Analysis on Parking Sharing Capacity Based on Supply-Demand Relationship

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Abstract

This paper studies the sharing capacity of parking garages in areas with different land use properties and close distances, such as the sharing capacity of parking garages in public buildings and surrounding residential areas. The parking demand of land with different properties is featured with difference in time for realizing the sharing of parking garages and maximizing the utilization of resources. The relationship between the supply curve and the demand curve of shared parking space in time and space is studied through the image, and the actual management measures of shared parking space are explored to maximize the sharing capacity of parking space. However, since parking demand, especially night parking, involves two natural days, the time series of curves should be appropriately changed.

Keywords: Shared parking, Management measures, Maximize parking sharing capacity, Supply and demand

1 Introduction

Along with the development of economy and the increase of car ownership, the demand of parking is growing. However, construction of urban parking infrastructure is relatively perfect; parking capacity has basically reached the saturation state, and parking problems are increasingly intensified. In the era of rapid sharing economy development, the concept of shared parking came into being.

The concept of shared parking was first proposed at the Urban Land Institute in 1984. Chen Xin [1] has pointed out: "the concept of shared parking is to make use of the spatial and temporal complementarity of parking demand among different land properties to realize the transfer of parking demand from peak to low peak places." Therefore, the sharing of parking garages refers to that of parking space in a certain area by considering different land properties and taking advantage of the difference in parking demand in time, so as to serve other areas with large supply and demand conflicts. Since the acceptable distance between the parking space and the destination is usually about 500 meters, in this paper, it is determined that the service radius of shared parking is 500 meters when studying the demand area of shared parking [2-5]. When it comes to the parking sharing capacity of the region, on the one hand, the parking characteristics regarding the supplier of shared parking garages are considered to obtain the external supply capacity of parking garages; on the other hand, the demand for shared parking in surrounding areas is investigated. According to the relationship between the shared parking supply curve and the shared parking demand curve, management measures are proposed to maximize the sharing capacity [6-9].

As for parking management, Todd Litman [10] once pointed out that parking management is the use of various policies and programs to make parking resources more effective; Kun Chen [11] also proposed to adjust the relationship between supply and demand by means of dynamic differential pricing. The essence of the parking problem is the imbalance between supply and demand in time and space. In the research of this paper, corresponding management strategies will be explored to make parking supply and demand reach the equilibrium state in time and space as far as possible, so as to further maximize the parking sharing capacity [12-13]. In addition, some optimization algorithms [14-20] are proposed to improve network performance which are very instructive for solving relevant problems.

The parking characteristics are similar in areas which have similar land use properties. In some public buildings, like schools, there will be empty parking spaces in some periods, which can provide shared parking spaces for the residential areas that are relatively old and have insufficient parking spaces. Therefore, this paper focuses on the research on the parking sharing capacity of public buildings for

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residential areas within 500 meters of the surrounding areas and the management measures to improve the parking sharing capacity.

2 Analysis of Shared Parking Supply Curve

2.1 Time-shared Parking Supply Function

The parking demand of public buildings appears mainly during the working hours of the day. The parking demand curve shows a parabolic shape that is low at both ends and high in the middle within 24 hours of a day (the diagram of parking demand in public buildings on natural days). For the sharing of parking garages, the free parking garages of public buildings are mainly used. Thus, the number of free berths presents a concave parabola of being high at both ends and low in the middle on the time line (the schematic diagram of shared parking supply in public buildings on natural day). The shared parking of public buildings is primarily aimed at parking in residential areas during non-working hours or the period from the first night of the working day to the morning of the next day. Therefore, when constructing the relation between the number of available shared parking garages and time, the time series is changed so as to take the time axis from 16:00 in the afternoon of the first day to 16:00 in the afternoon of the next day. The image of this function is roughly a convex parabola with low ends and high middle ends (the schematic diagram of shared parking supply for public buildings after changing time series). The curve is in line with the phenomenon that the longer the supply time of parking berths is, the fewer the number of berths is. Figure 1 shows the evolution of the shared parking supply curve.

