Transport Policy 39 (2015) 63–76

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

Analysis of a new public-transport-service concept: Customized bus in China

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ARTICLE INFO

Article history:
Received 2 December 2014
Received in revised form
2 February 2015
Accepted 12 February 2015
Available online 24 February 2015

Keywords:
Customized bus
Demand-responsive transit
Flexible transit service
China

ABSTRACT

In recent years, an innovative mode of public transport (PT) service, known as customized bus (CB), has been springing up across China. This service, providing advanced, personalized and flexible demand-responsive PT, is offered to specific clientele, especially commuters. The present work analyzes, for the first time, the evolution of this new PT concept across 30 Chinese cities where CB systems are currently in operation or under construction. Unlike conventional bus transit service, CB users are actively involved in various operational planning activities. CB personalizes PT service by using interactive and integrated information platforms, such as internet website, telephone and smartphone. The analysis comprises three components: first, a comprehensive examination of the background of CB and its temporal and spatial distribution in China; second, an analysis of the operation-planning process, including elements of online demand collection, network route design, timetable development, vehicle scheduling, crew scheduling, real-time control, and fare design and collection: third, a summary of the results of the examination and analysis, presenting pros, cons and recommendations. The successful implementation of CB in China demonstrates that this new PT service concept can effectively meet the ever-increasing mobility needs of large populations nation-wide. Similarly, the present work can provide a valuable reference for policymakers, academic researchers, PT practitioners and others worldwide.

1. Introduction

Customized bus (CB) is a new and innovative mode of demand-responsive transit systems that provides advanced, attractive and user-oriented service to specific clientele, especially commuters, by aggregating their similar travel-demand pattern using online information platforms, such as Internet, telephone and smartphone. In recent years, CB has become very popular in more and more Chinese cities because it is more comfortable, convenient and reliable than conventional bus transit systems and more efficient, cost-effective and environmentally friendly than private cars. Therefore, CB serves as a good alternative in order to reduce urban traffic congestion, improve traffic safety and alleviate energy consumption and greenhouse gas-emission problems.

Because of its various advantages, CB is actively promoted nationally and locally in China and currently operates successfully in 22 cities, with 8 more cities having this service under construction and many more municipalities considering launching it. CB is generally regarded as a successful transportation system mode that can for the most part meet increasing and diversified mobility needs in China and elsewhere. Therefore, a good understanding of the development of CB in China, its operation-planning process and its pros and cons are important for guiding future CB development. Toward this end, this work provides a systematic analysis of the experience accumulated of CB in China.

1.1. Background of CB

Following the implementation of economic reform and open-door policy in the late 1970s, the economy of China experienced remarkable growth, which led, among others, to rapid urbanization and motorization. From 1978 to 2013, the urban population increased from 170 million to 730 million, and the urbanization rate from 17.9% to 53.7%. In 1978, there were only 193 cities in China; by 2013, the number reached 658. Six of the cities (Beijing, Shanghai, Guangzhou, Shenzhen, Chongqing, and Tianjin) have a population of more than 10 million each city, accounting for 21.43% of the 28 cities around the world with a population of more than 10 million each city. It is estimated that by the end of 2020, the rate of urbanization in China will reach approximately 60%

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http://dx.doi.org/10.1016/j.tranpol.2015.02.004
0967-070X/

(Xinhua News Agency, 2014). What is more, the number of private motor vehicles for civilian use has increased to 137.41 million in 2013 (National Bureau of Statistics of the People's Republic of China, 2013). This combination of urbanization and motorization has been placing an ever-increasing amount of pressure on the current transportation infrastructure across the country, resulting in such widespread problems as traffic congestion, traffic fatalities and injuries, traffic pollution and increased energy consumption.

To deal with the fast-increasing urban travel demand and these attendant serious problems, policy decision-makers have begun to invest a greater share of their limited budgets in road infrastructures, including expanding old roads and building new ones. However, the speed of expansion of the road network is much slower than that of the increase in travel demand. Usually, newly opened roads are quickly filled with vehicles by induced traffic demand and become congested soon after opening. The rapid urban sprawl also makes it more difficult, time-consuming and frustrating for citizens to travel between their residences and work/recreational places. In addition to increasing road capacity (supply), another way to alleviate the problem is to reduce road traffic (demand). To do so, decision-makers must begin to adopt demand-management measures, such as restricting car ownership, imposing toll roads and raising parking fees. However, the effects of these measures are relatively limited. Sometimes, in fact, they even lead to an increase in the total number of vehicles and make the situation worse. Since the 1990s, policy decision-makers in China have come to realize that they cannot solve these problems just by building additional roads or restricting travel demand. They need a more effective and efficient approach to transportation-related problems, solutions that deal in a feasible and favourable manner with achieving sustainable urban transportation systems.

Public transport (PT) is now looked upon as the best choice to solve these problems in China, with both national and local governments advocating its priority in cities (State Council of the People's Republic of China, 2012). Little by little, they have begun to use the carrot-and-stick technique to this end, on the one hand, restricting car ownership and use and increasing toll and parking charges (stick) and, on the other hand, investing in advanced and attractive PT systems (carrot) (Ceder, 2004). Since the 2000s, Chinese decision-makers have begun to shift some of their budgets from roadways to PT. However, the distribution of the investments among different modes of PT systems is not balanced. Most investments have gone into high-capacity, rapid PT systems, such as inter-city high-speed rail, metro rail, and bus rapid transit (BRT), and little is left to modernize essential bus services (Peng et al., 2012). These forms of PT systems, however, are still not effective in attracting private car users or in coping with increasing and diversified mobility needs, especially in cities with high population densities. Innovative forms of PT are therefore required to successfully draw people from their cars in order to reduce congestion, accidents and pollution, and to cater to ever-increasing, diversified transport demands (Ceder, 2007).

With the rapid development of information and telecommunication technology, an innovative mode of PT systems, known as customized bus, has been promulgated to provide advanced, personalized and flexible demand-responsive transit service to specific clientele, especially commuters. Indeed, this mode has been springing up across China. Different from conventional bus transit systems, in which users are passive recipients of predefined, standardized bus service, users of the CB system are actively involved in various operational planning activities throughout the entire service-design process so as to be able to relish a deluxe and personalized bus service. By using interactive, integrated information platforms, such as the Internet, the telephone and the smartphone, the CB service is very attractive to citizens as manifested in significantly increased PT patronage in more and more Chinese cities.

1.2. Literature review

Because CB is a very new PT system – it was first introduced and implemented in Qingdao in August 2013 – there is little literature about it (Zhan and Dong, 2014). However, the concept of vehicle sharing is not new, the earliest car-sharing system having started in Zurich in 1948 (Shaheen et al., 1998). Kirby and Bhatt (1974, 1975) discussed the subscription bus service, which is somewhat similar to CB, in the United States. They analyzed in detail ten case studies of a subscription bus service and identified seven characteristics that were deemed critical to its successful operation. The authors provided guidelines on planning, organization and the operation of such subscription bus services. Bautz (1975) summarized Kirby and Bhatt's (1974) work on the statistics of a set of representative subscription services and compared cost and revenue data from a subscription bus service and a subscription van service. McCall (1977) analyzed the evolution and operations of a subscription commuter-bus-service system, named COM-BUS, which was successfully operated in Ventura, Los Angeles, and Orange Country, California. McKnight and Paaswell (1985), who dealt with a subscription bus service in the Chicago area, pointed out that it could help reduce the peak demand and deficit on some of the commuter railroad lines. They identified six issues to which a PT agency should pay attention in order to launch such a subscription bus service. Chang and Schonfeld (1991) developed analytical optimization models to compare conventional and subscription bus systems that provided a feeder service to a single transportation terminal. Using defined operator and user costs, they identified the condition under which either service was preferable. Potts et al. (2010) conducted a comprehensive review of six main types of flexible PT services that were not fully demand responsive or fixed route that had been operating in the United States and Canada for the past 10 years. A decision-making framework was provided to PT agencies for considering flexible PT service under different environments.

