Hindawi Publishing Corporation
Mathematical Problems in Engineering
Volume 2015, Article ID 372496, 5 pages
http://dx.doi.org/10.1155/2015/372496

Research Article

Research on the Coordinated Design of Bus and Taxi Station

Jiangfeng Xi, Quan Wang, Tongqiang Ding, Lili Zheng, Shengli Wang, and Wei Li

College of Traffic, Jilin University, Changchun, Jilin 130022, China

Correspondence should be addressed to Tongqiang Ding; dingtq@jlu.edu.cn

Received 30 July 2014; Accepted 10 November 2014

Academic Editor: Hong Chen

Rises in the number of transit buses, bus routes, and overall traffic volume in China's cities, coupled with interference from other transport modes, such as taxis loading and unloading passengers nearby, have led to increasing traffic delays at bus stops, which is considered one of the factors degrading service levels and traffic operations on urban roadways. This paper studies traffic characteristics at bus stops, investigates variations in delay from different types or designs of bus stops, and analyzes the impact of it on traffic capacity, the purpose of which is to propose a solution to predicting the feasibility of an integrated design of bus stops and taxi stands with the help of mathematical models and based on the objectives of optimal traffic operations and passenger transfer.

1. Introduction

Transit buses and taxis are an integral part of the urban public transport system. Bus transport is characterized by its high passenger capacity, high efficiency, low per-passenger road use, and low environmental impact and is seen as an important measure for alleviating urban traffic congestions. Taxis convey passengers between locations of their choice, offering convenience, speed, and more flexible services. This differs from other modes of public transport where the pick-up and drop-off locations are determined by the service provider and is favored by short-distance passengers [1].

Taxis pulling over and picking up passengers is one of the main causes of delay on urban roadways with high traffic volume, especially in sections near bus stops where passenger transfers occur [2]. A passenger would also step into traffic lanes to get a taxi, often posing safety concerns. It is therefore necessary to prevent taxi pick-ups from happening outside of designated taxi stands on roads with busy traffic [3].

Many researchers have been conducted on the planning and designing of transit bus stops; however, the same cannot be said about taxi stands. Taxi transport has no fixed routes and it follows a random pattern of vehicle arrival, making it very difficult to plan and design taxi stands that are applicable universally or over a large area. In addition, as transit bus transport often put the greatest emphasis over other modes of public transport when it comes to developing a city-wide public transport system, the conventional approach is so that services like taxis should not affect bus operations, which suggests that a taxi stand should be positioned near a bus stop rather than between two adjacent bus stops on the same route, which would lead to more blockages and longer delays for buses [4].

An integrated design of bus stop and taxi stand, which will be referred to as "a bus and taxi stop" hereon, can help introduce more ways to regulate taxi service, reduce delays to buses, and also provide a better transfer experience for passengers.

2. Models

2.1. Probability Distributions of Vehicle Arrival. The flow of traffic is a complex process influenced by a number of random factors. The arrival of vehicles is a random process. There are two ways of describing vehicle arrival in probability: (1) discrete distributions, which are used to study the volatility of traffic in a certain time period, and (2) continuous distributions, with focus on traffic characteristics such as speed, time, and distance.

Transit buses and taxis are different from other modes of transport in that changes in traffic volume are not significant between peak and off-peak hours, and the vehicle arrival is

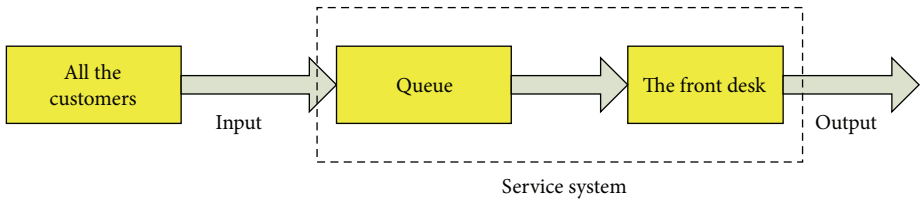

Figure 1: The queuing service system.

a random process. Therefore, we can use the Poisson distribution to describe the number of buses and taxis arriving in a given time interval [5].

