ISSN: 2472-3703 DOI: 10.6911/WSRJ.202102_7(2).0008

Research on Dynamic Pricing Strategy of Customized Bus

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Abstract

Under the call of "vigorously developing public transportation" and the evolution of People's travel demand, customized bus comes into being. In order to promote the healthy development of the customized bus market, this paper presents a dynamic pricing strategy based on the previous researches and the consideration of the actual situations. This dynamic pricing strategy refers to divide the operation period of the customized bus into the initial period and the stable period, and to set different fares at different times according to different development objectives by applying differential discounts. Based on this dynamic pricing strategy, a pricing model is constructed to maximize the benefit of the enterprise, and particle swarm optimization algorithm is used to solve the model. In the case study, a commuting route from Shanghai Lingang Industrial District to the Main City of Shanghai Lingang is taken as an example to verify the rationality of the pricing strategy, thus providing a reference for the scientific pricing of customized public transport.

Keywords

Public transport; Customized bus; Dynamic pricing strategy; Pricing model.

1. INTRODUCTION

In recent years, with the development of the Internet and the improvement of the service quality in People's travel demands, a new type of public transportation with both individuation and intensification has appeared in China public transportation system, that is, customized bus. It brings together travelers with the same travel needs, provides them with a more comfortable service than regular buses, and provides them with their own routes, departure times and stops. At the same time, the personalized service and market-oriented factors lead to the inevitable increase in fares, even higher than the fares of the traditional public transport. However, too high ticket prices will not attract customers; too low ticket prices will cause the loss of operating units, and may even quickly destroy the development of customized public transport market. Therefore, the customized bus ticket pricing appears to be particularly important.

Foreign scholars have done a lot of research on customized public transportation since 1970s, in addition to the research on route planning, the research on public transport fare by foreign scholars was mainly based on Aaron Ramsey's theory and marginal cost theory before 1980s (Vukan Vuchic, 2006). Since 1980s, scholars have improved the marginal cost pricing method, which makes the profit and loss balance between social benefit and public transport operation (Glaister and Lewis, 1978; Tabuchi, 1994; Ferrari, 1995). Tao Liu and Avishai (Avi) Ceder (2015) analyze the evolution of this new public transport concept across 30 Chinese cities where customized bus systems are currently in operation or under construction. With the development of the customized public transportation in China, the pricing strategy of customized bus has been studied by Chinese scholars. Based on the theory of Game Theory and Traffic Psychology, Guan Weixin (2016) established a tripartite game model of operation

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202102_7(2).0008

enterprise, passenger and government. Huang Weiqi (2018) and others based on the urban transportation network, constructed an upper-level pricing decision-making model aiming at the optimization of enterprise profit maximization and system, and a multi-way stochastic user equilibrium model as the lower-layer. Zhang Qingshan (2019) constructs a two-tier matrix fare game model based on revenue maximization, and establishes game relations between customized bus and regular bus, rail transit, taxi and private car respectively.

However, previous studies on the pricing of customized bus have paid less attention to the dynamics brought by the market factor in the operation of customized public transport. This paper starts from the practice of the customized bus in China, considering that the fare of the customized public transport should vary according to its own purposes in different development periods. Based on this dynamic pricing strategy, this paper constructs a pricing model to maximize the benefit of the operating enterprises under reasonable constraints, and adopts particle swarm optimization (PSO) as its solution algorithm. This paper selects the industrial area and the main urban area of Lingang New City, Pudong New Area, Shanghai, China as the travel end points area, and plans to implement the customized bus service between these two areas. The pricing model is used in this case, and then the generalized travel cost is calculated to verify the rationality of the bus fare based on this pricing strategy.

2. MODEL

2.1. Model Hypothesis

In this paper, the process of bus fare pricing is regarded as a decision-making process. This paper is based on the case that the bus operator is the decision maker, the fare is the decision variable, the profit maximization is the target, the acceptable range of passengers for fares and the main competitors' passenger generalized travel cost are the constraints. In this paper, a pricing model is constructed by considering different discount schemes in different development periods. Through this dynamic pricing strategy to make operating companies in general profit, and maintain the development of the customized public transport market.