Growing individual aspirations for more access and mobility have generated the need for a greater variety of transport services (World Bank, 1996). To that end, the State Council of the People's Republic of China released guidelines on the prior development of PT systems, especially charter bus service, in Chinese cities in 2012 (State Council of the People's Republic of China, 2012). Qingdao thereupon launched the first CB system that August in China (Zhan and Dong, 2014). Hu and Zhang (2014) briefly analyzed the background, definition, operation planning process, characters, and advantages of the CB service provided in Qingdao. One month after Qingdao, CB was implemented in Beijing (Xinhuanet, 2013; Beijing Public Transport Holdings Ltd., 2014). Xu et al. (2013) discussed the key system components, advantages and potential applications of CB in China, concluding that CB could enhance a city's PT system.

1.3. Objectives

The purpose of this paper is to provide a systematic examination and analysis of the development and current state of CB practices in China. To attain this objective, data on background, planning and operations were collected from 30 Chinese cities and the following operations performed: First, the temporal and spatial distribution of CB in China was examined. Then elements of its operations-planning process were examined: online demand, network route design, timetable development, vehicle scheduling, crew scheduling, real-time control, and fare design and collection. Lastly, the results of the examination and analysis were summarized to arrive at pros and cons of the system and to make recommendations. This report on CB in China, analyzed here for the first time, can offer a valuable reference for policy-makers, academic researchers, PT practitioners and others worldwide.

2. CB development in China

CB is now spreading through China like bamboo shoots after a spring rain. Since its introduction in Qingdao in August 2013, about thirty cities now either operate a CB service or have one under construction. Table 1 summarizes the historical development of CB systems in China. After Qingdao, Beijing, the capital of China, was next in line, with the Beijing Public Transport Holdings, Ltd., one of the biggest bus companies in China, launching a CB system in September. Subsequently, the service was introduced in Jinan and Tianjin in October and December, respectively. These four cities are all located in the Bohai Economic Rim, which is one of the three largest metropolitan regions in China.[2] Perhaps one reason for the introduction of CB may be that the four cities, but especially Qingdao and Beijing, have rich, first-hand experience in providing commuter bus and community shuttle-bus service, both of which are somewhat similar to CB.

In 2014, CB systems began to be opened very rapidly in other cities in China. In the first ten months of 2014, CB systems were launched in nineteen cities, constituting 82.61% of the existing CB systems now in operation in the country. What is more, CB systems are now under construction in seven cities while many other Chinese cities are in the process of planning and designing such systems. The spatial distribution of CB systems in China is depicted in Fig. 1. We can see that twenty-three cities (76.67%) are in the eastern part of the country; three cities (10.00%) are in the central part; and four cities (13.33%) are in the western part of China. In addition, 19 cities (63.33%) are in one of the three metropolitan regions. The reason for this deployment is that cities in the eastern part of China, especially in the three metropolitan regions, have a higher population density, better information and telecommunication technologies and stronger economies than Chinese cities elsewhere in the country. The total population of the thirty cities is 287.80 million, which accounted for about 21.15% of the total population of China in 2013. The total gross domestic product (GDP) of the thirty cities is 23,474.21 billion RMB, which amounts to about 41.27% of China's total GDP in 2013 (National Bureau of Statistics of the People's Republic of China, 2013). The figure also shows that about one fifth of the population occupies more than two fifths of its wealth. On the other hand, traffic congestion, traffic accidents and traffic emission problems are more serious in these thirty cities, and thus both local governments and the citizenry have a strong desire to develop and use CB systems.

To meet diversified passenger-travel demand, various CB systems have already been, and will continue to be developed. According to their different functions and characteristics, they can be classified as follows:

- *Customized commuter bus:* This kind of CB service is provided to carry commuters from their residential areas to work areas. It is the most common CB system that is now in operation in most cities.
- *Customized school bus:* This CB system is designed to provide pupils with a direct, safe and rapid transit service from their homes to schools. It is now in operation in Qingdao, Jinan and Foshan.
- *Customized business bus:* This kind of CB system is mainly designed for some large business activities. For example, the Beijing Public Transport company provided a customized business bus service for the Beijing International Automotive Exhibition in April 2014 (Beijing Public Transport Holdings, Ltd., 2014).
- *Customized community bus:* To solve the "last mile" transport problem, a customized community bus service was developed to bring a community's residents to transit hubs; e.g., railway/subway stations.
- *Other customized feeder/shuttle bus:* Except for the four main CB systems listed above, other kinds of customized feeder/shuttle bus systems are in the process of design and implementation to satisfy diverse mobility needs.

[2] The two other metropolitan regions are the Yangtze River Delta and the Pearl River Delta economic zones as shown in Fig. 1.

Table 1
Development of CB systems in China.

Year	Month	City
2013	8	Qingdao
	9	Beijing
	10	Jinan
	11	
	12	Tianjin
2014	1	Taizhou, Wuhan,
	2	Harbin
	3	Dalian, Kunming, Quanzhou, Wuxi, Xuzhou, Shenzhen
	4	Xiamen
	5	
	6	Mianyang, Suzhou, Fuzhou, Zhengzhou
	7	Ningbo
	8	
	9	Chengdu, Changzhou, Foshan
	10	Nanjing
Future (under construction)		Guangzhou, Hangzhou, Shanghai, Shenyang, Shijiazhuang, Xi'an, Xinxiang

CB is a totally demand-driven and user-oriented transportation system. Usually, it is very difficult to persuade people to change from using private cars to utilizing a PT service, as people are, in general, resistant to such a change. However, because CB can provide various citizens with personalized, comfortable and cost-effective travel service to meet their different travel demand, a considerable proportion of car users have shifted to PT. The CB service is usually designed by means of an online, interactive service-design process, involving both passengers and operators.

3. Demand-based CB service design

In transit service design, the fundamental question facing transit agencies is how to design the service well enough so that it can attract private car users to give up their cars. An advanced, attractive and viable transit service probably should be designed to make transit users feel that using transit service is like eating potato chips: once you start, it is hard to stop (Ceder, 2007).

CB is a demand-based transit system that aggregates the travel demand of individual passengers to provide personalized transit service. In transit planning, passenger-demand estimation – i.e., estimating the size, composition and distribution of passenger demand – is usually the first and most vital question facing operators because passenger-demand data is an essential input

Fig. 1. Spatial distribution of CB systems in China.

parameter for designing or redesigning any transit service. Traditional demand-estimation methods usually employ mathematical model, such as transit-assignment models, or historical data to estimate origin–destination (O-D) matrices. However, these methods may suffer from the problem of prediction errors because of their failure to accurately describe the complex choice behaviour of various passengers. The rapid advances in information and communication technology have now made it possible to conduct real-time online surveys, in which passengers are asked directly about their precise O–D, departure times and even personal contact information; and so to collect more accurate passenger-demand data. CB uses online passenger-demand surveys based on interactive, integrated information platforms, such as internet websites, and smartphone apps, to collect demand data and provide passengers with customized transit service.