The basic formula for the Poisson distribution is as follows:

$$P(k) = \frac{(\lambda t)^k e^{-\lambda t}}{k!}, \quad k = 0, 1, 2, 3, \ldots, \tag{1}$$

where t is the time interval or counting interval; $P(k)$ is the probability of k vehicles arriving during the counting interval; λ is the average arrival rate per unit of time; $M = \lambda t$ is the average number of vehicles arriving during the counting interval.

The bus arrivals obey the Poisson distribution with arrival rate λ_1, while the taxi obeys λ_2.

2.2. Queuing Theory Model. In an integrated bus and taxi stop design, buses and taxis arrive at the stop according to Poisson distribution [6]. We can use the queuing theory model to describe the queuing buses and taxis when arrivals reach the service capacity [7].

2.2.1. Components of a Queuing System. The general queuing service system (Figure 1) has three basic components: the input process, queuing rules, and services [8]. The input process refers to the customer arrival queuing system; queuing rules refer to how the customers queue for service; and services refer to the organizations providing services to the customers. The queuing system studied in this paper refers to an integrated bus and taxi stop waiting to pick up passengers in a queuing system. The integrated stop is the front desk; the input process refers to the buses and taxis coming into the site to pick up or drop off passengers and they are considered to be accepting the service [9].

The queuing system for standing vehicles belongs to the $M/M/1$ type of queuing system [10]. Considering the standard vehicle and the additive characteristics of the Poisson distribution, we can define that the overall arrivals for buses and taxis are subject to a Poisson with arrival rate λ, where $\lambda = 2\lambda_1 + \lambda_2$, and it is a distributed queuing system input [11]. In this queuing system, assuming that the time each passenger takes to board or alight is T, the average service time for the integrated stop is $(N_1 + N_2)T$, where N_1 is the average number of passengers alighting at the stop and N_2 is the average number of passengers boarding at the stop, and μ is the average service rate:

$$\mu = \frac{1}{(N_1 + N_2)T}. \tag{2}$$

Define $\rho = \lambda/\mu = (2\lambda_1 + \lambda_2) \cdot (N_1 + N_2)T$ as the service intensity. Then, some formulas of the $M/M/1$ system are as follows [12]:

(1) the probability of zero vehicles waiting in the system

$$P(0) = 1 - \rho, \tag{3}$$

(2) the probability of n vehicles waiting in the system

$$P(n) = \rho^n (1 - \rho), \tag{4}$$

(3) the average number of vehicles in the system

$$x = \frac{\rho}{1 - \rho}, \tag{5}$$

(4) the average queuing length

$$q = \frac{\rho^2}{1 - \rho} = \rho \cdot x, \tag{6}$$

(5) the average consumption during the queuing time

$$d = \frac{1}{\mu - \lambda} = \frac{x}{\lambda}, \tag{7}$$

(6) the average waiting time in the queue

$$W = \frac{\lambda}{\mu(\mu - \lambda)} = d - \frac{1}{\mu}. \tag{8}$$

2.2.2. $M/M/N$ System. If the integrated stop can accommodate more than one parked vehicle at the a time, allowing multiple service channels, then the queuing system is called a "multichannel service" system, also known as an $M/M/N$ system, and we can use ρ/N as the service intensity of the system [13].

A single line in a multichannel service or $M/M/N$ system has the following formulas:

(1) the probability of zero vehicles in the system

$$P(0) = \frac{1}{\sum_{k=0}^{N-1} (\rho^k/k!) + \rho^N/N!\,(1 - \rho/N)}, \tag{9}$$

