# IMPACTS EVALUATION OF URBAN TRANSPORTATION POLICY WITH ENVIRONMENTAL CONSIDERATION

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**Abstract:** This research provides answers to the question "What will be the social impacts of a given urban transportation policy?" and provides the nucleus of a decision support tool for urban planning. Decision-makers have been unable to integrate the complex relationships between transportation and related fields (urban land use, economics, demographics, energy consumption, and environmental impacts) that contribute to the true costs of travel. This research formulates a mathematical model that quantifies the regional impacts of urban transportation policies from system point of view, considering system travel time, system travel costs, and CO emissions to help the urban planners to predict impacts of transportation policies. This paper models real-world travelers' decision behavior, considering multiple income classes, multiple transport modes, and physical network constraints. At the end, we use this model to show the impacts of area licensing scheme for case of simplified Taipei city.

**Key Words:** urban transportation policy evaluation, environmental impacts, impact evaluation

## 1. INTRODUCTION

The transportation systems in many developed cities fail to promote economic growth by providing for efficient transport of commercial goods, nor do they provide convenient services to residents in meeting their daily transportation needs [Birk, 1993]; rather, many systems clog city space, pollute city air, inadequately provide services for city residents, draw major portions of city financial resources for operation and maintenance, and hamper urban economic growth. Such problems can be traced back to the urban planning process. Decision-makers have been unable to integrate the complex relationships between transportation and related fields (urban land use, economics, demographics, energy consumption, and environmental impacts) that contribute to the true costs of travel. This has introduced problems that not only transportation planners but also urban planners now need to face [Greene, et al.,1995; OECD, 1995; Philpott, et al., 1994]. It is therefore necessary to provide a quantitative model to estimate the impacts of transportation policies on urban regions.

The research presented in this paper models real-world travelers' decision behavior, considering multiple income classes, multiple transport modes, and physical network constraints. By introducing an intangible cost (the mode-aversion cost) into the generalized travel cost function, this research proposes a quantitative approach to measure the "full cost" for travelers. Traveler selects mode and path to minimize his/her fully travel cost. However, travelers' decisions are based on "individual" cost and not consider that much about "system" cost (traffic congestion, air pollution, and other social costs) for the whole urban area. This research proposes a quantitative approach to measure the "system cost" of society to help the urban planners to predict impacts of transportation policies.

## 2. MODEL FORMULATION

Two different levels of processes are quantified in this research. First, at individual level, by introducing an intangible cost (the mode-aversion cost) into travelers' behavior decision model, this research quantifies the true cost of travel [Chu, 1997]. Second, at the regional level, by adopting cross-sector social modes, this research quantifies the regional economic impacts of transportation policies. The framework for the research, depicted in Figure 1, consists of one core function and two core sub-models: generalized travel cost function, the model of travelers' decisions, and the model of total social cost. The generalized travel cost function is a comprehensive cost function that contains tangible and intangible cost for a traveler. The measurement of intangible cost will be introduced later. The model of travelers' decisions based on the user-optimal principle (Wardrop's user principle) estimates the travelers' behavior on selecting the path and transport-mode when the transportation policy changes. This model is used twice in this algorithm. The first time is used in calibration process (shadow area in Figure 1) to estimate intangible cost. The second time is used to estimate the impacts of transportation policy. The input data we need for model of travelers' decision are empirical traffic data including origin-destination matrix and mode usage; traffic network data including paths on network, arc capacity, etc; and transportation policy alternatives. The output of this sub-model is equilibrium traffic flow pattern. During the calibration process, the intangible costs will be modified until the traffic flow pattern closed to empirical pattern. Then we input this equilibrium traffic flow to model of social costs to estimate air pollutants, total travel time and costs from the traffic pattern. The details of generalized travel cost function and two sub-models are described in following.

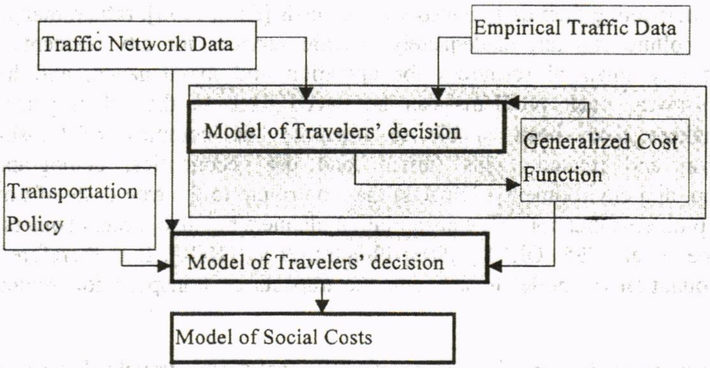

Figure 1. Framework of model

## 2.1 Generalized Travel Cost Function

Many cost analyses have recently been done to evaluate transport-mode alternatives but they tend to over-simplify travel cost function when compared to real-world situation. A "comprehensive" cost function proposed by Qin et al listed most of the factors that should be included in the cost function [Qin, et al., 1996]. However, they have focused on the tangible costs of travel time and other monetary expenses that come directly out of the commuters' pockets. To structure a real comprehensive cost function, first, we follow the Qin's analysis to formulate *Travel costs*. Qin's trip costs include travel time and travel monetary cost. That is,

