomes to the corresponding real numbers.
5. **Step5** Calculate the fitness functions for each chromosome.
6. **Step6** Reproduce the population according to the distribution of the fitness function values.
7. **Step7** Carry out the crossover operator by a random choice with probability \( p_c \).
8. **Step8** Carry out the mutation operator by a random choice with probability \( p_m \), and then we have a new population.
9. **Step9** If the converge condition is reached, return the optimal solution; if not, go to **Step6**.
4. NUMERICAL RESULTS

Because the transportation planning software (MINUTP) needs to operate under the DOS environment, the whole simulation procedure and algorithms are wrote in one batch file including three parts, known file input and output, transport requirement forecasting, genetic algorithm. Besides, to do the travel demand analysis needs some data collections and model assumptions in each step. Most of data needed in this analysis were obtained from the transport planning reports and records of the Kaohsiung Rapid Transit Corporation (KRTC), and part of from the official annual statistical reports of the Kaohsiung City Government. Furthermore, the simulated year setting is from the based year 1997 to the situation on year 2010.

Through the evaluation procedure, as describe above, the change of public transport market share are illustrated in Figure.1. The urban vision of Kaohsiung city is to encourage people to use the public transport more (Step 1). Under this urban vision, the transport goal is to raise the percentage of the public transport market share (Step2). Next, designing the quantitative content of integrated transport policy alternatives to match the long-term urban planning of Kaohsiung city by expert interviews and discussions. Then, setting the GA parameters to generate the initial random population and to start on this whole evaluation process.

The Figure 3 displays the convergence curves measured in terms of the summation of maximum transport market share. As can be seen from the figure, the market share can converge to 41.21% after the forty-ninth generations. The contents of this integrated transport policy are investing MRT and LRT system; the parking fee for vehicle is 50 NTD per hour, and the motorcycle is 20 NTD per hour; the traveling cost of vehicle owner is 5 NTD and the motorcycle is 2 NTD.

![Fig. 3 Genetic Algorithm Results](image-url)
5. CONCLUSION

To deal with the urban transport problems effectively, long-term developments of the urban should be full considered in conjunction with land-use, socio-economy, environmental impact, finance and sustainability factors rather than restricted in single face of transport policy. Some results showed that improving the urban transport problems was relied on integrated transport policies to reduce demand of investment and impacts of huge costs.

The efficiencies of assessment would be decreased with considering the multi-dimensional integrated transport policies cause of complicated combination factors. Therefore, most researches were simplified the model to dissolve the impact of the factors interaction problems. The purpose of this project developed a newly framework to facilitate the assessment of multi-dimensional integrated transport policies.

The combinations of factors including investment, pricing, management, and regulation were considered in the modified model. Genetic algorithms were employed to dissolve these interactions of considering factors in the proposed model. For this purpose, the genetic optimizer, combines the transport demand four step analysis, used to estimate travel demand in predicted year, with the transport policy integration, used to combined different dimensions transport policy and strategies, is developed. Finally, the relationships between quantified objectives, policy combinations, and performances would be analyzied using the proposed model in this study. The suggestions would be also provided in the proposed model for the decision makers when drafting urban integrated transport policies.

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