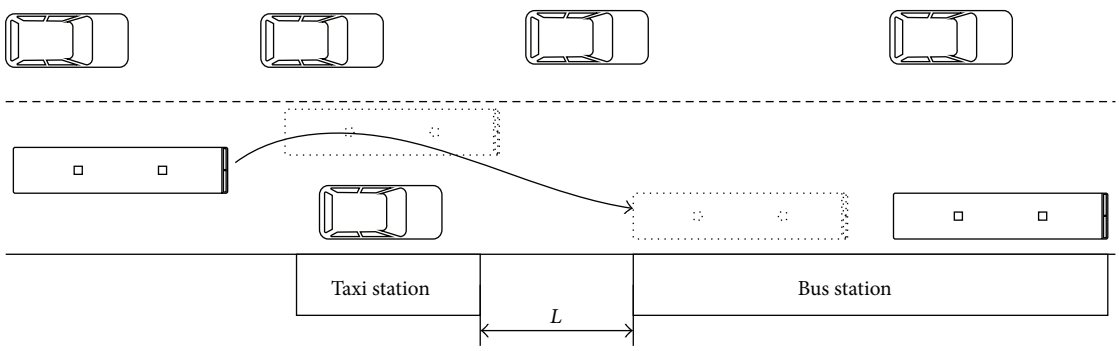

Figure 2: Distance between bus stop and taxi stand.

(2) the probability of k vehicles in the system

$$P(k) = \begin{cases} \dfrac{\rho^k}{k!} \cdot P(0), & k < N \\ \dfrac{\rho^K}{N!N^{k-N}} P(0), & k \geq N, \end{cases} \tag{10}$$

(3) the average number of vehicles in the system

$$x = \rho + \frac{\rho^{N+1}}{N!N} \cdot \frac{P(0)}{(1-\rho/N)^2}, \tag{11}$$

(4) the average queue length

$$q = x - \rho, \tag{12}$$

(5) the average consumption during the queuing time

$$d = \frac{q}{\lambda} + \frac{1}{\mu} = \frac{x}{\lambda}, \tag{13}$$

(6) the average waiting time in the queue

$$w = \frac{q}{\lambda}. \tag{14}$$

We can tell whether the integrated stop is valid based on the number of vehicles and the length of the queue in the system, which requires the number of queuing vehicles (standard vehicles) to be no more than N. If the probability of their being more than N vehicles is small (usually less than 5%), the integrated stop is considered suitable, otherwise not [14]:

$$P(>N) = 1 - \sum_{n=0}^{N} P(n). \tag{15}$$

In this case, it is convenient for passengers to transfer and will not cause interference to bus operations.

2.3. Design of the Integrated Bus and Taxi Stop. If the probability is high because there are more than N queuing vehicles in the system, it would indicate that the integrated stop has a great impact on the bus and taxi services. In this case, it is not optimum to set up an integrated bus and taxi stop and is advisable to arrange the taxi stand at a distance from the bus stop, which would decrease bus delays from interfering taxis [15]. An excessive distance between the bus stop and the taxi stand would not be convenient for transferring passengers. The distance needs to be sufficient enough for buses to go in or out of the bus stop without delays from parking or parked taxis. Based on researches on vehicle lane changing behaviors [16], we can determine the distance L between the taxi stand and the bus stop (Figure 2). Vehicle lane changing behavior concerns driver behavior and traffic conditions; it is therefore highly volatile; thus L can only be given an estimated value, such as $L = 50$ m [17].

Both the bus stop and the taxi stand need to "shelter" the parked vehicles (Figure 3). Therefore, the parking spots should be allocated directly on the lane closest to the curb, and the stop should be located on the boarding area or pavement. The parking principle would be first in first out, so that a vehicle could not overtake the one in front of it. Thus, the length of the stop would need to be long enough to accommodate whole vehicles in the parking spots.

A single vehicle's parking length d should include the vehicle length l and the safe parking distance b (taken to be 1.2 m) between adjacent parked vehicles. The length of the stop would then be the sum of n such parking lengths [18]; therefore

$$C = nd = n(l + b). \tag{16}$$

As there is no fixed schedule for taxi operations, taxis should have only a short parking time at the stop. Therefore, the length of the taxi stand should be only long enough to serve just one taxi at a time, which is about 4 m.

The length calculated by the above formula agrees with actual lengths at taxi stands.

