PARKING TOWER SIZE DETERMINATION AND TRAFFIC IMPACT ANALYSIS

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abstract: Parking towers, while they may partially solve the parking problem, can also create some unwanted side effects. Therefore, there is much opposition against the construction of parking towers. How to eliminate the annoying side effects and obtain the benefits from parking tower construction is really a big issue for a city like Taipei to tackle. Thus, in this paper, we explore different parking characteristics, develop a parking tower operation simulation model, and apply the model to evaluate the optimum tower size for sites with various parking characteristics and types of parking towers.

1. INTRODUCTION

Buying a car today may not be so difficult for most people in Taipei. Finding a parking space, however, is really a nightmare. Nonetheless, owning a car for most people is highly desirable. If they have the economic capability, they will not give up buying a car. Therefore, the number of cars is continuously growing. Furthermore, most of the time, vehicles do not run on the street. Instead, they are motionless at the side of the road. Consequently, it is clear that sufficient parking space for vehicles is a necessity in a modern society.

Urban parking is a common problem in most developed and under-developed countries. Taipei, the biggest city and capital of Taiwan, is one example. It presently has a population of around 2.63 million and the number of vehicles registered is 0.62 million. Thus, on average, one out of every four persons owns a car. Privately-owned parking space, however, can accommodate only 79,300 vehicles. This means that more than 85% of vehicles do not have a regular parking space and need to be parked on the roadside. Unfortunately, roadside parking spaces, including those in alleys, can supply only approximately 0.24 million spaces. These figures show very clearly that parking demand is much higher than the available space. Illegal double parking or triple parking is not uncommon in the city. If cars from neighboring cities are taken into account, the severity of the parking problem in Taipei is not difficult to imagine.

The serious shortage of parking space results primarily from government and public unawareness of the importance for vehicle owners to own private parking spaces. Theoretically, general-purpose public parking is provided by government, while private parking should be provided by the private sector or individuals. However, people don't see the need to own a parking space when purchasing a car. Furthermore, to maximize profit, the land developer

always fully exploits the available land and provides as few parking spaces as possible. Supply of parking space consequently is always less than demand. People generally rely on government to provide parking spaces or simply park their cars on the street. In addition, the government has no vision and adopts no actions to prevent the inadequate parking situation from deteriorating further. Also, the poor parking space standard set in the building code has not been seriously reviewed.

For the already congested urban area, illegal parking makes the traffic situation even worse. To alleviate the traffic condition, parking enforcement and elimination of roadside parking are measures generally adopted. Regarding this situation, parking facility investment is very much encouraged in highly-populated areas. However, land resource in highly-developed urban area is extremely limited and is very expensive. It is just not easy to provide enough parking space either for public or private use.

To solve this problem, the city government enacted a provisional measure trying to stimulate parking investment from the private sector. This measure revises the original building ordinance and permits 36 meter-tall parking towers to be constructed in residential-zone areas using only 6 meter-wide alleys as access roads. This thoughtless measure has encountered great opposition from residents. The residents think the parking tower facilities won't solve the problem. They will only create even worse problems such as traffic congestion, air pollution, lack of safety and traffic noise, thus degrading the quality of life. Currently, the city government faces an almost complete failure of its parking tower policy. It seems to have begun with a bad start and ended with a worse outcome. But what lessons can we learn from this experience ? What is it people really need ? What can they afford ? What role should government play ? Addressing these issues may suggest some directions to be taken in formulating a parking policy and merit being carefully explored. In this paper, however, we will only focus on the parking tower impact and try to draw some conclusions for determining parking tower size.

2. PARKING TOWER POLICY RELATED ISSUES

Initially, the government tried to solve the parking problem by constructing parking towers. The policy is to supply more off-street parking spaces so as to rid the street of illegal parking. Once the illegal parking is eliminated, hopefully, the traffic situation can then be improved. However, this simple logic seems not to be workable. A great proportion of the general public does not agree with this idea. It is obvious that there exists a rather big gap between the government and the general public. Some arguments from the general public may be emotional. However, some are rational. This suggests that some related issues are necessary to be carefully examined.

To make things clear, it is helpful to evaluate the arguments scientifically. Through objective study and effective communication, the government, developer, and general public can reach a better alternative to solving the serious parking problem. In the following, some related arguments of the parking tower policy are discussed.

2.1 Policy Contradiction

The original purpose of the policy was to solve the public parking problem, not the private parking problem. Thus, based on the policy, all the parking tower spaces should be open to the public. They can not be sold to individuals. However, commercially, the policy is not profitable and is unfeasible. In fact, almost all the parking spaces are sold to individuals. This is inconsistent with the policy goal.