Firstly, the total duration of a customized bus line is divided into the initial period and the stable period. The discount rate should be different between the initial stage of operation and the stable stage of operation, that is, the operating company usually attracts the passenger flow through the large discount strategy in the initial period, and uses ''the long-term reservation enjoys the preferential benefit” in the stable period. Based on the experience of customized bus from China, this paper divides the discount rate into the first, the second and the third stage according to the length of booking days.

As for the rule of refund, it should have referred to the “step-by-step” rule of air transportation, but in order to simplify the model here, this paper assumes that the same handling fee will be charged for refund. In addition, considering the low probability of the passenger’s behavior of “Don’t get on the bus after buying the ticket and don’t apply for refund”, this part of the revenue is ignored while modeling.

2.2. Symbolic Description

The symbolic descriptions involved in the model are shown in Table 1.

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Table 1. Symbolic description

Name	Description	Notes
N_1	The number of cycles a customized bus line is divided into at the initial period of its operation	
N_2	The number of cycles a customized bus line is divided into in its total operation	
$N_2 - N_1$	The number of cycles a customized bus line is divided into at the stable period of its operation	
n_1	Any cycle in the initial period of operation for a customized bus line	$n_1 \in \{1,2,\cdots,N_1\}$
n_2	Any cycle in the stable period of operation for a customized bus line	$n_2 \in \{N_1+1, N_1+2,\cdots,N_2\}$
c_{n_i}	It is a function of the actual number of seats, which represents the per capita operating cost of the initial and stable period of the development of the customized public transport operators respectively	$i = 1、2$
θ	The handling rate for passenger refund	
δ_{n_1}	The discount rate in the initial period of operation	
$\delta_{n_{20}}$	The discount rate for those who do not have the discount during the stable period of operation	$\delta_{n_{20}} = 1$
$\delta_{n_{21}}$	The discount rate available to passengers who have reached the first stage for a predetermined number of days during the stable period of operation	$\delta_{n_{21}} < \delta_{n_{22}} < \delta_{n_{23}}$
$\delta_{n_{22}}$	The discount rate available to passengers who have reached the second stage for a predetermined number of days during the stable period of operation	
$\delta_{n_{23}}$	The discount rate available to passengers who have reached the third stage for a predetermined number of days during the stable period of operation	
φ_0	The proportion of passengers who do not have any discount rate during the stable period of operation	
φ_1	The proportion of passengers who have the first-stage discount rate during the stable period of operation	
φ_2	The proportion of passengers who have the second-stage discount rate during the stable period of operation	
φ_3	The proportion of passengers who have the third-stage discount rate during the stable period of operation	
k_{n_1}	The refund coefficient for initial period of operation	
$k_{n_{2j}}$	The refund coefficient of different preferential classes during the stable period of operation	$j = 0、1、2、3$
R	The revenue that the operator gets	
R_{n_1}	The revenue that the operator receives at the initial period of the operation	
R_{n_2}	The revenue that the operator receives at the stable period of the operation	
$P_{n_{10}}$	The original fare at the initial period of the operation	
$P_{n_{20}}$	The original fare at the stable period of the operation	
P_{n_1}	Actual fares paid by passengers at the initial period of the operation	$P_{n_1} = P_{n_{10}} \cdot \delta_{n_1}$
$P_{n_{2j}}$	Actual fares paid by passengers with different discounts at the initial period of the operation	$P_{n_{2j}\,(j=0、1、2、3)} = P_{n_{20}} \cdot \delta_{n_{2j}(j=0、1、2、3)}$
P_α	The common bus fare for the same starting and ending point	
P_β	The fare for choosing rail transit from the same starting point to the same starting point	
P_γ	The required fare for choosing the private individual mode of transportation from the same starting point to the same starting point	
Q_{n_i}	It represents respectively the number of person who purchase tickets per cycle in the initial period and stable period of the operation of customized bus	$i = 1、2$
$Q_{n_{2j}}$	The number of person who purchase tickets per cycle under different preferential conditions during the stable operation period	$Q_{n_{2j}\,(j=0、1、2、3)} = Q_{n_2} \cdot \varphi_{j(j=0、1、2、3)}$
Q'_{n_i}	It represents respectively the number of person who refund tickets per cycle in the initial period and stable period of the operation of customized bus	$i = 1、2$
$Q'_{n_{2j}}$	The number of person who refund tickets per cycle under different preferential conditions during the stable operation period	$Q'_{n_{2j}\,(j=0、1、2、3)} = Q_{n_{2j}\,(j=0、1、2、3)} k_{n_{2j}(j=0、1、2、3)}$
$Q_{n_i} - Q'_{n_i}$	It represents respectively the actual number of passengers per cycle in the initial period and stable period of the operation of customized bus	$i = 1、2$