$$\textit{Travel costs} = \textit{Monetary cost} + \textit{Time cost} \qquad (1)$$

Monetary cost includes depreciation, opportunity interest, registration fee, insurance fee, fare, fuel cost and maintenance cost, toll, parking fees, etc. Time cost includes waiting time, distribution time, and line-haul time. Line-haul time, is defined using the Capacity Restraint Assignment Method with BPR form. The converter, Value of time (VOT), converts the time into monetary units. VOT is estimated by the opportunity cost for the travelers. We assume a traveler's VOT of a given income class is equal to his or her hourly work pay.

We present an example introduced in that Chu's paper [Chu, 1997]: ten income classes commuters travel from Chungcheng to Taan, two areas in Taipei City. Figure 2 show the calculation results of their tangible costs, as in Equation 2 for using different transport modes. The table and figure show that the tangible cost for using private car is much higher than other modes for every level of income. Therefore, if the commuters are behaving rationally and if their selection of transport modes depends only on the tangible costs, then there should be only a few private cars on the road and most travelers should select one of the three other modes. However, in the real world, this is not the case. There are many private cars on the road.

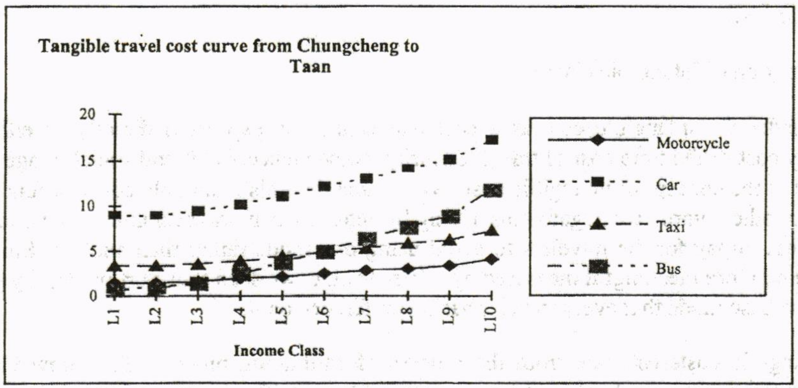

Figure 2. Tangible travel cost curve (Chungcheng to Taan).

We adopted the assumption model in Chu's paper that there exists an "intangible cost," which explains the discrepancy between the rational transport mode selection and the observed behavior. This intangible cost is considered a psychological cost that cannot be directly computed. Security, convenience, habit, and social image are all included in the concept of intangible cost. Therefore, the trip cost function, as we proposed, should be in the form of Equation 2.

*Generalized Costs = Time cost + Travel monetary cost + Intangible cost*

*= Travel time *Value of time + Travel monetary cost + Intangible cost*

*= (Access walking time + Waiting time + Line-haul time + Parking time + Distribution time* Value of time + (Initial cost + Unit-distance cost*Travel distance + Toll + Parking fee) + Intangible cost* (2)

Note that this cost function is not a constant, it depends on which path to choice, what kind of mode to use, how much the traffic flow on path, and the intangible cost. The line-haul time is defined using the Capacity Restraint Assignment Method. Capacity restraint assignment deals with overloaded links in the network. In several suggested methods, the Bureau of Public Roads (BPR) method is often used. The travel time is represented by the general polynomial function (Equation 3), which is positive and monotonicly increasing and all of the other parameters in the generalized cost function are positive. Therefore, the generalized cost function is positive and monotonicly increasing.

$$TTA = T_0 \times [1 + \alpha \times (\frac{AF}{AC})^{\beta}] \qquad (3)$$

Where TTA presents the travel time on arc. AF presents arc flow and AC presents arc capacity limitation. $T_0$ is the ideal travel time on arc. $\alpha$ and $\beta$ are parameters. ( for our case, $\alpha$ is assumed to be 0.15 and $\beta$ is assumed to be 4.) This generalized travel cost function is regarded as the traveler's trip decision function. In other word, if the traffic engineer having the information of generalized travel cost function of individuals then the traffic assignment problem will become a cost minimization process. Next, we show an approach to estimate the intangible cost.