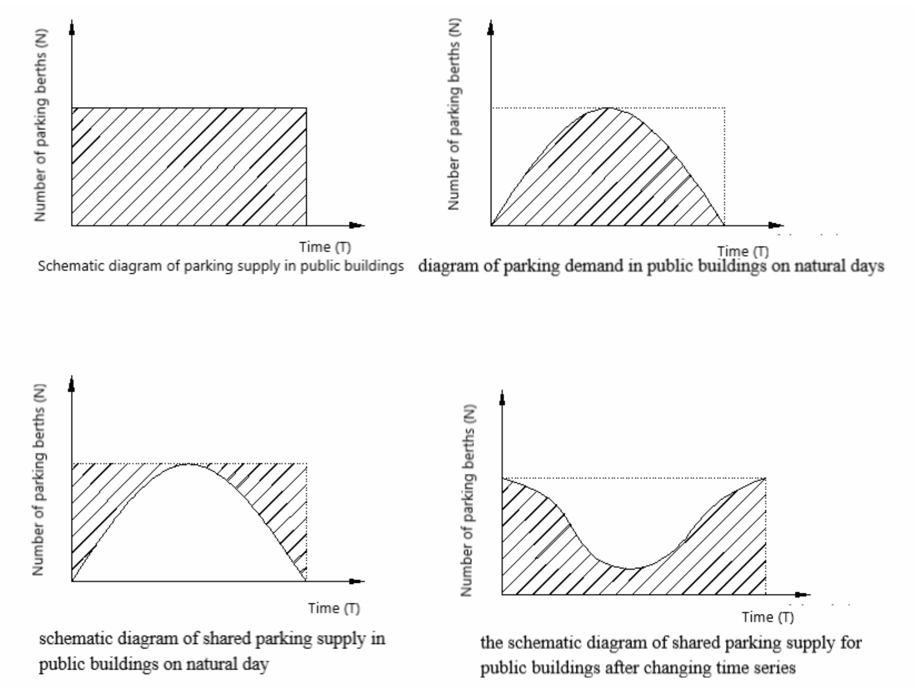

Figure 1. Time-shared parking supply curve change diagram

Based on previous research results, Fang Guo [21-22] had pointed out that the number of berths to be reserved should be 5%~10% of that of berths to be built to cope with emergencies. Therefore, when parking berths of public buildings are shared, 90% of the total free parking berths of public buildings are used as the total shared parking supply, and the remaining 10% of parking berths tend to meet the elastic demand.

2.2 Explanation for the Geometric Meaning of the Shared Parking Supply Curve

Draw a line parallel to the timeline, and make it intersect the shared parking supply curve at a and b, corresponding to T_1 and T_2 on the timeline, as is shown in Figure 2.

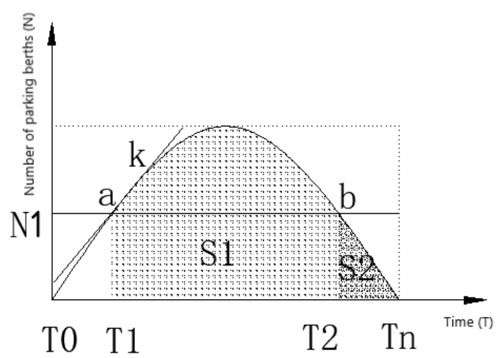

Figure 2. Function diagram of shared parking supply

(1) The time difference between a and b is denoted as Δt_1, $\Delta t_1 = T_2 - T_1$, corresponding to N_1 on the N axis: indicates that there are N_1 parking berths, which have to provide the parking time with the time length of Δt_1;

(2) $\Delta t_2 = T_n - T_2$, is the possible supply parking time; Δt_2 is determined jointly by the parked vehicles on the parking garage and the supply parking time, and it is the time after the number of berths is reduced, which means that the berth may or may not be occupied. In this case, Δt_2 is the possible supply parking time.

(3) The graph area S_1 formed between the shared parking supply curve and segment Δt_1 on the corresponding T-axis indicates that there are N_1 parking spaces which must provide parking with a time length of (b-a). Thus, S_1 is considered as the absolute parking supply capacity of each parking space.

(4) Corresponding to Δt_2, S_2 can be referred to as possible supply parking capability.

(5) $K = \frac{\partial p(t)}{\partial T}$ represents the change rate of parking supply during that period. The larger $\frac{\partial p(t)}{\partial T}$ is, the faster the number of available parking spaces increases in a short time, and the longer the shared parking time can be, the greater the supply capacity is.