The online demand-based service-design process in these CB systems, as depicted by the flowchart in Fig. 2, is a dynamic, interactive and bi-level decision-making problem. Instead of making decisions for all decision variables instantly in one step, both passengers and operators finish their decision-making process in a multi-stage manner, gaining feedback from each other at each decision stage. The whole decision-making process can be divided into four stages as shown in Fig. 2: travel survey, call for passengers, seat reservations and seat purchase. Each stage can be formulated as a bi-level programming problem, with passengers as the upper-level decision-maker and operators as the lower-level decision-maker. This path is totally different from traditional transit- planning activities, in which operators are treated as the upper-level and passengers as the lower-level decision-maker. During this demand-based service-design process, an interactive, online information platform is built for both passengers and operators to disseminate and collect information to support their decisions. Obviously, CB is user-oriented and designed to cater to different kinds of user demands. The four decision-making stages are explained in detail as follows:

- *Travel survey*: Potential CB users were first asked to register online to an information platform, whether an internet website or a smartphone app. They then can log into the program and submit a travel request, which includes information about travel O–D, departure times, whether round trip or one way, etc. Usually, a mobile phone number or an email address is required for receiving verification information from the transit operator after one successfully books a CB service. Such an online survey form used to collect potential CB users' travel-demand data is shown in Appendix A. In the future, passengers can log in, as well, to update their profiles.
- *Call for passengers*. Based on the aggregate travel-demand data provided by potential users, transit operators then design some appropriate initial CB routes. The origin area, destination area, departure and arrival times, boarding and alighting stops of the planned routes are announced on the information platform to recruit users. Potential users then choose those routes that suit them best. If the number of passengers choosing a route is large enough – e.g., more than 50% seats of a vehicle[3] – then the route will be regarded as effective and put into the final route set, and its service is scheduled; otherwise, the recruitment of passengers will continue.
- *Seat reservations*. Once final routes are determined and service is scheduled, passengers can see the final scheduled service information and reserve seats through the online information

[3] This load factor, defined as the ratio of the number of bookings to the number of vehicle-seats, is only for Beijing. It may be different for other cities.

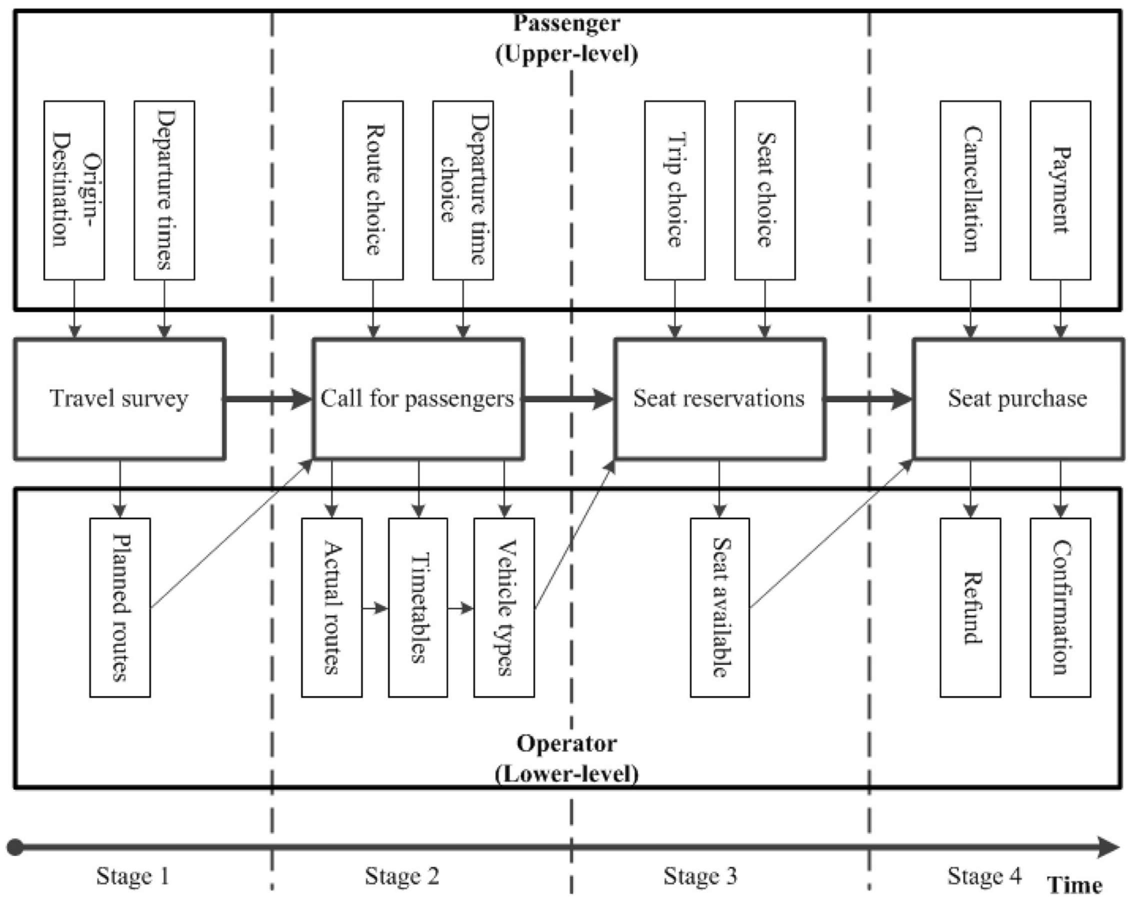

Fig. 2. Dynamic and interactive demand-based service-design process in CB.

platform. If there are empty seats, passengers who do not participate in the *travel survey* and *call for passenger* stages can also make reservations for seats. CB operators will not stop to announce real-time seat-status information until no seat is available.

- *Seat purchase*. After booking seats, passengers need to pay for the booked CB service, using online banking, credit card or transit smart cards. If they successfully make a payment, passengers will receive confirmation information, usually in the form of a short message via mobile phone or by checking the confirmed status directory on the information platform. Passengers who subscribe to the service for a current time-window can directly subscribe to the service for the next time-window without any prior reservation. Passengers can also ask for a refund if the scheduled service does not occur because of some unexpected reasons, such as an insufficient number of bookings.

The online travel demand survey provides the foundation of CB service design. Only with accurate travel-demand data can CB operators conduct operation-planning activities, whether route design, timetable development, or vehicle and crew scheduling. This dynamic, interactive, four-stage, demand-based service design process helps transit operators to design a customized travel service that satisfies the various requirements of different passengers.

4. CB operation-planning process

The CB operation-planning process commonly includes five basic activities, usually performed in sequence: (1) network route design, (2) timetable development, (3) vehicle scheduling, (4) crew scheduling and (5) real-time control. The systematic decision sequence of these five activities is outlined in Fig. 3 (adapted Ceder, 2007 and also appearing in parts in Ceder and Wilson, 1986; Desaulniers and Hickman, 2007; Muñoz and Giesen, 2010).

Generally speaking, the output of each activity positioned higher in the sequence becomes an important input for lower-level decisions. Occasionally the sequence in Fig. 3 is repeated; the required feedback is incorporated over time. Different from traditional PT operation planning process, which is fulfilled in a considerably long planning horizon; e.g., a year, a season or a month, the CB operation-planning activities are completed in a relatively short time. This planning process, furthermore, is conducted in an interactive manner, with real-time communication between CB users and operators based on an online information platform.

4.1. Network route design

The network route-design activity in Fig. 3 is aimed at designing a new CB network or redesigning an existing network. The goal is to define a set of routes for a planning area, with each route associated with a sequence of stops (Ceder and Wilson, 1986; Ceder, 2007). Generally speaking, traditional methods for bus-network route design are based on historical passenger-demand information, and usually the network route-design problem is formulated as a mathematical programming problem. Based on some predefined specific optimization parameters, optimization techniques are then employed to solve the optimization problem over the entire decision-making horizon (Guihaire and Hao, 2008). The network route-design method used in CB systems, however, is