## 2.2 Estimation of Intangible Cost

We consider the intangible cost as a cost that cannot be expressed directly as either the monetary cost or the time cost of travel. Security, convenience, habit and social image are all included in the concept of intangible cost. We assume that this intangible cost is a function of mode. In other word, we regard this intangible cost as a mode-aversion cost which is a willingness-to-pay for the travelers to avoid using one mode rather than another. Since this cost will be more meaningful measured by relative value, we set a transport mode, say private car, as the base mode that every traveler has no preference on it.

The intangible costs estimate from the process of calibration process. To follow the real behavior, there are several assumptions for intangible cost. These assumptions serve as rules of calibrating model with the empirical data.

Rule (1): The intangible cost should not decrease with the travelers' income level. The higher income level travelers have a higher preference on using private cars, therefore, the intangible cost for other transport modes should increase with the travelers' income level.

Rule (2): The result of the calibration by adjusting the intangible cost should show a reasonable mode distribution across different income level travelers. The mode distribution curve over the income levels should be graduates.

Rule (3): The result of travel time for the network should be in the reasonable range. The travel time for every path should be close to the empirical data from the real-world case.

Rule (4): The total transport modes distribution should be close to the empirical data.

## 2.3 Model of Travelers' Decision

This sub-model presents a simulation of the traveler's behavior in the sense of Wardrop's user-optimal principle [Wardrop, 1952] in which each traveler's objective is to minimize his or her travel cost. Wardrop's user-optimized principle was formulated by Beckmann, McGuire, and Winsten [Beckmann, 1956]. Beckmann's formulation considers one class of traveler and one transport mode, in other words, it imposed a symmetry requirement for the cost function. Dafermos [Dafermos, 1972] extended Beckmann's approach to multiclass-users problems. Florian [Florian, 1976] and Abdulaal and LeBlanc [Abdulaal, et al., 1979] considered the multi-modal problem. After the theory of the multiclass-user-and-single-mode problem and the theory of the single-class-user-and-multi-modal problem had matured, researchers became interested in the combined problem of the multiclass-user-and-multi-modal traffic assignment problem. Florian [Florian, 1977], Florian and Nguyen's [Florian, et al, 1978], LeBlanc and Farhangian [LeBlanc, et al., 1982], and Lam and Yang [Lam, et al., 1992] provided partial solutions to this problem [Sheffi, 1985].

A wide-used type of models in dealing with mode selection is multinomial choice probability model that combined probability theory and econometrics. This type of models proposes probabilistic approaches for mode selection to avoid directly measuring intangible cost. In fact, if individual's complete travel cost can be estimated then the selection in mode and trip path should be determined and not a probability any more. By introducing intangible costs into cost function, Chu developed a model that combine a modal split-assignment for multiclass users and that also consider the wealth effect on mode selection [Chu, et al., 2000]. Chu's model extends Wardrop's user optimal principle for path assignment to a mode-path assignment.

This research follows Chu's approach by formulating the user equilibrium traffic assignment problem as a nonlinear complementarity problem (NCP). By transforming the NCP to a fixed-point problem and applying Brouwer's theorem, continuity establish a quite general existence theorem for user equilibrium can be proved for our model [Aashtiani, et al., 1981].

### *2.3.1 Model Algorithm*

This research adopts the diagonalization (or relaxation or nonlinear Jacobi) algorithm to solve the equilibrium traffic flow problem. The whole network travel pattern (or flow pattern) converges until no one is able to reduce personal travel cost by switching mode or path. The process of solving a traffic assignment problem is to find a traffic flow pattern that is consistent with the relevant equilibrium criteria. If the cost functions are positive and continuous, then an user equilibrium will exist, and because of the application of complementarity theory, if the cost functions are strictly monotonically increasing, then the user equilibrium is unique.

Step 0: Initialization.

Obtain an initial feasible path-flow vector ***x***. In this research, we solve the Equation 4 without fixing the diagonal flow and set the equilibrium results as the initial flow pattern. Set iteration counter, *n*, equal to 1.

Step 1: Diagonalization.

Fixed off-diagonal flows at their value for each arc. Set $f^{-}_{a,m,c}$ (in Equation 4) as a constant. Therefore, the objective function in Equation 4 with only one variable (i.e., the generalized cost function $c_{a,m,c}$ is a function of $x$ only); all the other flows that may affect the cost for class $c$ using transport mode $m$ on arc $a$ are not variables during the *n*th iteration. The values of these other flows (by other modes, classes, and arcs) are fixed. In other words, cross-arc cross-mode, and cross-class effects by other flows are frozen. Note, this formulation does not fix the flows themselves and the Hessian of Equation 4 is diagonal since all cross-arc effects are kept fixed.