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2.3. Modeling

In the initial period of the operation for customized bus line, the revenue in every cycle was expressed as:

$$R_{n_1} = \left(Q_{n_1} - Q'_{n_i}\right)\left(P_{n_1} - c_{n_1}\right) + Q'_{n_1} P_{n_1} \theta \quad (1)$$

In the stable period of the operation for customized bus line, the revenue in every cycle was expressed as:

$$R_{n_2} = \sum_{j=0}^{3} \left[\left(Q_{n_{2j}} - Q'_{n_{2j}}\right)\left(P_{n_{2j}} - c_{n_2}\right) + Q'_{n_{2j}} P_{n_{2j}} \theta\right] \quad (2)$$

The main objective of the pricing model is to achieve profit maximization by adopting different preferential policies for different periods. So the objective function of the model is:

$$\begin{aligned} \max R\left(P_{n_{10}}, P_{n_{20}}\right) &= \sum_{n_1=1}^{N_1} R_{n_1} + \sum_{n_2=N_1+1}^{N_2} R_{n_2} \\ &= \sum_{n_1=1}^{N_1} \left[\left(Q_{n_1} - Q'_{n_i}\right)\left(P_{n_1} - c_{n_1}\right) + Q'_{n_1} P_{n_1} \theta\right] + \sum_{n_2=N_1+1}^{N_2} \sum_{j=0}^{3} \left[\left(Q_{n_{2j}} - Q'_{n_{2j}}\right)\left(P_{n_{2j}} - c_{n_2}\right) + Q'_{n_{2j}} P_{n_{2j}} \theta\right] \\ &= \sum_{n_1=1}^{N_1} Q_{n_1} \left\{\left[1 + k_{n_1}(\theta - 1)\right] P_{n_{10}} \delta_{n_1} + \left(k_{n_1} - 1\right) c_{n_1}\right\} + \sum_{n_2=N_1+1}^{N_2} \sum_{j=0}^{3} Q_{n_2} \varphi_j \left\{\left[1 + k_{n_{2j}}(\theta - 1)\right] P_{n_{20}} \delta_{n_{2j}} + \left(k_{n_{2j}} - 1\right) c_{n_2}\right\} \end{aligned} \quad (3)$$

In addition to the government's constraints on the fares of the customized public transport operators, they are also subject to the generalized travel costs of competing modes of travel between the same starting and ending points, the most important constraint, of course, is the passenger's acceptance of the fare for that mode of travel.

In summary, the constraints of the pricing model is: $P_\alpha < P_\beta \le P_{n_{10}} < P_{n_{20}} < P_\gamma$

3. MODEL APPLICATION: CASE OF LINGANG NEW CITY

3.1. Case Background Description

Lingang New City is located in the southeast of Pudong, Shanghai. Its total area is 296 square kilometers. It consists of nearly 100 square kilometers of main city area and about 220 square kilometers of industrial area. It is understood that a part of the people working in the existing industrial zone live in the Main City of Dishui Lake, which has lower housing prices and sells limited-price houses. The average distance from the industrial area to the main urban area is about 16 km, and the means of transportation available are traditional buses and taxis. However, the present transportation is not convenient. On the one hand, although the fare of traditional bus is only 1 or 2 yuan, the bus departure interval between the two transport zones is between 20 and 40 minutes, and it takes commuters at least an hour to take regular buses, even makes more transfers. On the other hand, although it takes only 25 minutes to get destination by taxi, it costs about 45 yuan. The inconvenience of travel will make Lingang New City lose a lot of talent, especially just graduated or non-private car commuters.

Therefore, this paper adds a new mode of trip, that is customized bus, between the two regions, and uses the dynamic pricing strategy model constructed in chapter 2 to set the ticket price. Then, "Yihao Oujing", the residential area of limited-price commercial housing in the main

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202102_7(2).0008

city area of Lingang New City, and "Lingang Industrial Manufacture Park", the Central Zone of Lingang Industrial Zone, are chosen as the travel end points of the customized bus line. The location of this pair of OD(Origin-Destination) is shown in Figure 1.