In business district where public parking demand is high, the land rent is far too high to permit a reasonable profit from parking cars. Simply running a parking business is no way to survive. Therefore, not many such facilities are built. On the contrary, in residential areas, where public parking demand is low, constructing a parking tower for private parking is more profitable. This is because land acquisition is far easier and less expensive. Besides, private parking demand in these areas is rather high. Consequently, most parking towers are built in residential areas, especially those areas needing to be renewed. This outcome obviously does not meet the policy goal and solves only a very few parking problems.

2.2 Parking Affordability

As stated above, parking towers are constructed mostly in residential areas. Accordingly, those who are directly affected by the parking tower operation include people living nearby and those parking on the adjacent roadsides. For those parkers, their major concern is the continuing right to park their cars on roadside without paying fees. Their expectation obviously doesn't coincide with the government's goal of trying to eliminate roadside parking and thereby improve the road traffic environment.

It was found from a home survey that more than 70% of cars pay no fees to park on the roadside. Also, 80% of drivers spend more than 5 minutes looking for a roadside parking space and 40% of drivers spend even more than 10 minutes. This data clearly shows that finding a parking space is not easy in residential areas. Nonetheless, residents don't have the desire to park their cars in a parking tower and strongly oppose the parking tower construction. Only 30% of respondents replied that they might use the parking tower facility. Closely examining the reasons, we find that money is the most crucial factor, specifically, an inability or unwillingness of people to pay the parking expenses. Therefore, constructing a parking tower accomplishes nothing and makes no sense to them. As they can not afford to own or rent an off-street parking space, they will still have to park on the roadside. If the government tries to prohibit roadside parking, they will face an even worse parking situation. This may be the actual reason that the strong protest continues. This also means that if residents can not afford to pay and park their cars inside a parking tower, the policy to solve the parking problem by constructing parking towers is in vain and not realistic.

This dilemma is particularly acute in Taipei. The parking towers are located mostly in areas needing renewal where land acquisition is much easier and land price is inexpensive. In general, people's ability to afford parking tower fees is also less in those areas. In addition, the

area activity is low. There is not much general-purpose public parking demand. This means that the government may be playing the wrong role. The government should concern itself with public parking only. The private parking problem should be left to residents themselves to solve. Furthermore, residents should have the freedom to choose the environmental quality they can afford. People would like to enjoy a good community environment. However, the premise is that they can afford it.

Even if people can afford it, there may still be the enforcement problem. People just don't want to pay to park. They always choose the cheapest way to own and operate a car. Besides, drivers don't walk far. Our survey reveals that 50% of drivers walk less than 5 minutes. This is also part of the reason that illegal parking prevails. On the other hand, if there is no difficulty in parking on the roadside, people may be indirectly encouraged to buy cars. Thus, a successful parking tower policy should take all these factors into consideration. The tower's site, size, and its market area should be carefully examined.

2.3 Negative Impact

A very high percentage of residents responds that parking towers will have negative impact on traffic, landscape, pollution, and security, etc. They don't believe that the parking tower can improve the community's living quality. Therefore, an objective study is needed. In the following, however, only the traffic impact will be described and explored.

3. TRAFFIC IMPACT STUDY

As mentioned previously, the parking towers are located mostly in residential areas. Here, they obviously will cause some negative impact. The "not in my backyard" sentiment is inevitable. People residing around the sites of parking towers are fighting these kinds of developments. The best way to communicate with residents effectively is to make all the impact crystal-clear. Thus, analyses of the traffic volume, time of waiting in line, and traffic conditions in the vicinity of the tower are a necessity.

3.1 Traffic Volume

Whether a parking tower will bring extra traffic to the area is the most important issue concerning the general public and frequently it is the chief focus of opposition to the tower. It is not absolutely certain whether the traffic will increase. This depends actually on who are the users of the parking tower. If the users are the residents who presently park their cars on the roadside, then there will be no increase in the traffic volume. It may even decrease traffic volume on some road sections. In this case, the parking tower really improves the parking and living environment. On the contrary, if the parking tower is used mostly by non-residents or it creates more parking demand due to an increase in car ownership because of the convenience of parking a car, then the traffic volume in the adjacent alleys should increase. Construction of

parking towers in this case, therefore, does not effectively solve the parking problem. Instead, it may make things worse. This is also the key point that people worry about. Therefore, whether or not the traffic volume increases due to parking tower construction is highly dependent on the additional parking demand generated.