Step 2: Optimization.

Solve the minimization objective function subject to conservation of flow, the nonnegative flow constraint, and the capacity constraint.

$$\min_{f_{a,m,c}} \sum_{c} \sum_{m} \sum_{a} \int_{0}^{f_{a,m,c}} C_{a,m,c}(x+f^{-}_{a,m,c})\,dx \qquad (4)$$

s.t. $\sum_{m} \sum_{r} h^{rmc}_{pq} = h^{c}_{pq}$ = path flow of class $c$ form $p$ to $q$

$\sum_{m,c} f_{a,m,c} \le \bar{f}_{a}$ = capacity constraint of arc $a$

$h^{rmc}_{pq} \ge 0$

Where $f_{a,m,c}$ = arc flow for class $c$ using mode $m$ on arc$a$ $= \sum_{pq} \sum_{r} \delta^{ramc}_{pq} h^{rmc}_{pq}$

$f^{-}_{a,m,c}$ = the arc flow except $f_{a,m,c}$

$$\delta^{ramc}_{pq} = \begin{cases} 1, & \text{if } a \in path(p,q,r,m,c) \\ 0, & \text{if } a \notin path(p,q,r,m,c) \end{cases}$$

$c_{a,m,c}$ is arc cost function for class c by using mode m. Note that all the generalized cost functions used are strictly increasing in the arc flow (Equation 3), a property which guarantees that the solution to each sub-problem is unique.

Step 3: Convergence test.

If the arc-flow vector $\boldsymbol{x}$ that generated in $n$th iteration is the same as that of $n\text{-}1$th iteration, that is $| \boldsymbol{x}_n - \boldsymbol{x}_{n-1}| < \alpha\, \boldsymbol{x}_{n-1}$, where $\alpha$ is a (dimensionless) predetermined constant, then stop. Otherwise, set $n = n+1$, and go to Step 1.

After the iteration process converges, we obtain the equilibrium traffic pattern. In other words, we know the final decision of every income class about which path and what transport mode to use for every origin-destination pair.

### *2.3.2 Model Calibration*

We calibrate the model by modifying the set of intangible costs (mode-aversion costs). The stop criterion for the process of calibration is the error of mode distribution less than 1%. After the calibration process, we assume this set of intangible costs is fixed through the process for analyzing the transportation policy.

## 2.4 Model of total social cost

Based on the output of the individual decision model, i.e., the set of equilibrium path flows, we compute the social costs. Social costs include internal and external costs. When travelers estimate the cost of a trip, they will consider the internal costs that are discussed in detail in generalized cost functions as discussed in the Appendix. However, in this system, the whole society pays for the total costs.

### *2.4.1 System travel time and cost*

The consideration of travel time as a social cost is a significant issue. On a given road, everyone is assumed to travel at the same speed, but if n cars are on the road, everyone moves slower than if the number is only $n\text{-}1$ cars. Thus, the addition of an $n$th user imposes additional travel time on all $n$ users because of the reduced speed. This concept of an increase in travel time for all travelers resulting from an increase in the number of vehicles using the road is called "marginal travel time" for the $n$th car. Therefore, this difference between marginal travel time and average travel time for the $n$th car is an external cost affecting the transportation system. As we mentioned that the whole society pays for the total costs, therefore, we use the total travel time to evaluate the performance of transportation policy. The path travel time includes that time walking to access the transportation mode he/her choice (access walking time ), that time waiting for that mode (waiting time), that time travel in/on the mode (line-haul time), that time of parking (parking time), and the time walk from parking place to his/her destination (distribution time). The formulation of system travel time is Equation 2.

$$STT = \sum_m \sum_p (PTT(m)) \times (N(m)) \tag{2}$$

Where STT presents system travel time, PTTT presents path travel by using mode m, and N(m) presents the number of passengers using mode m. The path travel cost includes the cost to have that right to use that mode (initial cost), the cost to use the mode, and the parking fee. The formulation of system travel cost is Equation 3

$$STC = \sum_m \sum_p (PTC(m)) \times (N(m)) \tag{3}$$

Where STC presents system travel cost, PTC(m) presents path travel cost by using mode m, and N(m) presents number of passengers using mode m.

### *2.4.2 Air pollution cost*

Most pollution, such as air pollution, affects non-road users as well as road users, whereas travel time and travel fuel costs primarily affect road users. Road transport is responsible for the emission of most of urban air-pollution: carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NOx), which are produced by internal combustion engines. In addition, transport is also a major contributor of sulfur oxides (SOx) and particulate matter with a diameter of less than 10 μm (PM-10) emissions [EPA in Taiwan, 1993].