2.3 Analysis of Shared Parking Supply Capacity Maximization

In the time period T_0-T_n, the maximum supply capacity of P parking berths is [P× (T_n-T_0)], shown as the rectangle area in Figure 3. To maximize the supply capacity of shared parking, the slope of the left side of the parabola should approach infinity, or in other words, the number of shared parking berths should increase sharply in a short time.

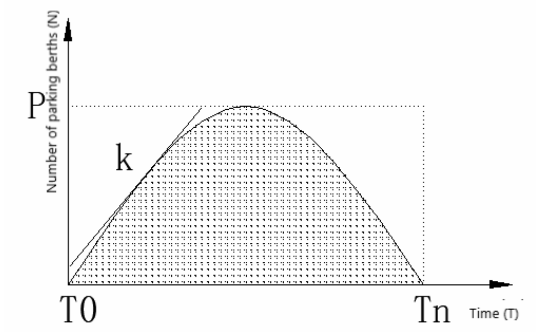

Figure 3. Maximization of shared parking supply capacity

3 Analysis of Parking Sharing Demand Curve

3.1 Time-shared Parking Demand Function

The parking demand in residential areas mainly exists in non-working hours, and the parking demand curve shows a concave parabola within a 24-hour period (see the left in Figure 4). After the time series is changed, the time axis is taken from 16:00 p.m. of the first day to that of the next day. The image of this function is roughly in a convex parabolic shape, with low ends and high middle (see the right in Figure 4), which is in line with the reality of residential parking demand. Figure 4 displays the evolution of the parking demand curve.

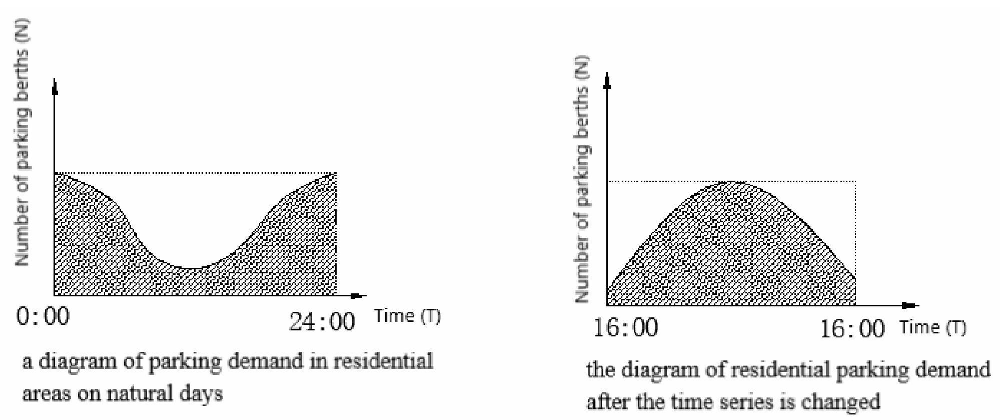

Figure 4. The time-shared parking demand curve change diagram

3.2 Interpretation of the Geometric Meaning of the Shared Parking Demand Function

$K = \frac{\partial p(t)}{\partial T}$ is the change rate of parking demand in this period (see Figure 5). The larger k is, the faster the number of parking spaces for shared parking demand increases in a short period of time.

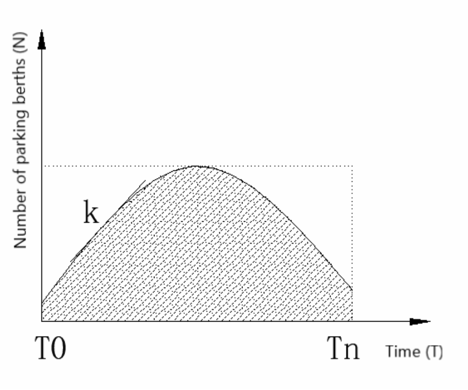

Figure 5. Function diagram of shared parking demand

4 Research on Parking Sharing Capacity

4.1 Parsing of the Conception of Shared Parking

Shared capacity is determined by both demand and supply. Only when supply is matched with demand in time and space can it become shared capacity. Therefore, when studying the parking sharing capacity of public buildings with parking garages for residential areas, it is necessary to analyze not only the shared parking supply capacity of public buildings, but also the relationship between shared parking supply and shared parking demand in residential areas. The graph of shared parking demand and shared parking supply is constructed in the time-parking number coordinate system. Remember the shared parking supply function $P(t)$ and take $D(t)$ as the shared parking demand function, then for the shared capacity C, there is $C=[\int P(t)dt]\cap[\int D(t)dt]$.