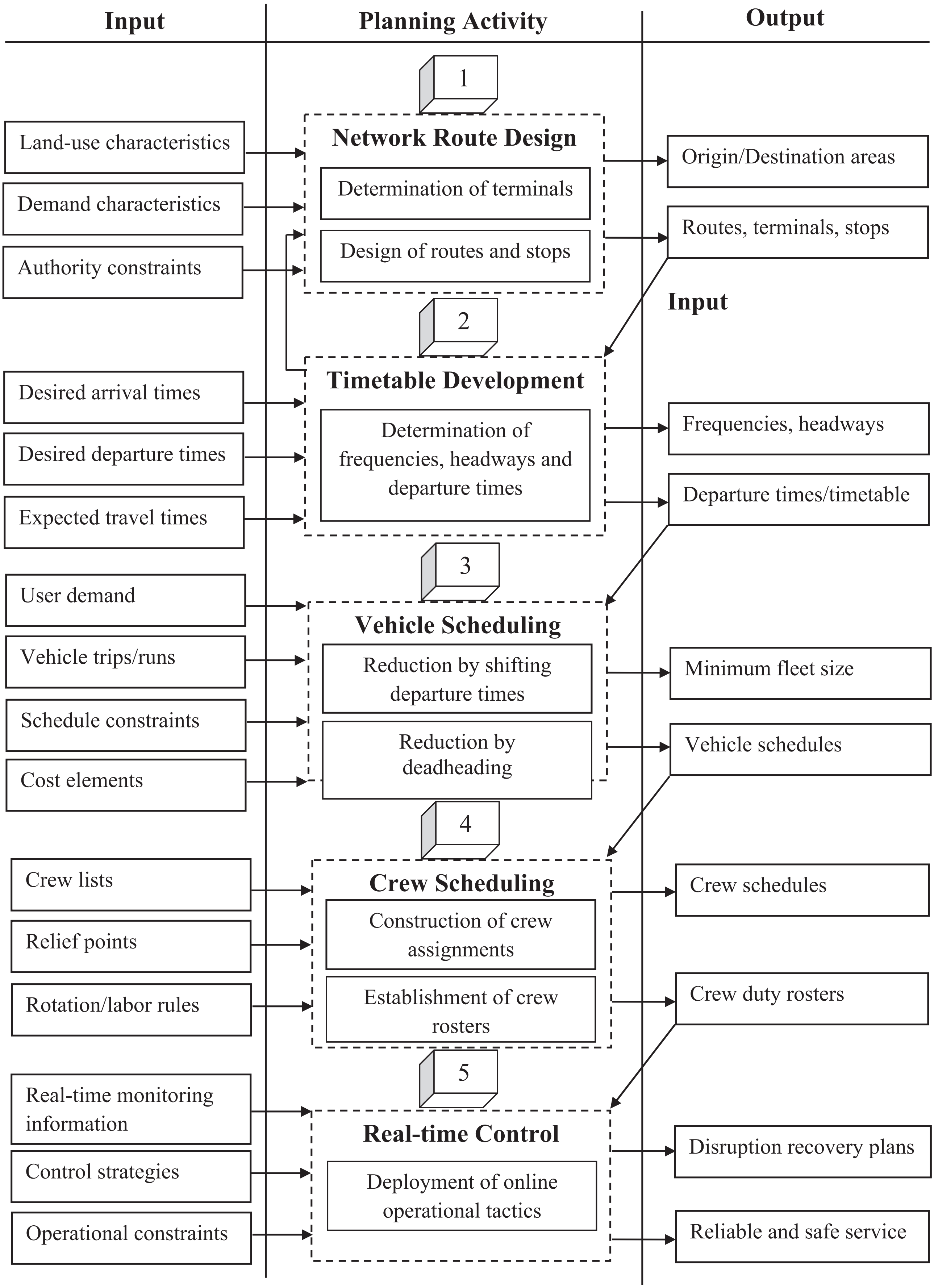

Fig. 3. Functional diagram (system architecture) of a common CB operation-planning process.

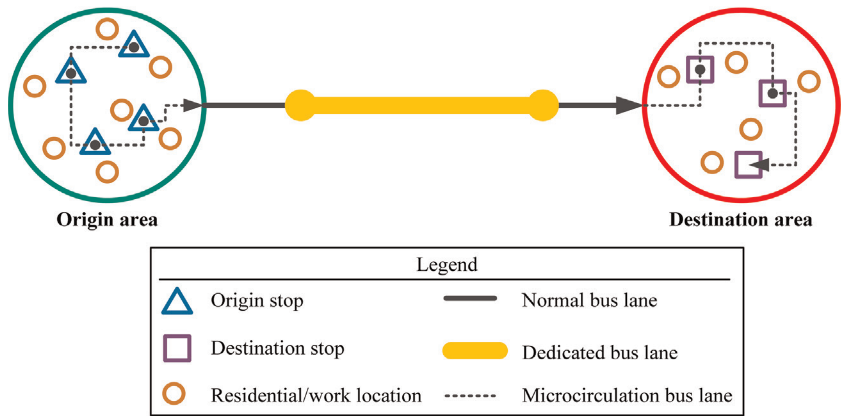

Fig. 4. Illustration of a typical CB route.

totally different from these traditional methods. In CB systems, the problem is not formulated as any complex and cumbersome mathematical programming problems. Instead, it is heuristically solved in a graphical, dynamic and human–computer interactive manner with the participation of both operators and users.

With the help of online, interactive, integrated information platforms, CB operators collect user-demand data in real time. User demands that have similar origin area, destination area, departure time and arrival time are aggregated. A route is then designed to serve users between origin and destination areas. A typical CB route is graphically illustrated in Fig. 4. In such a CB route, stops are generally located only within the origin and destination areas. These stops are designed to be located very close to users' residential and work places so that riders can enjoy a no-walking and door-to-door trip-chain service. Moreover, some microcirculation bus lanes are designed within the two areas to conveniently, rapidly and smoothly pick up and drop off users.

Between the origin and destination areas, there are usually no stops.[4] Thus, unlike conventional bus transit systems, CB vehicles do not need to stop at transit stops between the two areas, and thus users can enjoy a direct express service. Furthermore, the routing strategy between origin and destination areas may take into account dedicated bus lanes, which CB vehicles are allowed to use; as a result, passenger travel time can be significantly reduced, especially during congested peak hours, compared to traditional bus transit systems, which use mixed (car and bus) lanes.[5] In addition, CB drivers can flexibly change route segments on the basis of current road-traffic conditions, and use less-congested segments so that the total passenger travel time can be further reduced. These network route-design process and vehicle-routing strategies are totally different from the conventional fixed-route and fixed-stop operations scheme.

The main characteristic of the CB network route is that there are no interchanges or transfers. When designing CB network routes, operators need to consider only the location of origin and destination areas, origin and destination stops, and routing strategies between the two areas. This dynamic, interactive decision-making process is described in flow chart form in Fig. 5. The process is completed by both users and operators using the integrated information platforms, with real-time feedback

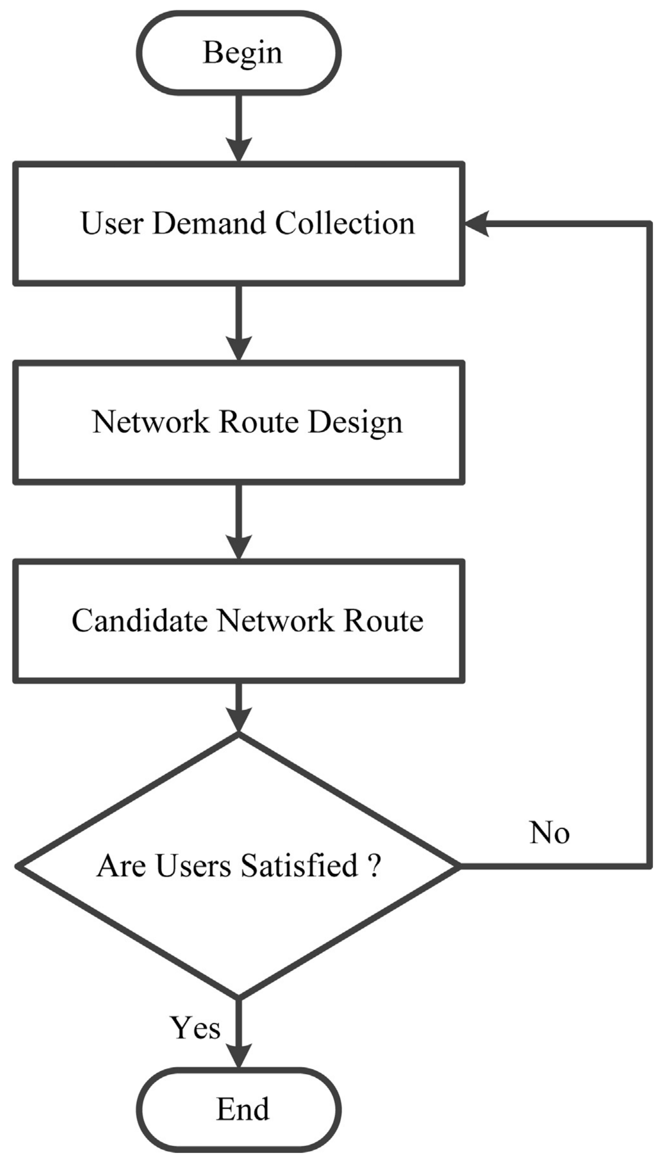

Fig. 5. Flow chart of the basic interactive, network route-design process in CB.