This research takes a macro-scale approach (start-up and hot soak emission are, therefore, disregarded). For the case we discussed in this paper is a simplified city of Taipei, and in Taipei, 95% of Taipei's air-pollutants and 99% of CO come from motor vehicles. Therefore, here we particularly focus on carbon monoxide (CO) emissions as an example to illustrate the process of incorporating air pollution concerns into transportation projects. We examine CO emissions using a version of the TRANSYT 7-F model [Mayeres, et al., 1996], which determines total vehicle emissions over any path. The general form of this model is

$$ROP = \frac{A \times e^{B \times v}}{C \times v} \tag{5}$$

Where ROP presents the rate of pollutant production (unit: g-vehicle/ft). v presents the average wehicle velocity. A, B, and C are parameters. The research presented in this paper applies Equation 5 to estimate CO emissions. Equation 5 is applicable for estimating CO emissions, hydrocarbon (HC) emissions, and nitrogen oxide (NOx) emissions.

### *2.4.3 Other social costs*

Some other costs that might be included in the social costs are road landing, noise pollution cost, water pollution costs, accident costs, incident delay costs, global climate change costs, amenity costs, and other social costs. However, in this research, we consider only CO emissions to demonstrate how to include the pollution costs in the cost accounting. These other costs are completely discussed in [Qin, et al., 1996] and the computation process can be found in [Mayeres, et al., 1996]. To keep the scope of research manageable, we do not consider these costs here.

## 3. CASE OF ALS IN SMALL CITY

This section applies the model developed in Section 2 to a case to estimate the system impacts of area licensing scheme (ALS). We simplified Taipei's transportation systems as a five-hub network system to be our study case. Based on this transportation network, we analyze ALS area licensing scheme for this simplified Taipei city which changes the cost of using roads for private vehicle users.

### 3.1 Structure a simple city

To illustrate the results of model of this research, we modify Taipei City into a simple city and use this simplified city as our case. Based on geographical and functional considerations, we partitioned the greater Taipei municipalities into five major transportation hubs (Figure 3). These five hubs, Center, East, North, West, and South are defined in Table 1. Table 2 shows the surfaces that connect these five hubs in terms of the number of lanes.

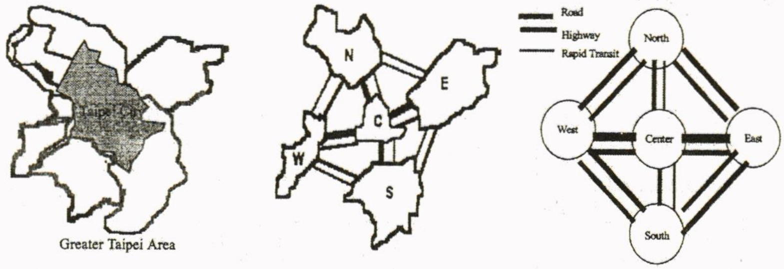

Figure 3 Five-Hubs Partitioned Taipei City Map

Table 1. Transportation Area Partition

| Transit hubs | District Area |
|---|---|
| Center | Chungcheng, Taan, Tatung, Sungshan, Wanhua, Hsinyi, Chungshan |
| East | Keelung, Hsinchih, Nankang, Haulien, Neihu |
| North | Tamshui, Shihlin, Peitou |
| West | Sanchung, Lunchou, Panchiao, Hsinchu, Taouan, Hsienchuang, Shulin |
| South | Wenshan, Yunho, Tucheng, Hsintien, Chungho |

Table 2. Surface for Taipei City (unit: lane)

| From/To | To/From | Roads | Highway | Rapid Transit |
|---|---|---|---|---|
| Center | East | 24 | 6 | |
| Center | North | 16 | | 1 |
| Center | West | 26 | 6 | |
| Center | South | 28 | | 1 |
| East | North | 2 | 4 | |
| East | South | 2 | 6 | |
| North | West | 4 | 4 | |
| West | South | 10 | 4 | |

Source: aggregated based Taipei street map and DOTSI report from Bureau of Transportation, Taipei City government, 1996

This research focuses on the traffic situation during the morning peak hour period (from 7:00 a.m. to 9:00 a.m.), therefore, most data and results are limited to this period. During the workday's morning peak hours, simplified Taipei city has an average travel demand of 699,300 personal trips. In this research, we assume that there are 10 income classes, three types of transport surface: local road, highway, and rapid transit rail; and five kinds of transport modes: motorcycle, car, bus, taxi, and rapid transit.

