A Simulation Model for Managing the Parking Systems of Kaohsiung: A System Dynamics Approach

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ABSTRACT

This paper tries to develop a simulation model for managing the parking systems for the city of Kaohsiung. The system dynamics methodology is employed to formulate the model. The causal structure is compartmented into five sectors: (1) the urban activity/travel sector, (2) the modal split sector, (3) the parking sector, which comprises parking supply and parking demand subsystems for both curb and off-street parkings, (4) the traffic/parking interaction sector, and (5) the financial management sector, which attempts to develop causal links between the revenue sources and expenses of the parking system. The model provides the city administrators a policy lab for parking systems management.

INTRODUCTION

Every automobile trip begins and ends with the storage of the vehicle. Therefore, parking becomes an integral part of the urban transportation system. Conventional urban transportation planning efforts emphasize on the provision of adequate moving and storage facilities for the travelers so that their desired activities could be accomplished conveniently. However, the provision of ample roads and parking spaces attracts increasing automobile usages, which in turn leads to the construction of more roads and parking spaces; and the cyclical process goes on and on. Due to the immensity of current urban transportation problems, ranging from congestion to environmental issues, various new approaches to reduce the adverse effects of automobile travel have been proposed. Many of these policies advocate measures which encourage shifts from auto to more efficient transportation modes, such as public transportation, rather than the traditional solution of increasing highway capacity and enhancing parking availability (Witheford 1972). However, these policies evoked considerable controversy and disagreement among planners, transportation engineers, public transit officials, business interests, politicians, and the public. The variety in the applications of parking management strategies in different locations and development stages and the broad range of interest groups affected make parking management a complex and sensitive issue (Parker 1980).

In this paper, we attempt to employ the system dynamics approach to examine the problems, understand the behaviors in the complex system, and formulate a causal structure which will help the evaluation of some of the potential parking management strategies.

THE PARKING PROBLEMS IN THE CITY OF KAOHSIUNG

The city of Kaohsiung, a big industrial and commercial port city in southern Taiwan, has been growing rapidly during the last three decades. At present, the population exceeds 1.3 millions and the container transhipping is ranked number four in the world. Yet like many other cities in the world, Kaohsiung now faces various problems in her rapid development process. The traffic and parking problems in the central business district (CBD) are among the most serious.

People in Kaohsiung used to be proud of their transportation facilities: the streets are much wider than those in most of the other cities in Taiwan and has a reasonably convenient bus transit network. In the 70's, although vehicular travel grew with the increased population, average family income, and other industrial, commercial and land use activities, the transportation systems accommodated the travel demands adequately in general (Kaohsiung 1984). However, during the last five to six years when the family income increased to a certain level, the automobile ownership started to grow at an accelerating rate, which consequently brought more and more automobiles on the roads.

With the wide streets, the traffic, although crowder than before, is still not as congested as many of the other big cities in the world. However, the CBD area does not have enough spaces to accommodate the massive flow of traffic and parking demand. In order to solve the parking problem, the city government invested multimillion dollars to build a ten-story parking garage in the Yen-Cheng District. However, the utilization rate of the garage has never been over 40 percent of its capacity. There are two major reasons for the underutilization: (1) almost all the other parkings around this garage, either on-street or off-street, are provided free to the public, and (2) the CBD area has been shifting gradually from Yen-Cheng District to its adjacent Shin-Shin District. On the other hand, the insufficient budget allocated to the management needed for the parking violation enforcement has resulted in very serious illegal parking problem, which further deteriorates the traffic condition. A recent survey conducted by the authors shows that over 97 per cent of the parkings are provided free. The problem of parking violations is very serious, varying from opposite parking to double or even triple parking, but less than 4 per cent of the violations received tickets. With the increasing population and vehicle ownership, the parking problems in Kaohsiung's CBD area will be more severe and proper parking management strategies are badly needed.

THE NEED OF SYSTEM DYNAMICS APPROACH

During the past decade, attitudes toward urban growth, environmental protection, energy conservation, social responsibility, and taxes to support public transportation programs have noticeably changed. In response to the problems created by the reliance on auto travel, many planners are now concentrating on a unified transportation management approach which addresses all elements of the urban transportation system. Parking, being one of the most important sectors in the urban transportation system, should gain more attention in the transportation planning process. This is due to the fact that parked vehicles are easier to control than moving vehicles (Parker 1980).