4.2 Analysis of Shared Parking Supply and Shared Parking Demand

As the number of shared parking spaces is related to demand and supply, it is difficult to be determined. Therefore, from the perspective of shared time, the following two situations exist in the supply and demand of shared parking.

Parameter interpretation in the Figure 6:

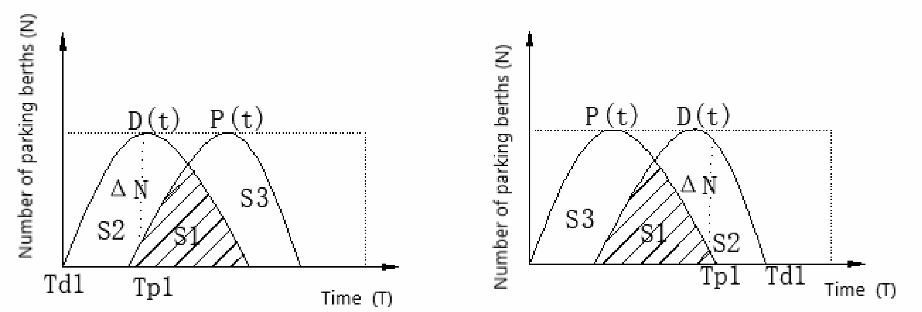

Figure 6. Parking sharing capacity in case one

S1: the coincidence part concerning the demand curve and the supply curve of shared parking; it is parking sharing capacity. $C=[\int P(t)dt]\cap[\int D(t)dt]=$ S1.

S2: the shared parking supply curve fails to cover the part of the shared parking demand curve, which is the potential sharing capacity

S3: the part of the shared parking supply curve that exceeds the shared parking demand curve is idle sharing capacity

$\Delta N=\max\{D(t)-P(t)\}$: represents the biggest contradiction in quantity between the demand and the supply of shared parking.

$\Delta t=|T_{p1}-T_{D1}|$: refers to the biggest contradiction in time between the demand and the supply of shared parking.

4.2.1 $P(t)\cap D(t)\neq\phi$

As The shared parking supply and demand curves intersect in time and space, the sharing of parking garages can be realized. Thus, parking spaces are shared.

Figure 6 shows that the demand curve and the supply curve of shared parking overlap in space and time, and parking can be shared within a period of time. However, the sharing capacity fails to reach the maximum, and there will be periodic parking resource waste and parking resource shortage.

The left figure in Figure. 7 shows that the shared parking supply cannot completely meet the demand of shared parking both in time and in space. At this point, the shared capacity of parking garages is equal to the shared parking supply capacity, which is expressed as $\int P(t)dt$. In this case, parking garages have maximized parking sharing capacity. The figure on the right side displays that the shared parking supply can completely meet the demand of shared parking in time and space, and at the same time, there is a phenomenon of parking resource waste. At this point, the parking sharing capacity is equal to $\int D(t)dt$, and can be maximized by increasing the demand for shared parking.

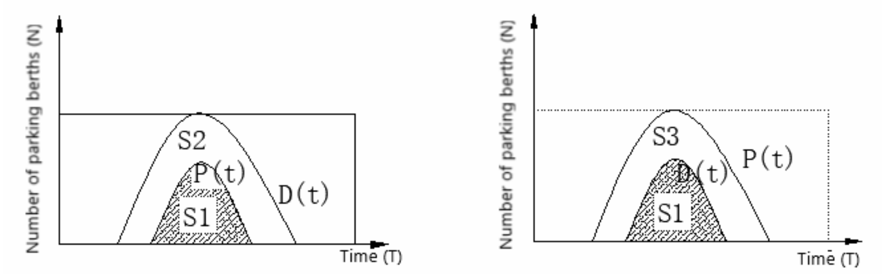

Figure 7. Parking sharing capacity in case two

4.2.2 $P(t) \cap D(t) \neq \phi$

This section introduces that the demand and the supply of shared parking do not intersect in time and space, as shown in Figure 8. In this case, the sharing of parking spaces cannot be realized, and the capacity of shared parking is 0.