From the survey, we determined most of parameters we need for cost function in Equation (3) and algorithm Equation (4). At the same time, we assume a set of initial intangible cost for income levels and modes. Then plug these data in and keep modifying the intangible cost until equilibrium traffic flows show the mode usage close to empirical data. Table 3 shows that intangible costs after model calibration. From now on, the set of intangible costs is fixed during the policy scenario analysis.

Table 3. Intangible Costs for income levels and modes (unit: NT dollars)

| Income Level | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| | High | | | | | | | | | Low |
| Car | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Taxi | 12 | 10 | 8 | 6 | 4 | 2.5 | 2 | 0 | 0 | 0 |
| Transit | 14 | 11 | 8 | 6 | 4 | 2.5 | 2 | 0 | 0 | 0 |
| Bus | 15 | 12 | 9 | 7 | 4.5 | 3 | 2.5 | 1 | 0.5 | 0 |
| Motorcycle | 20 | 15 | 12 | 8 | 6 | 5 | 3.5 | 1 | 0.5 | 0 |

Table 4. Basic traffic results for Taipei City

| Total passengers | 699,300 | | | | |
|---|---|---|---|---|---|
| | Motorcycle | Car | Taxi | Bus | Rapid Transit |
| Empirical Passenger % | 34.23% | 24.44% | 8.42% | 32.91% | |
| Target Passengers % | 33.50% | 24.00% | 8.00% | 30.50% | 4% |
| Passengers % after calibration | 33.18% | 23.97% | 8.38% | 30.59% | 3.88% |
| Number of vehicles | 210,940 | 111,725 | 39,065 | 5,348 | 78 |

Table 4 shows the basic traffic parameters of our model based on current data from Taipei City [Taipei Municipal Government, Bureau of Transportation, 1996] and [Taipei Municipal government, Department of Budget, Accounting and Statistics, 1996], including the percentage of transport-mode distribution and vehicles. Empirical data are collected from the real situation in 1996. However, there was not rapid transit system at the time. Therefore, in order to consider the passengers for rapid transit, we set a modified mode distribution as a "target" for the calibration process. The stop criterion for the process of calibration is the error of mode distribution less than 1%. The result of calibration shows that motorcycle riders are the largest percentage of total travelers, 33.18%, and bus passengers are the second largest percentage, 30.59%. Private car users and taxi users are respectively, 23.97% and 8.38%. Rapid transit passengers are only 3.88%. Regarding the number of vehicles: 210,940 motorcycles, 111,725 cars, 39,065 taxis, 5,348 buses, and 78 rapid transit vehicles are in use in simplified Taipei city during morning peak hours.

Table 5 shows the social impacts of our baseline case. The total travel time is 372,700 people-hours, in other words, during morning peak hours, the average traveler spends 0.53 hours to commute. The network cost, which includes all the tangible and mode-aversion costs except the travel time cost, is 968,160,090 NT dollars for the whole system, and on average every traveler spends 138.4 NT dollars to make the trip. This baseline case serves as a benchmark for the case study.

Table 5. Social impacts of the baseline case

| | Total | Per person |
|---|---|---|
| network travel time [people-hour] | 372,700 | 0.53 |
| network monetary cost* [NT$] | 54,713,310 | 78.3 |
| network cost* [NT$] | 96,816,009 | 138.4 |
| CO emissions [gm] | 1,990,696 | 2.84 |
| network average line-haul speed [km/hr] | | 33.15 |
| average line-haul speed to CBD [km/hr] | | 28.67 |

## 3.2 Area Licensing Scheme

We want to understand the traffic situation and social impacts when an area licensing scheme (ALS) is applied to the central business district (CBD) in simplified Taipei city. In the area licensing scheme, drivers are charged when they enter a certain area (in most cases, the CBD).

### *3.2.1 Policy Scenario*

We assume that private car and motorcycle travelers have to pay a license cost to enter the central business area during the peak hours. We also assume that the parking fees in the central area have been abolished and that the area license for cars and motorcycles costs is set at what used to cost. For those travelers whose destination is the CBD and who use cars or motorcycles, the ALS should not result in a significant change in cost. Those travelers who pass through the CBD during the peak hours will have an additional travel cost. This additional cost could push them either to switch to other transport modes or to take a longer path to bypass the CBD. We also assume that taxi, bus, and rapid transit are not affected by this policy directly (but could be affected indirectly.)

### *3.2.2 Simulation results*

Table 6 shows how the transport-mode distribution affected by the ALS. The number of motorcycle and car travelers is reduced by 15.25% and 2.9%, respectively, and they mainly switch to taxis and buses. When facing the chance of taking a longer path to bypass the CBD or using other transport modes to pass though the CBD, some of the higher-income motorcycle travelers switch to taxis because taking taxis on highways saves much time. Lower-income motorcycle riders, instead of taking a longer path, switch to buses because the cost of using the bus is lower than the additional license cost for motorcycles. The ALS has a secondary effect on rapid transit travelers. Their number is reduced by 8.7% because congestion on local roads to the CBD is mitigated, which causes more travelers to switch from rapid transit to road-system vehicles.