The parking problems in Kaohsiung do not stand by themselves, they should be treated from a systems point of view. That is, the solutions to the problems should be assessed not on each individual part but on the performance of the entire system. Thus, the potential parking management strategies should be evaluated not only by their contributions to the parking and transportation sectors but also with the considerations of their social, economic, and environmental impacts to the city of Kaohsiung. The complex, dynamic, and feedback features of the system merits a system dynamics approach to address the problem.

THE MODEL

A simplified causal diagram of the model is presented in Figure 1. To ease the discussion of the model, the diagram is divided into five sectors: (1) the urban activity/travel sector, (2) the modal split sector, (3) the parking sector, (4) the traffic/parking interaction sector, and (5) the financial management sector. These sectors are briefly discussed in the following sections.

The Urban Activity/Travel Sector

Travel demand in an urbanized area is influenced primarily by its population, the mobility provided by its transportation systems, the income level of the people, and its attractiveness in various aspects. The attractiveness of the area will be reduced with increasing population density, crime rate, traffic congestion, and air and noise pollution. As the level of income increases, vehicle ownership increases accordingly for the improvement of mobility. In most of the cities, social and commercial activities are concentrated in the CBD area which absorbs and produces a great amount of trips. However, since the available space in the CBD area is limited, the concentration of traffic and parking demand causes a lower accessibility of the area which in turn reduces the mobility and discourages travel to the area. In this study, trips are stratified as work-trip and non-work-trip. The attributes of these two types of trips make their travel and parking demands quite different from each other.

Modal Split Sector

Trips attracted to the CBD area are then splited into different modes of travel. In this study we assume two types of modes: transit and automobile. The choice between transit and automobile depends upon their utilities to the travelers. The primary factors of concern are the costs spent on the trip and the level of service (L.O.S.) of the choosen mode. The costs include both the monetary costs and the times spent for the trip.

The monetary costs associated with the use of an automobile include the operating expenses and the out-of-pocket costs spent on the trip and for parking the car. The time costs consist of three parts: the on-vehicle travel time, the time spent for parking, and the walking time to the final destination. The time spent for searching a parking space increases with the diminution of the availability of parking, which is reflected in the model by the parking demand to supply ratio in the CBD area.