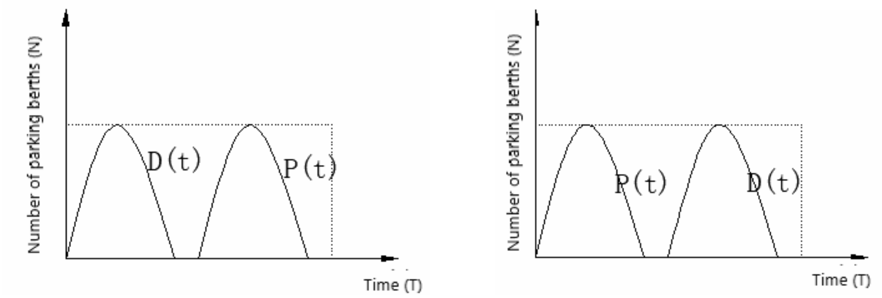

Figure 8. Shared parking capability does not exist

4.3 The Dynamic Influence of Shared Parking on Shared Parking Supply

The curve of shared parking supply is dynamic, and will be affected by the parking time and the number of shared parking vehicles in the previous period.

Suppose at the time of T=a, there are n vehicles that need to be parked, and the parking time is a--b, then the supply quantity of the shared parking garage will decrease n within the period of a-b. The shaded part in the figure shows a decrease in the supply capacity of shared parking garages. At moment b, when vehicles are driven away, the number of shared parking spaces will increase. In this case, whether the new number is equal to or lower than the original shared parking space supply number mainly depends on the parking time of shared parking vehicles. Then, the overall shared parking supply curve changes from P_1 to P_2, as shown in Figure 9.

4.4 Maximization of Parking Sharing Capacity

To maximize the parking sharing capacity, we should convert S3 and S2 to S1. S3 is idle sharing capacity that is transformed into parking sharing capacity. In other words, the shared parking supply curve and the shared parking demand curve are required to be infinitely close, and nearly coincide, which means that the slopes of the two curves are nearly equal at the same time, and the growth is

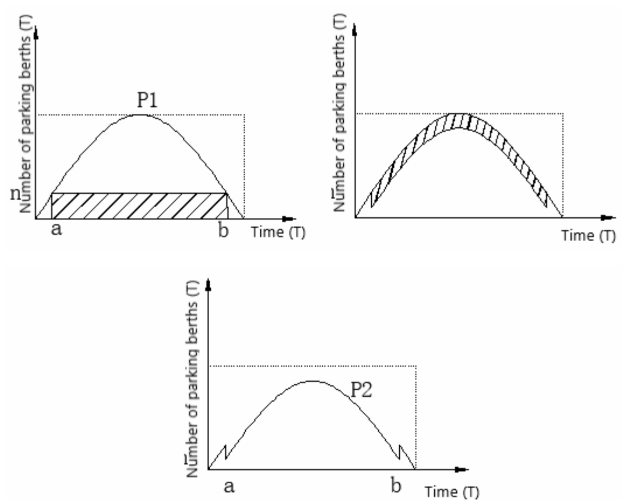

Figure 9. The change diagram of the shared parking supply curve

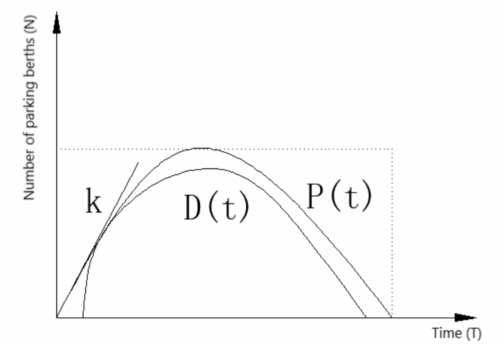

Figure 10. The diagram of instantaneous maximization of parking sharing capacity

consistent, as shown in Figure 10. At time t, the demand curve of shared parking coincides with its supply curve, and the sharing capacity reaches its maximum.

Converting S3 to S1 is up to requirements, which won't be elaborated in this article, but maximizing the parking sharing capacity under the condition that (S1+S2) remains unchanged or minimizing S2 and approaching 0 indefinitely is considered. Therefore, the wider and higher shared parking supply curve is great, which means reducing ΔN and Δt , and improving supply capacity as much as possible from time and quantity to meet the demand.