Table 6. Travelers redistribution by the impact of area licensing scheme

| Transport mode | Baseline case | Area licensing scheme | Percentage change |
|---|---|---|---|
| Motorcycle | 33.18% | 28.12% | -15.25% |
| Car | 23.97% | 23.27% | -2.90% |
| Taxi | 8.38% | 10.39% | 23.98% |
| Bus | 30.59% | 34.67% | 13.34% |
| Rapid Transit | 3.88% | 3.54% | -8.70% |

Table 7 Social impacts by the area licensing scheme

| | ALS |
|---|---|
| network travel time | 1.88% |
| network cost | -0.16% |
| CO emissions | -5.55% |
| network average line-haul speed | 2.26% |
| average line-haul speed to CBD | 7.63% |

Table 7 shows that the ALS would be a very effective policy in speeding up the mobility to the CBD and reducing the network's CO emissions but network travel time could increase. The average line-haul speed to the CBD increases by 7.63% and CO emissions are reduced by 5.55%. Travelers who switch from motorcycles to taxis increase congestion somewhat on the highways, but substantially reduce congestion on local roads. The network travel time increases by a small amount because access and distribution time are much shorter for motorcycles than for taxis and buses. The network cost is not changed substantially because the monetary cost for using other transport modes is higher but the mode-aversion cost for motorcycles is higher than for other transport modes. The ALS favors taxi drivers and the bus system because it encourages more passengers to use these two transport modes.

### *3.2.3 Discussion*

Singapore, in 1975, introduced an area licensing scheme to reduce traffic to the central business district during morning peak hours. Drivers are required to purchase a sticker in advance if they want to enter the CBD during the peak hours. This city has updated the ALS over the years and has also introduced many new technologies (e.g., an electronic road pricing technology) to support this scheme. The initial result of ALS back in 1975 has been a significant improvement in traffic: private car traffic has been reduced by 70%; morning emissions levels in the CBD have been lowered by 30% [MacRae, 1994]. However, the benefits of the area licensing scheme have been challenged by some researchers. Wilson (1988) argues that when the costs of rescheduling travel and the time spent purchasing the licenses (permits) are taken into account, the area licensing scheme may cost society more than it recovers from the scheme's benefits [Wilson, 1988].

To implement the area licensing scheme, the government has to provide properly planned alternative transport modes for travelers at an acceptable price and service level. Otherwise, the ALS may force businesses to move out of the central business district. This decentralization would damage the economy of the CBD and would also potentially increase transportation demand [OECD, 1995].

## 4. CONCLUSIONS

This research developed a model integrates transportation and transport-related impacts that is designed to aid transportation planners in evaluating alternative transportation policies. By considering a boarder range and quantifying impacts of transportation policies on urban issues, planners are be able to develop better policies that will improve the traffic situation and urban living quality.

Our approach provides support to transportation decision-makers before they implement a transportation policy. The model we used in this paper is a simple but real-word manageable approach for the multiclass-user and multi-mode traffic system. Based on a few reasonable assumptions, we developed a simple computation process and allowed the travelers simultaneously to select path and transport modes. This process also provided guaranteed results in terms of existence and uniqueness.

Our approach also explicitly includes most important costs of system. The results of this research demonstrate the model's ability to predict the transportation situations and transportation-related social impacts. This model readily allows researchers to test most of the transportation policies (for example, fuel price policies, parking/toll policies, and transit fare policies) by configuring a few parameters.

Another difference between our approach and other studies is that our approach considered a more realistic structure of cost function. Most studies consider of the tangible costs only (may be partially). Our approach not only includes most of tangible costs but also quantifies intangible cost as a mode-aversion cost. There are several discussions on the process of quantitative intangible. The set of intangible cost is not unique from the process of model calibration. Different sets of intangible costs maybe result in different generalized cost functions. However, the change in the policy impacts still in the same direction. For the purpose of understanding the change and rough scale of policy impacts to decision-makers need, this estimation of tangible cost could provide enough information.

Extensions of the current research will improve the quality of support that our model can provide. When the model is applied to long-term predictions, it should incorporate an elastic travel demand function. The travel demand we assumed in our research is fixed, but for more realistic situation, when a longer period in considered and travelers can change houses or jobs, the travel demand should become a function of generalized cost. On the other side, the model of social costs could be modified to calculate the social cost and benefit in advance.