If the government cannot prohibit roadside parking or residents can not afford to park their cars in the tower, then the most serious result may occur: the parking tower is fully utilized and the number of cars parked on the roadside remains largely the same. Of course, turn-around rate of a parking space plays a very important role in estimating the volume increase. The turn-around rate, however, is dependent on the site of the tower. If it is located in a purely residential area, the turn-around rate is low. Based on the data collected from the field, the rate is about 1.7. If it is located near a business center, the turn-around rate can be as high as 5.0. Knowing this information, we can estimate how much daily traffic a parking tower will attract. But the peak traffic is still unclear. It depends again on the parking tower location. The peak hour coefficient -- ratio of peak hour volume divided by daily volume -- in the residential area can be as high as 0.3 - 0.4. The peak hour coefficient of those towers near business centers, however, may be as low as 0.1. Those towers located in residential areas thus can generate daily volume approximately twice the total number of tower spaces available. The peak traffic can be roughly estimated as 40% of the spaces.

3.2 Waiting Lines

It is highly undesirable to have long lines of cars waiting outside a parking tower. However, such lines seem inevitable. In mechanical garages, vehicles do not move to the parking space under their own power, but rather are moved there mechanically. The problem with mechanical garages is their inability to accept surges of inbound or outbound traffic. Limited inbound capacity requires a large reservoir area to keep the cars off the streets. Mechanical garages generally provide satisfactory service only when the parking demand is relatively uniform throughout the day with no large peak flows. This may not be the case in general. In our experience, peak surges occur frequently. Consequently, long lines develop along the adjacent roadside during peak periods. This often results in nearby traffic congestion. Meanwhile, traffic hazards, traffic noise and air pollution increase. These negative impacts should be limited to a tolerable level.

Various types of parking towers are available in the marketplace. The elevator type and the rotary type are the most common types constructed in Taipei. To generate maximum profit from a small parcel of land, the developer generally builds two connected towers with only one ingress/egress. The builder tries to provide as many parking spaces as possible, but seldom takes the operation into consideration. As a result, in most cases, approximately 80 parking spaces (40 spaces for each tower) share only one ingress/egress. Although there are two sets of facilities, usually they are not operated at the same time. At any time, there is only one set in operation due to the spaces not being able to be assigned flexibly. Thus, to fully utilize the spaces, serious waiting lines can develop during peak periods. On the other hand, if an appropriate level of service (L.O.S) is to be achieved, the spaces will be greatly under-utilized.

This means a parking tower should not have excessive capacity. A proper size should be determined on the basis of real operation.

Factors affecting the waiting-in-line time include vehicle arrival rate and the parking tower service rate. The vehicle arrival rate can be estimated as mentioned in the previous paragraph. The service rate can be obtained directly from the site survey or calculated from the time needed for car positioning/withdrawing and mechanical operation. The time varies for operating mechanical facility and for drivers to position their cars and get out. Accordingly, different types of facility and driver will result in different service rate. The mechanical operating time can be obtained either from the manufacturer or from the field. To obtain the actual data, we have collected these data directly from the sites.

(1) Mechanical operating time

When parking a car, a driver positions his/her car on a plate and leaves the tower. Operator then operates the parking facility to put the car in a proper space. When withdrawing a car, operator first operates the facility and brings the car back to the car withdrawing room, where drivers can enter and drive their cars away. The mechanical operating time differs among various types of facility. For elevator-type facility, on average it takes 65 seconds to deposit a car and 77 seconds to withdraw a car. For the rotary-type facility, time to deposit and withdraw a car is the same. It takes 90 seconds for front tower operation and 140 seconds for rear tower. These times are longer than those given directly by parking tower developers. To be realistic, we have adopted data from the site as the input for our developed simulation model.

(2) Time for car positioning/withdrawing

Another important service-time element which contributes greatly to the operation efficiency is time for car positioning /withdrawing. Data observed from site reveals that a driver spends 40.6 sec in average to position a car. The associated standard deviation is 24.4 sec. To withdraw a car, a driver spends 39.6 sec on average and standard deviation is 27.1 sec. In this study, therefore, the service time is set on average as mechanical time plus 40 sec.

(3) Vehicle arrival rate

Parking characteristics vary with the location. The associated arrival rate, peak period, peak volume, and parking duration may have significant differences. Data collected from the public parking garages demonstrate that except for those in business areas, most parking facilities have peak periods lasting only 1 - 2 hours. Meanwhile, the associated peaking appears at different time periods.