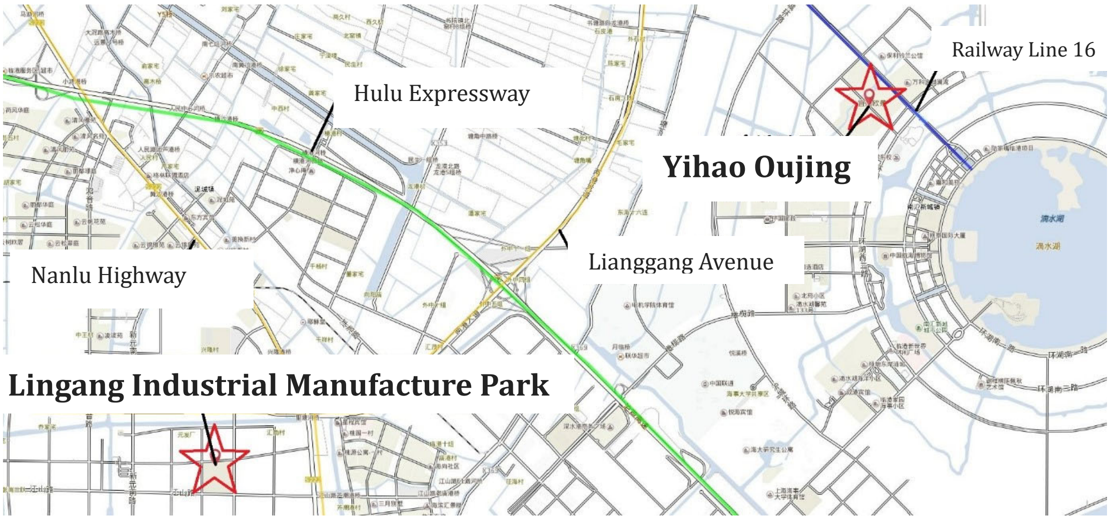

Figure 1. Location schematic of the selected pair of OD

3.2. Model Application

3.2.1 Model parameter setting

(1) Per capita operating cost

From the development of customized bus in China, we know that the most size of the customized buses are 45 seats, but in fact, the occupancy rate of customized buses is 65% to 75% per shift. As a result, the choice of a 33-seat bus can be an economical way to cope with passenger flow changes, so as not to lose money due to high vacancy rates.

Based on the market quotation of this kind of passenger bus, the one-month operating cost is estimated to be about 10,000 yuan. It is noteworthy that a month is recorded as 22 working days because of the large number of passengers travelling for commuting purposes. In addition, the occupancy rate of the initial period and the stable period of the customized bus would change. Since it has been replaced by 33-seat medium buses, the occupancy rate at the initial period according to the actual situation is 100% (33 people), and the occupancy rate at the stable period is 80% (26 people), then the per capita operating cost of the initial period is 7 yuan, that is $c_{n_1} = \frac{10,000}{22\times2\times33} \approx 7$, and the per capita operating cost of the stable period is 9 yuan, that is $c_{n_2} = \frac{10,000}{22\times2\times26} \approx 9$.

(2) Discount

For the discount, refer to the preferential system adopted by other cities in China to carry out customized bus, and set the discount at the initial period as 60%, that is $\delta_{n_1}=0.6$. During the stable period, those who have reached the first stage will enjoy a 15% discount, those who have reached the second stage will enjoy a 10% discount, and those who have reached the third stage will enjoy a 20% discount.

Therefore, $\delta_{n_{20}}=1$, $\delta_{n_{21}}=0.95$, $\delta_{n_{22}}=0.9$, $\delta_{n_{23}}=0.8$

From the reality, it can be seen that the passenger flow is stable when the customized bus line is in a stable period of operation. Passengers have enjoyed the benefits of the custom bus and

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202102_7(2).0008

are used to such trip mode, so the majority of passengers book long days. According to the experience of other cities in China, the proportions of passengers who have different discount rate are set as $\varphi_1=0.12$、$\varphi_2=0.31$、$\varphi_3=0.50$, and the proportion of passengers who don't enjoy discount rate is set as $\varphi_0=0.07$.