## REFERENCES

Aashtiani H. Z. and Magnanti T. L. "Equilibria on a Congested Transportation Network," **SIAM Journal, Algebraic and Discrete Methods,** Vol. 2, pp. 213-226, 1981.

Abdulaal M., and LeBlanc, L. J. "Methods for Combining Modal Split and Equilibrium Assignment Models," **Transportation Science, Vol. 13, No. 4,** pp. 292-314, 1979.

Beckmann M., McGuire, C. B. and Winsten, C. B., **Studies in the Economics of Transportation,** Yale University Press, New Haven, Connecticut, 1956.

Birk, Mia Layne and Zegras, P. Christopher **Moving Toward Integrated Transport Planning: Energy, Environment, and Mobility in Four Asian Cities**, International Institute for Energy Conservation, March 1993.

Chu, Chih-Peng, "A Decision Support Model for Transportation Policy and a Case of Taipei City," Ph. D. Dissertation, Stanford University, 1997.

Chu, Chih-peng, Lin, S. D. and Lin, C. H. "An Estimation of Intangible Cost for Commuters and its Policy Application," **Transportation Planning Journal Quarterly, Vol.29, No.4,** pp.863-882, 2000.

Dafermos, S. C., "The Traffic Assignment Problem for a Multiclass-User Transportation Network," **Transportation Science, Vol. 7,** pp. 73-87, 1972.

EPA in Taiwan, **The Annual Assessment Report of the Air Pollution Control in Taiwan Area For 1993**, EPA, Executive Yuan, Taiwan, R.O.C., 1993.

Florian, M. and Nguyen, S. "A Combined Trip Distribution Modal Split and Trip Assignment Model," **Transportation Research, Vol. 12,** pp. 241-246, 1978.

Florian, M. and Nguyen, S. "An Application and Validation of Equilibrium Trip Assignment Methods," **Transportation Science, Vol. 10, No. 4,** pp. 374-389, 1976.

Florian, M., "A Traffic Equilibrium Model of Travel by Car and Public Transit modes," **Transportation Science, Vol. 11, No. 2,** pp. 166-179, 1977.

Greene, David L. and Fan, Yuehui "Transportation Energy Intensity Trends: 1972-1992," **Transportation Research Record, Vol. 1475,** pp. 10-19,1995.

Lam, William H. K. and Huang, Hai-Jun "A Combined Trip Distribution and Assignment Model for Multiple User Classes," **Transportation Research, Vol. 26B, No. 4,** pp. 275-287, 1992.

LeBlanc, L. J. and Abdulaal A., "Combined Mode Split-assignment and Distribution-mode Split-assignment Models with Multiple Groups of Travelers," **Transportation Science, Vol. 16, No. 4,** pp. 430-442, 1982.

MacRae, K. Morgan, **Transportation Demand Management: A Policy Challenge**, Canadian Energy Research Institute, 1994.

Mayeres, Inge, Ochelen, Sara and Proost, Stef "The Marginal External Costs of Urban Transport," **Transportation Research, Vol. 1D, No. 2,** pp. 111-130, 1996.

OECD, "Sustainable Transport in Central and Eastern European Cities", **Proceedings of the Workshop on Transport and Environment in Central and Eastern European Cities,** Organisation for Economic Co-operation and Development, June 1995.

Penic, M. A. and Upchurch, J. "TRANSYT-7F: Enhancement for Fuel Consumption, Pollution Emissions, and User Costs," **Transportation Research Record, Vol. 1360,** pp. 104-111, 1992.

Philpott, Julia and Boyle, Stewart **Integrated Transport Planning: A Central and East European Perspective,** International Institute of Energy Conservation, Washington D.C., May, 1994.

Qin, Jiefeng, Weissmann, J., Euritt, M. A. and Martello, M. "Evaluating the Full Costs of Urban Passenger Transportation," **Transportation Research Record, Vol. 1518,** pp. 57-64, 1996.

Sheffi, Yosef, **Urban transportation networks: equilibrium analysis with mathematical programming methods,** Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1985.

Taipei Municipal Government, **Integrated Transportation Systems Analytic and Planning Model (DOTSI) and Its Application to Taipei Municipality,** Project Report, Bureau of Transportation, Taipei City Government, 1996.

Taipei Municipal government, **The Statistical Abstract of Taipei Municipality 1996,** Department of Budget, Accounting and Statistics, Taipei Municipal Government, Republic of China, 1996.

Wardrop J. G., "Some Theoretical Aspects of Road Traffic Research," **Proc. Inst. Civil Engineers, Part II, Vol. 1, No. 2,** pp. 325-378, 1952.

Wilson, W. Paul, "Welfare Effect of Congestion Pricing in Singapore," **Transportation, Vol. 15,** pp. 191-210, 1988.