If the utilization rate of space resources in public buildings is high, it is difficult to increase the number of shared parking spaces. Therefore, demand management can be adopted to adjust the relationship between supply and demand with the help of economic means. When the supply of shared parking is lower than the demand, the charging standard of shared parking should be raised. When the supply of shared parking exceeds its demand, the charging standard can be lowered. By taking the economic measure, we tend to maximize the parking sharing capacity and make full use of resources.

5 Case Study

5.1 Case Location Introduction

This campus of University of Shanghai for Science and Technology is located at No. 516 Jungong Road, Yangpu District, Shanghai. There are parking garages inside the campus for faculty and staff. Within 500 meters around the campus, there are many residential areas, as shown in Figure 11. There is a serious imbalance between supply and demand due to the small number of common parking spaces in residential areas. In this case, vehicles are randomly parked, which affects the internal road of residential areas and the aesthetics and comfort of residential areas. As the idle time of parking spaces in the campus overlaps with the parking demand time of the surrounding residential areas, parking spaces can be shared. Thus, parking problems in residential areas can be alleviated, and at the same time, campus resources can also be used to a great extent.

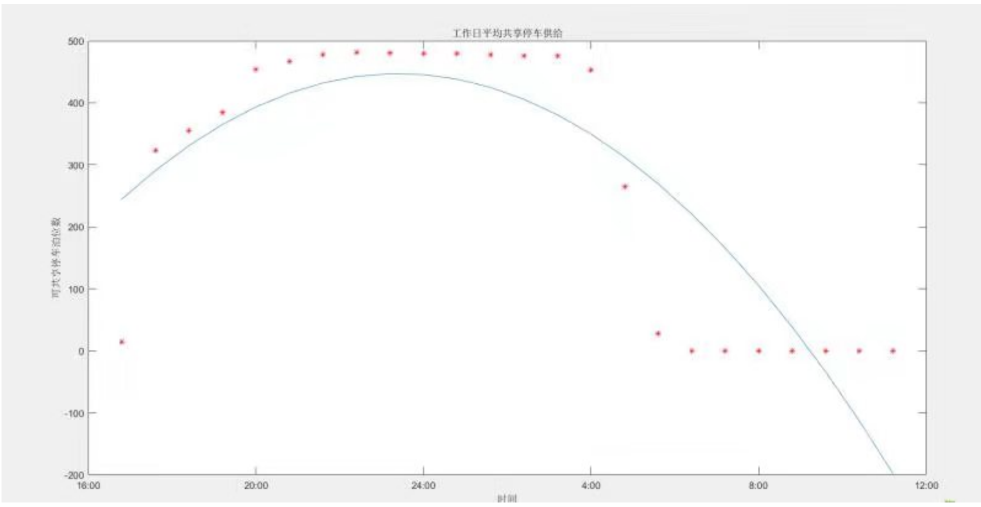

Figure 11. The average number of shared parking spaces available on campus during working days

5.2 Analysis on the Usage of Campus Berths from the Aspect of Time

The campus involved in this study has a total of 643 parking berths currently. According to the analysis of the weekly entrance and exit data and the one-week field survey of campus parking, the parking demand and traffic flow on campus were recorded during both working days and non-working days, and the average number of shared parking berths available was calculated and fitted, as shown in Figure 11 and Figure 12.

The demand for parking on campus varies with time (see Figure 13 and Figure 14). During the non-working hours of the campus, there is less demand for parking, but parking berths are available. In this case, sharing with outsiders can be realized from the perspective of quantity.

According to the entrance and exit data, the peak period is analyzed. Weekday traffic in the campus generally shows that the arrival peak appears from 7:00 a.m. to 9:00 a.m. and the departure peak is between 4:00 p.m. and 6:00 p.m. There is little difference between the flow-in and the flow-out in different periods of non-working days with less traffic flow. Parking spaces can be used for shared parking anytime. Properly avoiding the morning and evening peaks and shared parking time on campus can reduce the pressure of its dynamic traffic, and the impact of campus parking garage sharing on campus parking.