between them. If users are not satisfied with a candidate network route, operators will collect user-demand information and redesign the network route. Thus, one can see that the

[4] In some small cities with low population densities, a few stops may be located between the origin and destination areas in order to ensure a reasonable high number of patrons.

[5] Not every CB route is designed to be connected to dedicated bus lanes, but most of the existing CB routes are connected to such a lane. For example, 70–80% of current CB routes in Beijing are connected to dedicated bus lanes (Ministry of Transport of the People's Republic of China, 2014).

network route-design process in CB systems is completely user-oriented.

4.2. Timetable development

The goal of the timetable-development activity in Fig. 3 is to achieve a good match between CB vehicle capacity and user demand so that demand is accommodated while the cost of vehicles used is minimized. The results of this activity are a set of frequencies and headways, as well as a set of departure times for each CB route. In traditional bus transit systems, route frequencies and stop departure times are set firstly by operators. It is assumed that passengers will adjust themselves to a predefined timetable. However, this assumption is not realistic. In practice, because of fluctuation in passenger demand, uncertain road traffic conditions and passengers' complex travel behaviour, this approach usually leads to serious service-unreliability problems; for example, bus bunching (Ceder, 2007). In contrast to the traditional method, the method used to construct a timetable in CB systems is a graphical, dynamic and human–computer interactive approach with the participation of both operators and users, similar to the approach used in network route-design activity.

At the online demand-survey stage, CB users are first asked to record their desired arrival time at destination and desired departure time from destination in an online survey form (Appendix A). CB operators collect and aggregate these demand data in real time. The scheduled departure time of trip i at origin is given by

$$SDT_i^o = DAT_i^d - ETT_i^{od} \tag{1}$$

where DAT_i^d is the desired arrival time of trip i at destination; ETT_i^{od} is the expected travel time of trip i from origin to destination. Here, DAT_i^d is obtained from the online survey, and its value is self-reported by users. The value of ETT_i^{od} is determined by operators, usually by several field driving tests from origin to destination in the same period. It can be given by

$$ETT_i^{od} = \max_{k \in K}\left\{TT_k^{od}\right\} \tag{2}$$

where TT_k^{od} is the k^{th} travel time from origin to destination; K is the set of field driving tests. The maximum value of the test travel times is then regarded as the expected travel time.

The scheduled departure time of trip i from the destination is given by

$$SDT_i^d = DDT_i^d \tag{3}$$

where DDT_i^d is the desired departure time of trip i from the destination as collected from the online survey. With use of the online information platforms, DAT_i^d and DDT_i^d can be collected very quickly, and operators can easily determine the values of SDT_i^o and SDT_i^d. Obviously, unlike traditional methods, this method makes operators adjust the timetable to meet user demand. In addition, users of the same trip can negotiate with one another and with the driver to slightly shift the departure time so as to reach a final equilibrium result that satisfies all trip users; i.e., a Pareto-optimal solution.

4.3. Vehicle scheduling

The objective of the vehicle-scheduling activity in Fig. 3 is to create a set of trip chains or vehicle blocks; each chain is referred to as a vehicle schedule according to given timetables. A vehicle trip can be planned either to transit passengers along its route or to make a deadheading trip to connect two service trips efficiently. The major objective of this activity is to minimize the number of vehicles required or the total cost involved in employing various types of vehicles. In traditional bus transit systems, as mentioned, vehicle-scheduling usually does not explicitly consider passenger demand. In CB systems, however, this activity is accomplished, once again, in a dynamic interactive manner with the participation of both users and operators. This decision-making process uses several components, as shown in flow chart form in Fig. 6. Its steps are as follows:

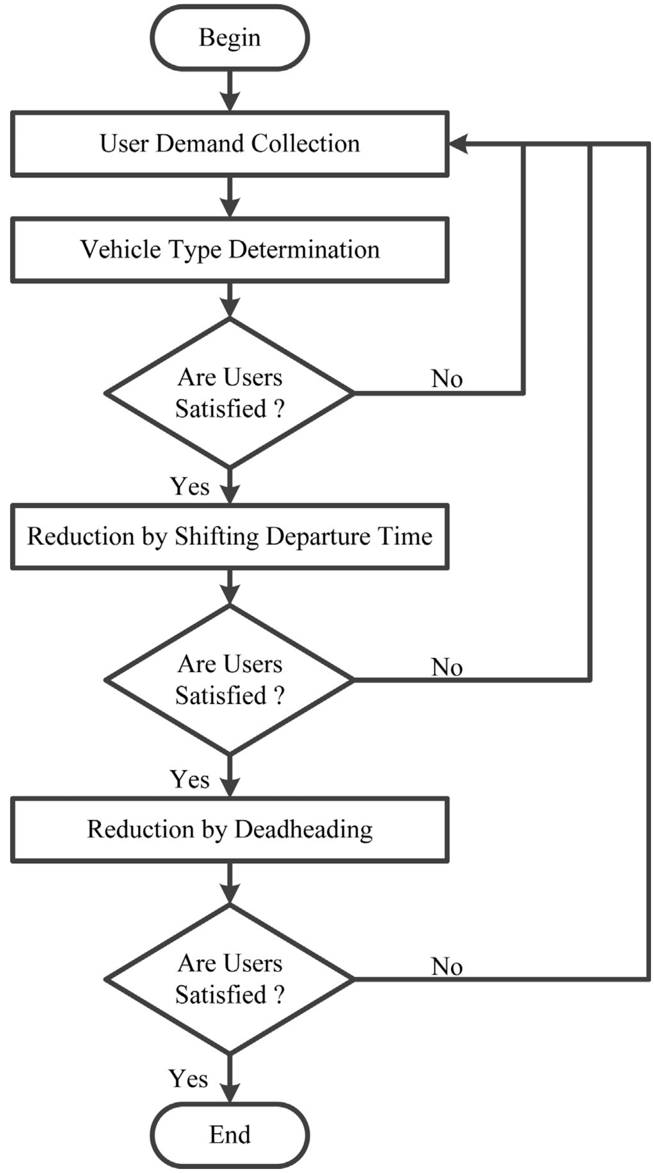

Fig. 6. Flow chart of the basic interactive vehicle-scheduling process in CB.

Step 1: User-demand collection. Based on the online information platforms, various types of user-demand information can be collected by CB operators in real time. Similar user demands are aggregated. A customized bus transit service is then designed to cater to users having a similar travel demand.
Step 2: Vehicle-type determination. According to the characteristics of the user demand, a vehicle of an appropriate type (size and comfort level) is assigned to serve these users. If they are satisfied, then go to *Step* 3; otherwise, return to *Step* 1.
Step 3: Reduction by shifting departure times. The fleet size is initially reduced by using feasible modifications in the creation

and editing of trip timetables and vehicle schedules (blocks); that is, shifting departure times based on some acceptable tolerances. If users are satisfied with the shifting results, then go to *Step* 4; otherwise, return to *Step* 1.