During peak period, there is no necessity for all parking spaces to be full. However, considering the smoothness of operation and effective utilization of the limited spaces similar to those used in Japan, a tower fully loaded within 2 hours may be a good design criteria to be adopted. However, to better understand the associated impact, a variety of scenarios will be tested and analyzed.

Arrival distribution during peak period has great impact on length of the waiting line. The best situation occurs when vehicle arrival is uniform. In this case, the waiting time and line length is minimized. On the contrary, the worse case appears when all the vehicles arrive in a short period of time. These two extreme cases don't occur in the real world. From the site survey, it is found that inter-arrival time distribution can be modeled as Erlang distribution. Consequently, a uniform distribution may not be a good assumption for the study. To be realistic, we will try different scenarios and see how much the line length and waiting time can be changed.

3.3 Vehicle Operation

Since most parking towers are located in narrow alleys, it may be necessary to check the turning radius. If there is not enough space for cars to turn into/out of the tower, the alley will be blocked by car-parking operation. Obviously, this is wrong and unfair. Besides, it will create environmental problems. In this study, based on the design car concept, the minimum turning radius is set at 8 meters. Meanwhile, to ensure traffic safety, the minimum sight distance should be checked, too. Since the vehicle's operating speed in the alley will not be very high, probably less than 20 kph, we set it at 20 kph. The associated stopping sight distance is thus calculated and set at 18 meters. This figure will be used to check whether the sight distance is enough. If a parking tower has inadequate sight distance, suitable measures should be adopted to keep traffic safe.

4. CASE STUDY

Three towers located in the residential area are selected for study. In order to know better the area traffic characteristics, traffic volume at the related intersections and parking characteristics such as parking duration, peak parking and vehicle arrival and departure are surveyed. The survey data indicates that the traffic volume generated from a parking tower will not significantly affect the road operation. In the alley, traffic volume is low. On the neighboring arterial, traffic volume is high. In both cases, low traffic generated from a parking tower has no substantial impact.

The parking survey showed that the number of cars parking on the roadside didn't change much. The number was quite stable. The number of cars parking during the weekend was higher than that of weekdays. Most cars had very long parking duration. The turn-around rate was less than 2. This reveals that due to difficulty in finding a parking space, people own a car but try not to use it often. Without a private parking space, they just want to get rid of the headache of car parking. Since most cars are parked on roadside, it also implies people don't pay parking fees and maybe they can not afford them. In addition, it may suggest that complete prohibition of roadside parking is unfeasible and unacceptable.

Findings from the parking survey demonstrate that there is high parking demand even in

residential area. Nonetheless, people are against tower construction. One of the reasons is the negative environmental impact due to the long lines of vehicles waiting to park. To study this problem, a simulation model was developed. The simulation input includes hourly vehicle arrival (% of parking tower capacity), arrival pattern within an hour, distribution of car parking duration, the number of parking towers of the simulated site and the associated tower capacity, related service time such as mechanical operating time and car positioning/withdrawing times, and length of the simulation period, etc. The outputs include the average car parking duration, average waiting time, average number of cars in the waiting line, the maximum waiting time, and the maximum number of cars in the waiting line, etc. Applying the simulation model, we simulate the operations at selected sites. The results are summarized as table 1. It suggests that the proper hourly arrival in case 1, 2, 3 is around 40-50 veh/hr (35%-40% of the capacity), 30 veh/hr (20% of the capacity), and 16 veh/hr (20% of the capacity), respectively. If the towers are designed to be fully-loaded within 2 hours, the proper size of towers in cases 1, 2, 3 should be around 90, 60, and 30 spaces, respectively. This suggests that each access channel can serve not more than 30-40 spaces. Otherwise, a long line will result. A pair of towers (80 spaces) with only one access channel is clearly not appropriate, especially in residential areas. Unfortunately, this type of parking tower is rather common in Taipei and is the outcome of government ignorance. The tower builders follow the government's ordinances and try to design towers to maximize their commercial profit; that is, to have as many tower spaces as possible. As a result, these towers not only negatively impact the environment but also are not able to function well.

Based on the government's ordinances, it is legal to have a parking tower built only 2 meters distant from a 6 meter-wide alley. This is a common case in Taipei. As a consequence, vehicle access is not convenient. Room for vehicles to wait and to smoothly operate is extremely restricted and does not meet 8 meter turning-radius requirement. Many drivers must maneuver their cars back and forth in order to enter or leave the tower. This situation severely reduces the service rate and makes the waiting problem even worse. During peak periods, vehicles line up along the alley, block traffic, and create environmental problems. As for the sight distance, most cases are ok, though some are a little bit short. However, this can be improved by limiting the vehicle's running speed or installing a reflector.