To transit riders, the only monetary cost is the fare. The time costs

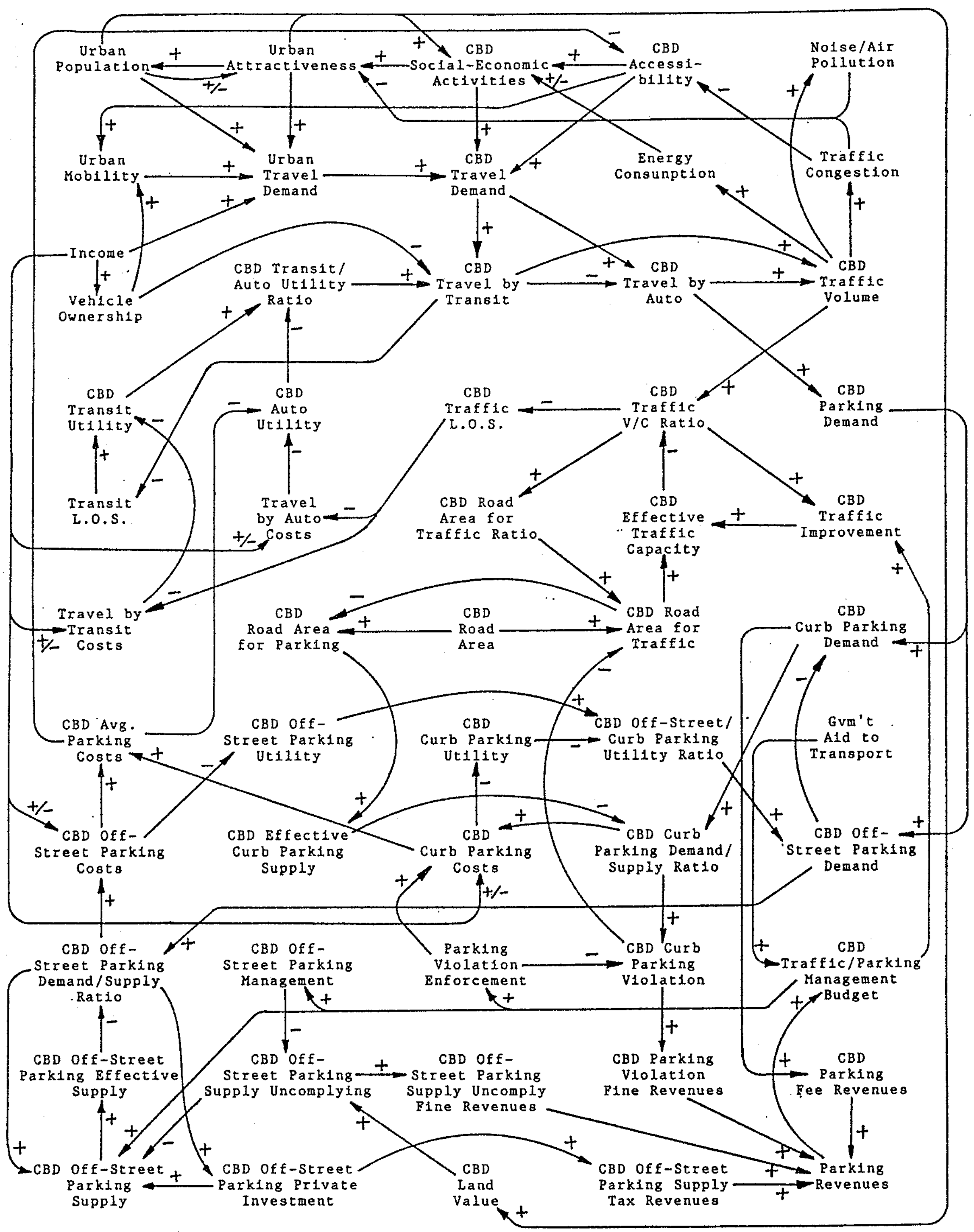

Figure 1. A Simplified Causal Diagram of the Model

include the walking time from the origin to the station, the time for waiting the transit, the on-vehicle travel time, the time for transfer, and the walking time to the final destination. In addition to the monetary and time costs, the level of crowdness of the transit is also an important factor to transit riders. When the level of crowdness rises above certain limit, the utility of transit is reduced, which leads to lower transit ridership.

On the other hand, when more trip makers are shifted from transit to automobiles, the total amount of vehicular trips grows rapidly, which results in traffic congestions and consequent increases in the monetary and/or time costs for both the transit and the automobiles. It should be mentioned that in this model, all the cost-related variables are adjusted by the level of income in the study area. Since the cost variables are the composition of the time costs and the monetary costs, the adjustment to the time cost and the monetary cost are positive and negative, respectively. This is because people of higher income level tend to have higher perceived value of time and lower perceived value of money.

The split of modes applies only to the "choice riders", those who can choose between automobile and transit. To those who do not have a choice, they are captive to the transit, so called "captive riders." Thus, in the model the automobile ownership is used to adjust the shares of trips taking transit and automobile. The number of automobile trip makers is translated into the number of automobile trips through the vehicle occupancy rate assigned. The number of automobile trips generated in this sector are then used to estimate the parking demand in the next section.

The Parking Sector

The parking sector consists of the supply part, the demand part, and the choice part. The capacity of parking supply depends on the parking spaces being provided and the average lengths of stay. In this study, parking spaces in a CBD area include: (1) curb parking, (2) off-street parking garages operated by the government, (3) off-street parking garages operated by private companies, and (4) off-street parking required around or at the basement of buildings. The curb parking spaces may be constrained by parking prohibition or restricted parking period. In addition, the efficiency of parking management affects the availability of effective parking spaces. The off-street parking required at each building may be illegally used for other purposes, which will force the designated users to use curb parking instead. For the off-street parking operated by either the government or the private firms, the space increases with the rate of new parking garage construction and decreases with poor maintenance.