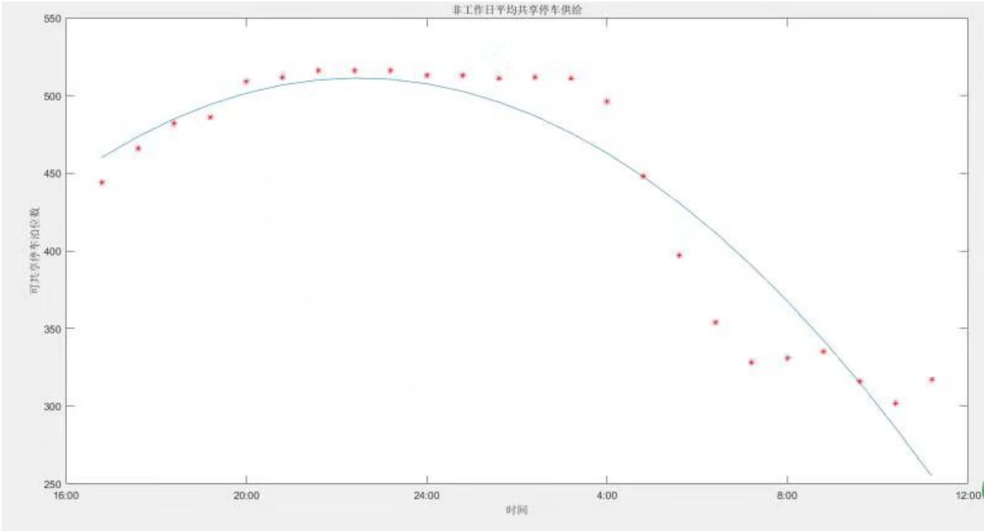

Figure 12. The average number of shared parking spaces available on campus during non-working days