There are difficulties in promoting mechanical parking facilities due to the unsolved negative impact. Parking tower policy currently is not acceptable and will be phased out. In the long run, to solve the parking problem, people should have their own parking spaces and not park their cars in the alley. With improvement in living standards, people will accept the necessity of and pay for off-street parking. Accordingly, parking towers may still be a good alternative to be carefully reconsidered in the future.

Negative impact results mostly from the improper size of parking towers. Meanwhile, people don't walk further than 300-500 meters. Too many spaces for each tower thus is not environment-friendly and does not meet market demand. Consequently, to minimize the impact, the best way may be to reduce the tower size when it is commercially feasible to do so.

5. LESSONS FROM THE STUDY

Lessons learned from the case study are summarized as follows:
(1). The traffic generated from a parking tower seems not able to have significant impact on local area traffic operation.
(2). It is not reasonable to build a big size parking tower without good access channels. A good size is approximately 30 spaces per access channel. The tower size currently in Taipei is mostly around 80 spaces per access.
(3). Enough room for vehicles to wait and maneuver is necessary and should not be ignored. To avoid vehicles waiting in line in alleys and interrupting traffic, room for two or more vehicles to wait is necessary. Besides, to have a tower operate efficiently, room for deploying vehicles' turning radius should meet the minimum requirement. Many towers in Taipei do not meet the requirement. Therefore, cars must be maneuvered back and forth. This is inconvenient, inefficient, and unfriendly to the community.
(4). Drivers can accept only short walking distance. Parking towers constructed in residential areas thus are helpful only for private parking. For public parking, this policy seems not workable.
(5). Alleys should be carefully planned and treated as a scarce resource and public utility. Both parking demand and home survey verify that there is a severe shortage of parking spaces in residential areas. Accordingly, scarce alley resources occupied by individuals should not be allowed. Meanwhile, not allowing roadside parking may be inadequate, too. Effective management of alley parking should be a crucial issue worthy of study.
(6). Construction of parking tower itself will not solve the parking problem. Lack of effective roadside parking restrictions can only encourage vehicle purchase and will make traffic even worse. Therefore, a comprehensive policy should be worked out if the parking problem is to be resolved.
(7). Parking tower construction should be regulated under building ordinances. It should be in harmony with land use zoning. If considering only the supply of parking spaces without other impact being taken into account, the parking policy would not succeed. Establishing a good parking environment acceptable to both general public and investor is a key to success.
(8). A business building should have enough parking space for parking demand generated from its business. It is unfair that parking problem due to private business is borne by the whole society.
(9). For the sake of pedestrian safety, pedestrian movement around the parking tower should be carefully considered in the parking tower evaluation process. In particular, for children's safety, those towers near elementary schools should be carefully planned.

Table 1. Results of the parking tower simulations

scenarios	Input											Output					
	hourly arrival (% of capacity)					every 10 min. arrival (% of hourly arrival)						line length (veh.) case1		case2		case3	
	1	2	3	4	5	1	2	3	4	5	6	avg.	max	avg.	max	avg.	max
1	50	50	0	0	0	17	17	17	17	16	16	0.6	2	13.8	37	3.5	12
2	50	50	0	0	0	30	20	20	10	10	10	3.7	12	32.7	62	9.4	18
3	34	33	33	0	0	17	17	17	17	16	16	0.0	0	4.6	11	2.4	8
4	34	33	33	0	0	30	20	20	10	10	10	0.1	3	10.0	15	2.5	8
5	25	25	25	25	0	17	17	17	17	16	16	0.0	0	1.0	7	0.3	4
6	25	25	25	25	0	30	20	20	10	10	10	0.1	2	6.3	14	2.3	6
7	20	20	20	20	20	17	17	17	17	16	16	0.0	0	0.6	6	0.3	2
8	20	20	20	20	20	30	20	20	10	10	10	0.0	2	0.8	6	1.7	6

* case 1 : elevator type, 3 single-towers with 120 spaces and 3 access channels.
* case 2 : rotary type, 2 pair-towers with 156 spaces and 2 access channels.
* case 3 : elevator type, 1 pair-tower with 80 spaces and 1 access channel.
** scenario 1 : Each hour of the 2-hr. peak period, the number of vehicles arriving parking tower is 50% of the associated tower capacity. Within each peak hour, the vehicle arrival pattern is uniformly distributed.
** scenario 2 : The situation of this scenario is similar to the scenario 1 except that the vehicle arrival pattern is not uniformly distributed.