Step 4: Reduction by deadheading. The fleet size is further reduced by inserting possible deadheading or empty trips. If users are satisfied with the deadheading insertion results, then stop; otherwise, return to *Step* 1.

The above dynamic and interactive vehicle-scheduling procedure can be completed with the help of a very useful graphical technique, called deficient function (described in detail in Ceder, 2007).

4.4. Crew scheduling

The goal of the crew-scheduling activity in Fig. 3 is to generate and select a set of feasible daily driver duties (a.k.a. shifts, workdays or runs) for CB drivers so that all vehicle blocks or trips are covered and operation and labor constraints complied with during a planning period of a given duration (e.g., a week or a month). In most CB systems now in operation, this activity is somewhat similar to the conventional bus transit systems. Usually the crew-scheduling problem is formulated as a set covering or partitioning problem (SCP/SPP), which is non-deterministic, polynomial-time hard (NP-hard) and very difficult and time-consuming to solve, especially when the size of the problem is large (Ceder, 2007). Unlike the former three planning activities, this activity does not include the participation of CB users: just operators. The operators are responsible for designing crew duties and rosters and then assigning drivers.

In this activity, however, there are two main differences compared to conventional bus transit systems. First, the size of the crew-scheduling problem in CB systems is not very big, an advantage stemming from two features of the system. First, the number of feasible relief points is very small because of the special route characteristics. Thus, the size of the optimization problem is not large and, therefore, can easily be solved. Second, because CB systems have only recently been launched in Chinese cities, the CB network-route structure there is not very complex, and the number of routes not very large. This is another characteristic contributing to reducing the complexity of the SCP/SPP. Currently, this scheduling activity is undertaken manually by CB transit operators. Furthermore, usually only seasoned drivers who have very rich bus-driving experience and good driving records have been selected for driving CB vehicles. These drivers are, of course, very familiar with the local network routes and road traffic conditions. Since almost all the CB systems in Chinese cities are organized and operated by local transit agencies, CB drivers are usually taken directly from these transit agencies. Commonly, in order to improve service reliability, some transit agencies allocate one or two candidate drivers in case of emergencies when the planned formal driver cannot perform the scheduled driving activity.

4.5. Real-time control

The real-time control activity in Fig. 3 is aimed at improving CB service reliability. For more than 50 years, it has been known that if no control strategies are used in bus operations, even very small disturbances can cause serious off-schedule running (Newell and Potts, 1964). Schedule deviations will be amplified and propagated along the route, causing service deteriorations, such as bus bunching and missed synchronized transfers. In order to control the inherent randomness of PT systems, control strategies, such as holding, skip-stop and short-turn, have been utilized (Daganzo, 1997; Vuchic, 2005; Ceder, 2007).

Most CB systems that are now in operation are equipped with global positioning system (GPS) devices and monitoring systems. The CB transit control center has real-time location, speed and direction information about all its vehicles. These historical data are stored in databases for future operations planning. What is more, there is real-time communication between the CB transit control center and drivers. Thus, based on current traffic conditions and CB vehicle locations, operators can disseminate real-time advisory information, such as speed warnings, low-battery/fuel caution, holding time information, etc., to the drivers in order to control the movement of vehicles. Drivers are expected to follow the advisory information so as to drive in an optimal way to improve service reliability. The advisory information can be displayed online on the on-board variable message sign (VMS) installed in

Table 2
Comparisons of different characteristics in operations planning of CB and conventional bus transit services.

Planning activities	Characteristics	Customized bus systems	Conventional bus systems
Network route design	Method	Human–computer interactive approach	Mathematical programming
	Demand collection	Real-time and accurate	Historical and approximation
	Participation	Both users and operators	Only operators
	Routes and stops	Fixed and flexible	Fixed
	Lanes	Combination of normal, dedicated and microcirculation lanes	Usually normal bus lanes
	Transfers	Door-to-door service, without transfers	With transfers
Timetable development	Method	Human–computer interactive approach	Mathematical programming
	Participation	Both users and operators	Only operators
	Departure times	Flexible and adjustable	Fixed
Vehicle scheduling	Method	Human–computer interactive approach	Mathematical programming
	Participation	Both users and operators	Only operators
	Vehicle type	High-level of vehicle comfort	Ordinary vehicle
Crew scheduling	Complexity	Much easier, with fewer routes and less relief points	Complex, with many routes and relief points
	Drivers	Seasoned drivers	Ordinary drivers
Real-time control	Communication	Real-time communication	Lack of communication
	Control strategies	Online operational tactics	Lack of real-time control

the vehicle where drivers can notice it easily.

Table 2 summarizes the main results of a comparison of the different operations-planning characteristics of CB systems and conventional bus transit systems. The main difference between them is that the planning process in CB systems is carried out in a human–computer interactive approach with the participation of both operators and users. This is especially the case, as seen, for the network route-design, timetable development and vehicle-scheduling activities. It is an approach that considerably reduces the complexity of the operations-planning process and improves the diversification and attractiveness of CB service.

5. CB fare design and collection

A reasonable fare system plays an important role in the success of a CB system. This section looks into the current fare design and collection systems used in cities where a CB system has been successfully launched.

5.1. Fare design

In practice, there are many methods for determining the price of bus transit service. The most widely used methods are the unit tariff, zone tariff and distance tariff schemes. For the CB systems that are in operation, most transit agencies have adopted the distance tariff scheme or the unit tariff scheme. The former means that the fare of a trip depends on its length. Usually, the longer the distance, the higher the fare. In the unit tariff scheme, all trips have the same fare, regardless of distance.

A fare in the distance tariff scheme includes two parts: variable and constant. The variable fare can be given by

$$F_1 = \max\left\{0, F'\left\lceil\frac{L - L_0}{L_1}\right\rceil\right\} + F_0 \tag{4}$$

where L is the length of a trip; F_0 is the basic fare that is compulsorily charged as long as one uses the CB service; F' is the fare factor employed for calculating fares for different trip lengths; L_0 and L_1 are the threshold length and length factor, respectively; and function $\lceil x \rceil$ is the celling function, which gives the smallest integer $\geq x$. According to this definition, when the length of a trip is less than the threshold length L_0, it will be charged only the basic fare F_0.

Combining the variable fare with the constant fare, the total fare can be given by

$$F = \alpha_1 F_1 + \alpha_2 F_2 \tag{5}$$

where F_2 is the constant fare; α_1, $(0 \leq \alpha_1 \leq 1)$ and α_2, $(0 \leq \alpha_2 \leq 1)$ are the discount factors of the constant fare and the variable fare, respectively.[6] It is obvious that when $\alpha_1 = 0$, the distance tariff scheme degenerates into the unit tariff scheme; i.e., the unit tariff scheme is a special case of the distance tariff scheme, with $\alpha_1 = 0$.

Table 3 summarizes the fare parameters of CB systems in six typical cities. The length factor in all six is set as 5 km, and the fare factor as 2 or 3 RMB. The threshold length differs from 10 km to 20 km. In order to increase patronage, all the cities offer various discounts to users who subscribe to the service for an entire month, ten-thirty days or five-nine days. Chengdu and Fuzhou provided big discounts at the trial operation stage. Beijing offers three different discounts: to student smart-card users, adult smart-card users and users paying by cash. The goal is to encourage users to use smart-cards. Tianjin uses two different basic fares for vehicles of different size. These various fare structures present very good references for other cities.

Generally speaking, CB prices are a little more expensive than conventional bus service, but much cheaper than driving a private car. Because CB services are provided mainly by local transit agencies, which are usually state-owned enterprises and subsided by local governments, the agencies' main goal is to maximize total social benefits instead of their own interests.