2.4. Case Study. We studied the section of People's Road between Chongqing Road and Beian Road in the city of

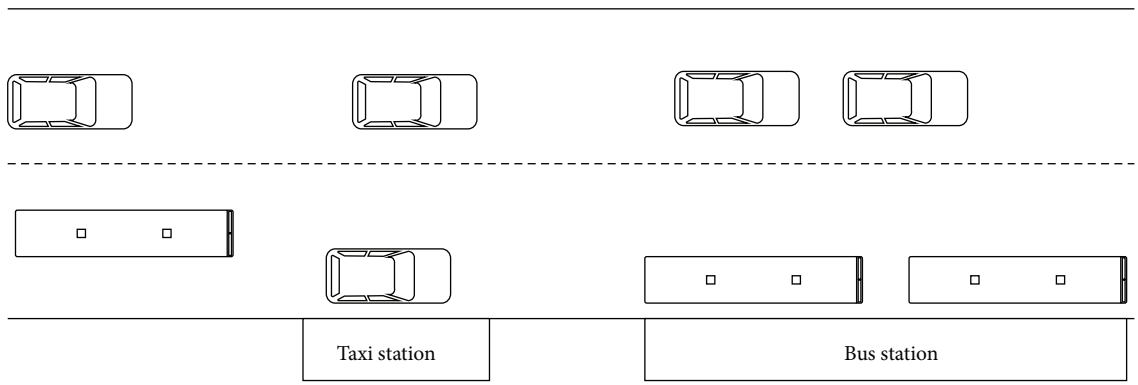

Figure 3: Lengths of the stop.

Changchun China, which is a 306 m long two-way road with eight lanes. Being one of the main traffic ways in a central business district, it is crowded with pedestrians and taxi operations, both of which lead to significant delays to buses. There are 12 bus routes operating from the south to the north, 8 of which load and unload passengers in this section of road.

The arrival rate for buses is 62 pcu/h in this direction and 12 for taxis, both following Poisson distributions. In one hour, we observed 242 people boarding buses and 302 people alighting. The numbers are 28 ad 36 for taxis. We assume it takes 7 seconds on average for a person to board or alight a bus and 15 seconds to board or alight a taxi.

Assuming that the traffic remains the same for the integrated stop, the arrival rate of the system is $\lambda = (62 \times 2 + 12)/3600 = 17/450$ pcu/h, and the average service time is

$$T = \frac{242 + 308}{62} \times 7 + \frac{28 + 36}{12} \times 15 = 142.1 \text{ s}. \tag{17}$$

The stop can accommodate three buses (six standard vehicles) at a time, making the service intensity $\rho/N = \lambda/\mu N = (\lambda/N) \times T = (17 \times 142.1)/(450 \times 6) = 0.89$.

Here, we assume that the integrated stop can accommodate eight standard vehicles at most at any moment. The probability of their being more than eight standard cars can be calculated as follows:

$$\begin{aligned} P(0) &= \frac{1}{\sum_{k=0}^{5}\left(5.37^k/k!\right) + 5.37^6/6!\,(1-0.89)} \\ &= \frac{1}{118.46 + 421.24} = 0.001853, \\ P(1) &= 5.37 \times P(0) = 0.009951, \\ P(2) &= 0.026717, \ldots, \\ P(8) &= \frac{5.37^8}{6!6^2} \times P(0) = 0.009951 = 0.049435. \end{aligned} \tag{18}$$

Thus, $P(>8) = 1 - \sum_{n=0}^{8} P(n) = 0.720142$.

This calculation shows that the probability of their being more than eight standard vehicles queuing is high. Thus, the taxis have a greater impact on the operations of the buses, and we cannot merge the taxi stand into the bus stop directly. Instead, we need to set up a taxi stand around 50 m ahead of the bus stop.