Parking demand is defined as the accumulation of vehicle parked at a given time as a result of activities at a given site. These may be maximum accumulations during the average day of the week, or during the peak season of the year. Irrespective of when they occur, parking accumulations result from interactions between three traffic variables: the total daily trips attracted, the time pattern of arrivals, and the average lengths of stay (Witheford 1972). In this study we are more interested in the parking demand during the peak period in CBD. Thus, the CBD automobile trips generated from the modal split sector are translated into the CBD peak parking demand according to an assumed pattern of arrivals and the lengths of stay in the study area.

To simplify matters, auto trip makers are given two choices, either park in an off-street garage or park on the streets. The choice is made according to the costs spent for parking and the parker's socioeconomic characteristics. The costs spent for parking consist of the monetary costs of parking, the time spent for searching a parking space, and the walking time from the parking lot to the final destination. The monetary costs for parking include not only the parking charges but also the average fine for illegal parking. When parking violation enforcement is enhanced, the costs of CBD curb parking increase, which lowers the utility of curb parking. The time spent for searching a parking space increases as the availability of parking spaces, which is represented by the reciprocal of the demand to supply ratio, decreases.

Traffic/Parking Interaction Sector

Streets in cities are used as a facility to provide spaces for moving and storing vehicles. Since road area in the city is limited, the sharing counterparts compete with each other when their demands exceed a certain level. In the model, the CBD road area is divided into road area for traffic and road area for parking according to a certain allocation ratio. The ratio is usually adjusted by the current level of traffic demand. Thus, when the traffic volume increases to a certain level, curb parking supply usually decreases due to the elimination of curb parking spaces or the shortening of the allowable parking period. Curb parking influences road traffic not only for the narrowing streets, but also for the disturbance of illegal parkings which either block the sight distance at the intersections or interrupt the traffic flow when parallel parking is undertaken. In the city of Kaohsiung, many parkers used to park their cars perpendicular to the curb, which further reduces the available road area for traffic.

Financial Management Sector

The model attempts to develop causal links between the revenue sources and expenses of the parking system. The revenue sources consist of (1) the parking fee revenues, which increase with the volume of parking, both curb parking and the off-street parking operated by the government, and the average parking fee being charged, (2) the parking violation fine revenues, which increase with the number of parking violation and the amount of fine, (3) the off-street parking supply uncomplying fine revenues, which increase with the amount of fine and the number of required off-street parking spaces being illegally changed to other usages, and (4) the tax revenues collected from the privately owned parking garages, which increase with the tax rate and the amount of parking spaces.

The collected revenues, coupled with government aids, are the source of the budget for (1) the construction of new parking garages in CBD, (2) the installation of curb parking meters, (3) the operations and maintenance of the existing parking facilities, (4) the capital investment in parking enforcement facilities, (5) the management for the control of illegal usage of the required off-street parking spaces, and (6) other parking related traffic control and management.

POLICY ANALYSIS

There are two major concepts of parking management. In one concept, parking management strategies are designed to provide adequate spaces for vehicles. In the other, parking strategies are employed to limit traffic in the CBD area (Parker 1980). From a unified systems management point of view, parking management strategy is a measure taken to alter the supply, operation, and/or parking demand of an area's parking system to facilitate the attainment of local transportation, economic, environmental, and other objectives (Direnzo 1979). Thus, it is inappropriate to adopt any one concept for a given area as the choice of a parking policy.

In this study, parking management strategies are grouped by various parking related problems. The potential parking management strategies are selected according to the associated problems and then tested to examine their effectiveness in the system. The following sections discuss these potential parking management strategies, the conditions under which they may be applied, and the associated model parameters need to be changed.