5.2. Fare collection

CB users need to pay before they use the service. Fares can be collected in two ways: online and offline. Under the online payment scheme, users can make a payment through online banking, credit card or transit smart cards. Confirmation information will be sent if the payment is valid and successful. Most of the cities have adopted the online payment scheme because of its simplicity. However, some cities, for example Shenzhen, are still using the traditional (offline) payment method; that is, users need to pay by cash when they board CB vehicles. If a CB agency cancels a subscribed service because of some *force majeure* factors, such as bad weather or natural disaster, payers are entitled to a full refund.

6. Advantages of CB

The advantages of CB can be described as follows: *CB is an advanced, personalized and flexible demand-responsive PT system that operates attractively, reliably and relatively rapidly, with smooth (ease of) and transfer-free, door-to-door passenger chains.* The interpretation of each advantage is as follows:

6.1. Personalization

Unlike conventional bus transit systems, in which users are passive recipients of a predefined, standardized bus service, CB system users are actively involved in the various operations planning activities of the whole service-design process. This enables them to develop a personalized transit service by using interactive, integrated information platforms, such as an Internet website, a regular telephone or a smartphone app. CB services are tailored to meet a user's preference, and users on their own initiative can affect various operations planning activities, such as network route design, timetable development and vehicle scheduling. The personalized services suit a user's need and improves satisfaction.

6.2. Flexibility

Conventional bus systems use fixed routes, fixed stops and fixed timetables, which are not user-oriented and sometimes make users feel clumsy and awkward. In contrast, CB systems make use of flexible route segments, variable stops and adjustable departure times based on real-time user demand and road traffic conditions. CB vehicles are allowed to use dedicated bus lanes, which can significantly reduce travel time, especially at peak hours. There are also no or fewer stops between O–D areas, obviating the need for users to wait. Based on real-time traffic information, CB drivers can change route segments to reduce travel time; for example, by bypassing a congested route segment. Furthermore, users can negotiate with one another to achieve a desirable departure time that satisfies everyone. These flexible aspects of CB systems can improve the level of service and reduce operational costs.

[6] Discounter factors α_1 and α_2 here are not allowed to be negative, since CB users do not receive subsidies from local governments or service providers.

Table 3
Summary of fare parameters of CB systems in six cities.

Parameter	Beijing	Chengdu	Dalian	Fuzhou	Tianjin	Xiamen
F_0 (RMB[a])	8	6	6	6	6.75 For a 45-seat vehicle, 12 for a 20-seat vehicle	10
F' (RMB)	3	3[b]	2	2	3	3
F_2 (RMB)	1	0	0	0	0	0
L_0 (km)	20	10	10	20	15	20
L_1 (km)	5	5	5	5	5	5
α_1	0.8 For monthly subscription,	0.7 For trial operation	0.8 For monthly subscription	0.6 For trial operation	0.9 For a quarterly subscription	0.7 For monthly subscription, 0.8 For more than a ten-day but less than a one-month subscription,
	0.9 For more than ten days but less than a one month subscription, 0.95 For a five-nine-day subscription					0.9 For a five-nine-day subscription
α_2	0.2 For students using a smart-card, 0.4 For adults using a smart-card 1 For payment by cash	1	1	1	1	1

Note: Data are collected from the online information platforms, which display fare information to users.
[a] RMB=renminbi, the official currency of the People's Republic of China.
[b] For $10 < L \leq 15$, $F' = 2$, and for $L > 15$, $F' = 3$.

6.3. Attractiveness

Compared with conventional bus transit, private car and taxi service, CB service is more attractive to users. First, CB service is more comfortable than conventional bus transit service. Every subscriber of a CB service is guaranteed a clean, snug and cosy seat. The overcrowding and dirty seating environment characterizing conventional bus transit systems are successfully avoided. Other amenities include good air-conditioning, free Wi-Fi, TV, radio, newspapers, magazines, drinking water, tissues, air purifier, medical kit, mobile phone chargers, and online displays of timetable, time and weather. Second, CB service is more cost-effective than using a private car or a taxi service. The level of service of CB is almost the same as and sometimes better than private cars and taxi, and the cost is much cheaper.[7] In addition, the cost of construction and operation of a CB system is cheaper than that of metro systems. Some CB transit agencies even buy health and life insurance for users. Given these features of attractiveness, the CB can really "beat" the car and, thus, successfully attract a significant number of private car users to give up their cars and shift to PT.

6.4. Reliability

In CB systems, there are small variances in measures of concern to both users and operators. Because CB routes are designed to include dedicated bus lanes, there are fewer travel delays caused by road traffic disturbances and disruptions. The total travel time is more reliable. Users can receive real-time pre-trip information about the specific stop, such as location and departure time, from an interactive, integrated information platform; drivers, on their part, have information about users, such as name, telephone number, address, etc., which reduces the risk that users will miss their trip. GPS devices are installed in the vehicle, and the transit control center can monitor the location of vehicles in real-time. Once there are schedule and route deviations, online operational tactics are transmitted to drivers to enable achieving a recovery from errors. Service punctuality and reliability are significantly improved under this advanced, real-time, tactic-based method of operation.

[7] It is estimated, for example, that for a 20-kilometer trip in Beijing, it would cost only 15 RMB to use the CB service, but it would cost more than 50 RMB to use a private car, taking fuel, parking and toll fees into consideration.

6.5. Rapidness

CB vehicles travel much faster than conventional bus and sometimes even faster than private cars. Usually there are no or few middle stops along CB routes, and thus vehicles can move at a stable speed and do not need to stop to pick up and drop off passengers. What is more, CB vehicles, in addition to the permitted use of dedicated bus lanes, sometimes have signal priority at signalized intersections. Another feature is that CB vehicles can dynamically change route segments in real time according to the current traffic condition in order to avoid traffic congestion. All of these characteristics contribute to improving the rapidness of a CB service.

6.6. Smoothness (ease of)

CB service is accessible to a multiclass of users. As described earlier, they can employ the telephone, internet, or smartphone app to subscribe to a service. Based on demand, CB boarding and alighting stops are designed to perfectly match users' origins and destinations; thus, they do not need to walk a long distance to/from the stop. Pictures of spatial positions of the boarding and alighting stops are displayed on the information platforms, so that users can conveniently become familiar with them. Finally, CB vehicles are designed with a low entry chassis and two sets of double doors so that users can board and alight easily and smoothly.

6.7. Transfer-free door-to-door

One of the biggest advantages of a CB system is that users do not need to make any transfers. The inconvenience and delay caused by transfers constitutes one of the most important factors deterring citizens from using a public transport service. Synchronized transfers in conventional bus transit systems are utilized to reduce inter-route passenger-transfer waiting time and to provide a well-connected service. In practice, however, synchronized transfers do not always materialize because of stochastic and uncertain factors, such as traffic disturbances and disruptions, fluctuations in passenger demand and bus drivers' erroneous behaviour. Without transfers, the origin and destination stops along routes are designed directly from users' departure and arrival places, enabling riders to enjoy a no-walking, transfer-free, door-to-door trip chain service.

In addition to advantages enjoyed by users and transit agencies, CB also offers various benefits to the public at large (externalities). First, it provides a promising solution to the problem of traffic congestion in many highly populated cities. It is estimated that a CB vehicle can effectively take the place of at least 30 private cars at peak hours (Zhan and Dong, 2014). It can successfully lure people from their cars so as to help relieve severe traffic problems in many cities with large populations and a high car ownership, such as Beijing, Shanghai and Guangzhou. Second, by reducing the number of private cars and using electric vehicles, CB contributes to reducing vehicle emissions and improving air quality and, consequently, human health. Statistics from the Beijing Municipal Environmental Protection Bureau (2014) show that vehicle exhaust accounts for 31.1% of PM2.5, which is to blame for causing thick fog, air pollution and human health problems.[8] CB's use of electric vehicles can help to mitigate this serious problem. Third, CB caters to the increasing diversity of travel demand. The rapid development of China's economy and the country's increasing wealth have raised a strong desire for comfortable, convenient and personalized PT service. CB, as a substitute service for private car and a complementary service to conventional PT, serves as a good alternative to meet the diversification of user demand and to fill the demand that is not adequately being addressed by conventional PT systems. Although we cannot change the direction of the wind (the diversification and evolution of user demand), we can adjust the sails (create advanced and personalized CB service), which eventually will pay off the expense.