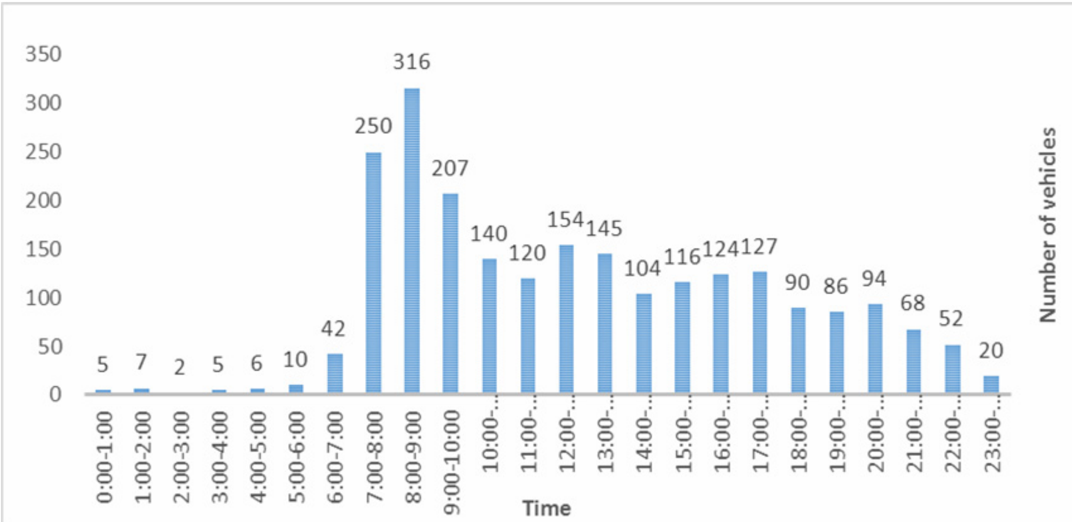

Figure 13. 24-hour traffic flow into the campus during working days

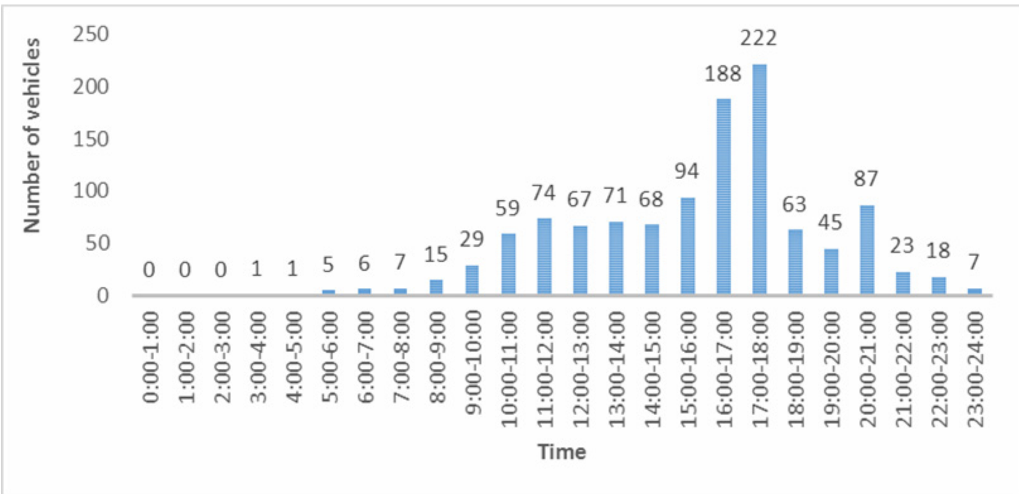

Figure 14. 24-hour traffic flow out of the campus during working days

5.3 Study on Maximization of Campus Parking Sharing Capacity

When studying the parking sharing capacity of the campus mentioned above, it is assumed that shared parking has no impact on the road traffic around the periphery of the campus. Meanwhile, the parking sharing capacity of the campus is the same every day, and has little impact on campus traffic.

Through long-term observation and investigation, the shared parking supply of the campus and the shared parking demand of residential areas can be shown as Figure 15.

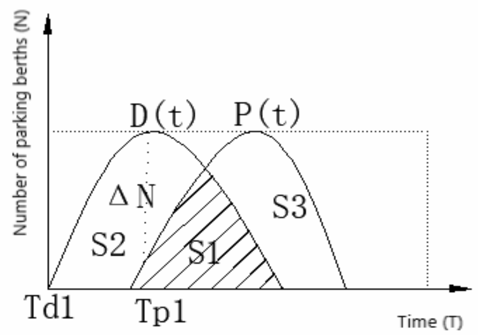

Figure 15. Campus berths shared with residential areas

Method one: Reducing Δt

$\Delta t = T_{p1} - T_{d1}$. The main influencing factor is the departure time of the campus staff, and it should be reduced, which means that the departure time of the staff should be earlier. The delay of school departure due to work is reasonable and cannot be changed, but the delay related to school meals may be changed. Therefore, we can transform the subsidy for meal into that for shared parking of teaching and administrative staff so as to promote the early departure of some teaching and administrative staff. Therefore, shared parking spaces are increased in this period with the enhancement of shared parking supply capacity.

Method Two: Reducing ΔN.

Reducing ΔN means increasing the supply of shared parking on campus. For one thing, we can set up a special temporary parking space on campus for shared parking. The establishment of temporary berths for shared parking should be considered on the basis that there is no impact on the overall traffic on campus or the impact is minimized. The time when the temporary berths are available and its specific location should be determined, and the free space with fewer people and less traffic flow on campus can be selected. For another, we can combine the normal parking demand and campus space. The increase of fixed parking spaces on campus not only solves the problem of daily parking on campus, but also makes full use of resources for further improving the parking sharing ability of the campus.

Method Three: Use Economic Means to Adjust the Relationship Between Supply and Demand.

Mainly during the period from Td1 to Tp1, the charge for shared parking is increased to reduce the demand for shared parking, the pressure of campus parking and the impact of shared parking on campus.

6 Conclusion and Future Work

This paper studied the capacity of shared parking space for residential areas of public building accessories and analyzed the relationship between the shared parking supply curve and the demand curve, which only suitable for large cities where there will be few vehicles leaving public buildings and less parking demand in surrounding residential areas at noon. In the case, the corresponding management measures were put forward from the diagram, so as to enhance its parking sharing capacity.

In the future, we need to further study the curve of shared parking capacity. and the relationship between the shared parking supply curve and the demand curve The parking sharing capacity studied in this paper is based on the assumption that both the supply and demand curves of shared parking are similar to the parabola. If the opportunity is given in the future, a large amount of data will be used to depict the real image model, to achieve more accurate assumptions, which perhaps not similar to parabola.

Acknowledgments

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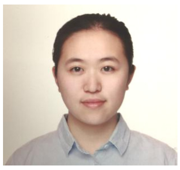

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