3. Conclusion

This paper introduced a model-based approach to study the feasibility of having an integrated design to reduce delays to buses from taxi transport by determining whether an integrated single stop design is plausible to serve both buses and taxis at the same time and used vehicle arrival, probability distributions, and queuing theory to look into the traffic characteristics at bus stops. We first analyzed the current traffic operations and then described bus and taxi traffic characteristics according to the appropriate traffic flow models. This paper agrees that the arrival of buses and taxis can be described with Poisson distribution and it abstracts the process of vehicles getting into the stop as a queuing model system. In doing so, the probability of queuing vehicles in the system can be calculated. Finally we applied the models on a real road and discussed the potential traffic conditions of redesigning the bus stops along that road. In future follow-up studies, the authors would like to look into more types of arrivals and a variety of queuing service systems with hopes to future improve the method and models.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1] H. Kim, J.-S. Oh, and R. Jayakrishnan, "Effect of taxi information system on efficiency and quality of taxi services," *Transportation Research Record*, no. 1903, pp. 96–104, 2005.

[2] B. Mao and H. Chen, "Sustainability analysis of Chinese transport policy," *The International Journal of Sustainable Development and World Ecology*, vol. 8, no. 4, pp. 323–336, 2001.

[3] X. M. Zhao, Z. Y. Gao, and K. P. Li, *Physical Review Atomic Molecular and Optical Physics*, Springer, 2008.

[4] K. J. Krizek, "Measuring accessibility: prescriptions for performance measures of the creative and sustainable city," *International Journal of Sustainable Development*, vol. 13, no. 1-2, pp. 149–160, 2010.

[5] R. Z. Koshy and V. T. Arasan, "Influence of bus stops on flow characteristics of mixed traffic," *Journal of Transportation Engineering*, vol. 131, no. 8, pp. 640–643, 2005.

[6] B. Schaller, "Entry controls in taxi regulation: implications of US and Canadian experience for taxi regulation and deregulation," *Transport Policy*, vol. 14, no. 6, pp. 490–506, 2007.

[7] D. Yue and F. Zhang, "A discrete-time Geo/G/1 retrial queue with J-vacation policy and general retrial times," *Journal of Systems Science and Complexity*, vol. 26, no. 4, pp. 556–571, 2013.

[8] Y. H. Tang and X. W. Tang, *Queuing Theory-Queuing Theory Basics and Its Analysis Technology*, 2006.

[9] C. Zheng and L. Jian, *Study on the Characters and Decision Analysis of City Men Outgoing by Bus*, Communication and Standardization, 2003.

[10] D. Nazzal, J. A. Jimenez, H. J. Carlo, A. L. Johnson, and V. Lasrado, "An analytical model for conveyor-based material handling system with crossovers in semiconductor wafer fabs," *IEEE Transactions on Semiconductor Manufacturing*, vol. 23, no. 3, pp. 468–476, 2010.

[11] D. Flores-Guri, "An economic analysis of regulated taxicab markets," *Review of Industrial Organization*, vol. 23, no. 3-4, pp. 255–266, 2003.

[12] G. Tiwari, "Urban transport priorities meeting the challenge of socio-economic diversity in cities-case study Delhi, India," in *Proceedings of the 20th South African Transport Conference*, 2001.

[13] P. S. Dempsey, "The rational basis for economic regulation of the taxi industry," 2001.

[14] D. Jeason and L. Ferreira, "Assessing travel time impacts of measure to enhance bus operation, part II: study methodology and main findings," *Road & Transport Research Journal*, 2000.

[15] Y. Wu and X. Qu, "Path planning for taxi of carrier aircraft launching," *Science China Technological Sciences*, vol. 56, no. 6, pp. 1561–1570, 2013.

[16] J. E. Fernández, J. de Cea Ch, and J. Briones, "A diagrammatic analysis of the market for cruising taxis," *Transportation Research Part E: Logistics and Transportation Review*, vol. 42, no. 6, pp. 498–526, 2006.

[17] H. Yang, M. Ye, W. Tang, and S. C. Wong, "A multiperiod dynamic model of taxi services with endogenous service intensity," *Operations Research*, vol. 53, no. 3, pp. 501–515, 2005.

[18] H. Jula, E. B. Kosmatopoulos, and P. A. Ioannou, "Collision avoidance analysis for lane changing and merging," *IEEE Transactions on Vehicular Technology*, vol. 49, no. 6, pp. 2295–2308, 2000.