7. Difficulties and recommendations

CB systems have already been successfully implemented in 22 cities in China, and are now under construction in 8 more cities. In addition, many other cities are in the process of planning a CB service. It is generally regarded as a success; however, there are still some problems that need to be addressed.

7.1. Policy and decision-making

Although the national government gives high priority to PT systems, especially charter buses, local governments should take an objective, rational attitude toward the development of CB systems. If current conventional bus transit systems can be optimized to satisfy user demand, then there is no urgent need to develop a CB system, because of its construction and operational costs. Since almost all the CB systems implemented in China's cities are organized and operated by local transit agencies, which are heavily subsided by the local governments, the transit agencies should spend their limited budgets wisely to provide good-quality, equitable service to satisfy the public at large, instead of various groups of special people. The transit agencies should publicize information about whether the construction and operation of a CB use government subsidies. Another good way of financing CB service is to have partners of other organizations, such as private transit operators, community groups and employers.

7.2. Advisory committee

A national advisory committee is now urgently needed to advise local organizers of all aspects of the CB development process. Currently, some cities have already successfully launched CB systems and accumulated much experience, which is valuable for cities that are now constructing and planning CB systems. However, no such standardized national advisory committee now sets guidelines on the planning and operations of CB systems. A national advisory committee composed of experts from different fields and cities should now be organized to synthesize the experiences of existing CB systems, establish criteria for CB planning, design and construction, evaluate CB proposals and hold technical and academic forums and conferences.

7.3. Planning and design

CB organizers should make everyone have easy access to information platforms, so as to attract more users to use them. The more people who use the information platforms to submit their travel-demand data, the better the CB service will become for everyone. In addition to Internet, telephone, and smartphone apps, other social media, for example microblogging, can also be used to enlarge and enable real-time travel-demand information to be shared both among users and between users and operators.

Currently, almost all the CB routes in China's cities are not well connected with other modes of transportation systems. At the planning stage, Both routes and timetables of should be planned to coordinate spatially and temporally with other PT system modes, such as metro, bus rapid transit (BRT) and light rail transit (LRT), so that users can enjoy a seamless transfer service.

A signal priority system and dedicated bus lanes need to be designed for CB to improve travel speed and reduce vehicle delays. Integration of CB planning and land use is often negated, because they are usually managed by different Chinese government departments or agencies. A good coordination of the two activities is needed for urban planning and transportation planning activities. In addition, CB logos, signs and in-vehicle decorations also have to be carefully designed to distinguish the CB system from conventional bus transit system, to modernize the image of CB, and to make users feel comfortable and cheerful.

7.4. Operations and management

From the perspective of transit agencies, the largest single cost of providing a CB service is generated by vehicle use and drivers' wages. In order to reduce operational costs, CB vehicles can be used for other social and recreational activities when they are not scheduled for providing CB service. In addition, drivers can be selected directly from the population of CB users so that PT agencies need not hire drivers (sort of a share driving given proper driving licences).

Pre-trip and en-route travel information need to be shared in real time among users, drivers and operators to improve service reliability.

[8] PM2.5, fine particles or particulate matter, refers to particles with an aerodynamic diameter of 2.5 μm or less.

7.5. New technology

New information and telecommunication technologies can be used to collect more accurate and larger-scale travel-demand data and enable real-time information sharing. New energy technologies need to be developed to reduce vehicle emissions, and new battery technologies will help to improve the range of electric CB vehicles between rechargings.

8. Conclusions

CB has already been successfully implemented or is under construction in 30 Chinese cities. More and more cities in that country are interested in planning and providing a CB service. This paper provides a systematic analysis of the current state of CB practices in China. From the comprehensive, in-depth analysis that was conducted, the following conclusions can be drawn:

(1) China's fast economic growth in the past three decades had led to rapid urbanization and motorization in that country, which in turn has resulted in ever-increasing and diversified travel demand. Innovative public-transport (PT) modes, like CB, are needed to draw people from their private cars to use PT and thus meet the ever-rising and more diverse mobility needs of many individuals in China.
(2) In August 2013, Qingdao launched the first CB system in China. It was then implemented in three other cities (Beijing, Tianjin, and Jinan) in 2013. As of October 2014, there were 19 cities in which CB was in operation and 7 more cities in which a system was under construction. Among these 30 cities, 23 cities (76.67%) are in the eastern part of China; 3 (10.00%) are in the central part of China; and 4 (13.33%) are in the western part of the country. In addition, 19 of the cities (63.33%) are located in the three main metropolitan regions. The total population and the total GDP of the 30 cities account for 21.15% of the national population and 41.27% of the country's GDP in 2013.
(3) CB services are tailored to meet users' preferences. User demand is assessed in real time through the use of interactive and integrated information platforms, such as Internet websites, telephone and smartphone apps. The dynamic, interactive, demand-based service-design process characterizing CB includes four main steps: travel survey, call for passengers, seats reservation and seats purchase.
(4) The operations-planning process in CB is totally demand-driven, activities including network route design, timetable development, vehicle scheduling, crew scheduling, control; all are based on real-time user-demand information. The main operations-planning difference between CB and a conventional bus is that CB uses a human–computer interactive approach with available online information.
(5) A distance tariff scheme and a unit tariff scheme are the two main fare structures adopted by most transit agencies for the CB systems that are now in operation. Prices for CB systems are a little higher than those for conventional bus systems, but much lower than using a private car or taxi. Usually, users can make payment online by using online banking, their credit card or transit smart card.
(6) CB is an advanced, personalized and flexible demand-responsive transit system that operates reliably and relatively rapidly, as well as with attractive vehicles, and with smooth (ease of) and transfer-free, door-to-door passenger chains.
(7) Problems and recommendations on policy decision-making, on creating advisory committee, on planning and design, on operations and management, and on new technology are provided. More attention needs to be paid to these problems to ensure sustainable operation and future development. Corresponding suggestions are given to serve as a basis for further research and interest of academic researchers, policy-makers, PT planners, practitioners and others interested in CB both in China and other countries.
(8) CB is an alternative PT system attractive to both users and operators with a potential to shift a significant number of private car users to PT service. CB provides a good means of reducing urban traffic congestion, improving traffic safety, and alleviating energy consumption and greenhouse gas emission problems.

There is a saying that the best way to make our dreams come true is to wake up. Therefore, it is time to wake up and take action to support the development of CB, so as to add another efficient and intelligent PT mode, and thus to increase the chances that commuters will switch from private cars to public transportation.

Acknowledgements

The authors would like to acknowledge the support of the China Scholarship Council for this study. Any opinions, findings, conclusions or recommendations expressed in this paper are solely those of the authors.

Appendix A. Typical online travel demand survey

This online demand survey form is of the kind used to collect potential users' travel demand data. The survey process is completed by using a human–computer interactive, integrated information platform with the participation of both users and operators.

Origin:					**Destination**:				
☐ Find on map					☐ Find on map				
Desired arrival time at destination:					Desired departure time at destination:				
☐ 8:15	☐ 8:30	☐ 8:45	☐ 9:00	☐ Others	☐17:15	☐ 17:30	☐17:45	☐18:00	☐Others
Trip type:	☐ One way (Morning)				☐ One way (Afternoon)			☐ Round trip	
Travel mode usually used:				☐Walking	☐ Bus	☐Subway	☐ Taxi	☐ Car	☐Others
Name (optional):									
Telephone number:									
Email address:									
Comments and suggestions:									

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