As mentioned previously, over 97 per cent of the curb parking spaces in the city of Kaohsiung are provided free. If this privilege continues, and judging from the growth trend of auto ownership in Kaohsiung, one may easily foresee a sharp increase in automobile trips in the near future. The installation of parking meters will increase the cost of curb parking and lower the utility of automobile trip-making. In the model, the strategy is played by adding the parking meter fee to the monetary cost of curb parking. The output of simulation shows that some of the trips shift to transit and some of the curb parkers switch to off-street parking. As a result, parking revenues are increased. In practice, the installation can be done by stages according to the demand to supply ratio in the system. In addition, parking surcharges can be conducted in congested areas.

In some of the congested areas, elimination of curb parking is a commonly used strategy to increase the road area for traffic. In this model, the elimination is performed through raising the ratio of the CBD road area for traffic. The elimination can also be conducted for the peak periods by shortening the allowable parking time. The increased hardship on parking in CBD will reduce the utility of curb parking and consequently the utility of CBD automobile trips, hence the attractiveness of the CBD area is reduced. In the mean time, however, the increased road area for the traffic raises the utility of auto trips and attracts more auto trips to the CBD area, if other parking spaces, such as off-street parking, are available. In the simulation the demand of off-street parking increases rapidly which results in an increases of the tax revenues from the privately owned garages and the parking fee revenues from the government operated garages. Since the consequence of increasing auto trips hinders the attainment of the proclaimed goals of energy conservation, environmental protection, and transportation efficiency, various strategies aimed at discouraging the auto travel, especially those single-occupancy-auto trips, are played as supporting actions to this strategy. These actions include establishing reserved parking for high-occupancy vehicles, raising all parking fees, increasing the parking costs for single-occupancy vehicles, carpooling and vanpooling programs, and other measures which improve the level of service of the transit system.

The survey conducted by the authors reveals the high percentage of illegal curb parking as well as the weakness of the parking regulation enforcement. The power of strict parking regulation enforcement patrol can be strengthened by increasing the budget for necessary manpower and equipment as well as by raising the amount of fine for parking violations. The increased revenues from parking violation fine serve as an important source of funds for improving enforcement patrol which reduces the number of illegal parking. However, the reduced number of illegal parkings will soon result in decreasing inflows from parking fine revenues. A complementary budget for parking violation enforcement should therefore be maintained.

Many of the traffic congestions during peak periods are largely caused by automobile work trips. A study by Shoup and Pickrell (Shoup 1980) shows that some of the pricing strategies designed to discourage the use of automobiles to CBD area have failed due to the parking subsidy from the employers. The strategies of short-term parking and late opening of parking are designed to reduce the available parking supply to the auto commuters. When implementing these strategies, transit service improvements or park and ride facilities along transit routes should be the supporting actions. For the retailing business, since most of the shopping trips occur during off-peak periods with short-term parking, these strategies lead to more efficient utilization of parking spaces.

Despite the raising costs of operation, high parking charges, and various transportation disincentives, all indications are that travel by private automobiles will continue to dominate transportation at least in the next two decades (USDOT 1976). To cope with this fact, the provision of proper amount of off-street parking spaces is still a necessity. In this model, revenues can be collected from various sources as discussed in the financial management sector. They are then contributed to a special parking fund which is then allocated to various usages, including the investment capital needed for the construction of multilevel parking garages. In the simulation, an appropriate allocation policy which matches revenues with the expenses of the system can be determined by trial and error method. The site of the new parking garages should be selected to meet the future parking demand.

The simulation model is designed in such a way that future scenarios can be generated for policy experimentation. For example: (1) an increase in urban population growth rate, which can be performed by raising the population growth factor in the model, (2) an increase of the level of income in Kaohsiung, which can be done directly by raising the income level in the model, and (3) the construction of a rail rapid transit system (the plan has already been proposed this year), which can be conducted through raising the utility of the transit system by a larger scale. However, owing to the very limited computer budget for this study, only the base case conditions are simulated.

CONCLUSION

In this paper, various parking management strategies are analyzed and tested, and their results are evaluated. Due to the difficulty in data collection and the relative limited experience about the causal relationships developed in this study, the model is still far from complete and meant to be illustrative rather than conclusive. Nevertheless, the causal structure established in this study does provide us a clear understanding about the complicated behaviors in the parking management system, which opens a door for further studies in this area.

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