(3) Refund

According to the previous analysis, the average handling fare rate for passenger refunds is set at $\theta=0.1$. And as we known that the instability in the initial stage of operation will lead to a higher rate of passenger refund, and the fluctuation of passenger flow in the stable period is not as big as that in the initial period, that is, the passenger refund rate will decrease.

So the passenger refund coefficient of the initial period is $k_{n_1}=0.18$. During the stable period of operation, the coefficient of refund for non-eligible customers is $k_{n_{20}}=0.09$, the refund coefficient for those who enjoy the first-order discount is $k_{n_{21}}=0.07$, the refund coefficient for those who enjoy the second-order discount is $k_{n_{22}}=0.04$ and the refund coefficient for those who enjoy the third-order discount is $k_{n_{23}}=0.01$.

(4) Constrains

Considering the fare of the conventional bus, which is the main competitive mode between this pair of OD, is 2 yuan, and combining with the practical experience of the similar line of the customized bus, this paper takes the fare range of the customized bus from 2 yuan to 15 yuan.

3.2.2 Substitution model

All values and related data are substituted into the dynamic pricing model and the simplified form is as follows:

$$\begin{cases} \max R\left(P_{n_{10}},P_{n_{20}}\right)=\sum_{n_1=1}^{N_1}R_{n_1}+\sum_{n_2=N_1+1}^{N_2}R_{n_2} \\ =\sum_{n_1=1}^{N_1}Q_{n_1}\left\{\left[1+k_{n_1}(\theta-1)\right]P_{n_{10}}\delta_{n_1}+\left(k_{n_1}-1\right)c_{n_1}\right\}+\sum_{n_2=N_1+1}^{N_2}Q_{n_2}\sum_{j=0}^{3}\varphi_j\left\{\left[1+k_{n_{2j}}(\theta-1)\right]P_{n_{20}}\delta_{n_{2j}}+\left(k_{n_{2j}}-1\right)c_{n_2}\right\} \\ =\sum_{n_1=1}^{N_1}Q_{n_1}\left(0.5028P_{n_{10}}-5.74\right)+\sum_{n_2=N_1+1}^{N_2}Q_{n_2}\left(0.8365P_{n_{20}}-8.71\right) \\ \text{s.t.}\quad 2<P_{n_{10}}<P_{n_{20}}\le 15 \end{cases} \tag{4}$$

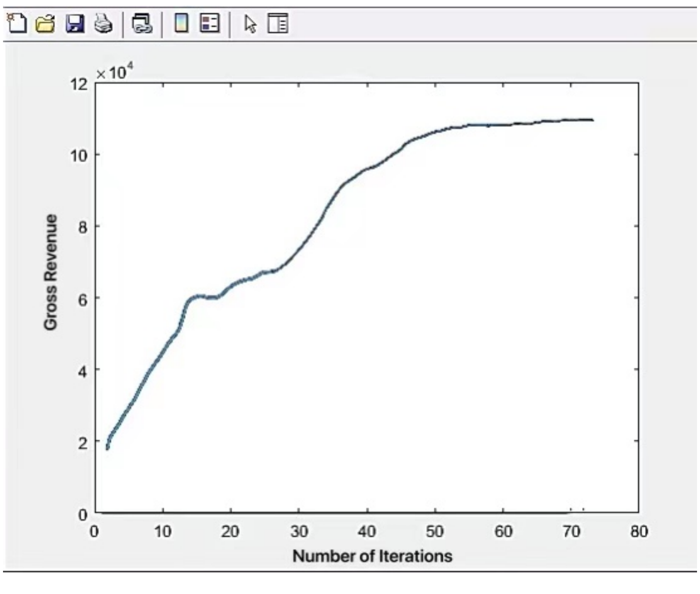

Figure 2. The gross revenues vary with the number of iterations

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202102_7(2).0008

3.2.3 Result

Particle swarm optimization (PSO-RRB- algorithm) is selected to solve the pricing model because of its advantages of fast convergence, high computational accuracy and easy implementation. Based the particle swarm optimization algorithm, in MATLAB software to write the program to solve the pricing model, the results obtained after running.

As we can see from Figure2, after about 53 iterations, the gross revenues have stabilized. The program calculates the maximum profit after 100 iterations is 107,864 yuan, and gets a set of ticket prices when the operator gets the maximum profit.

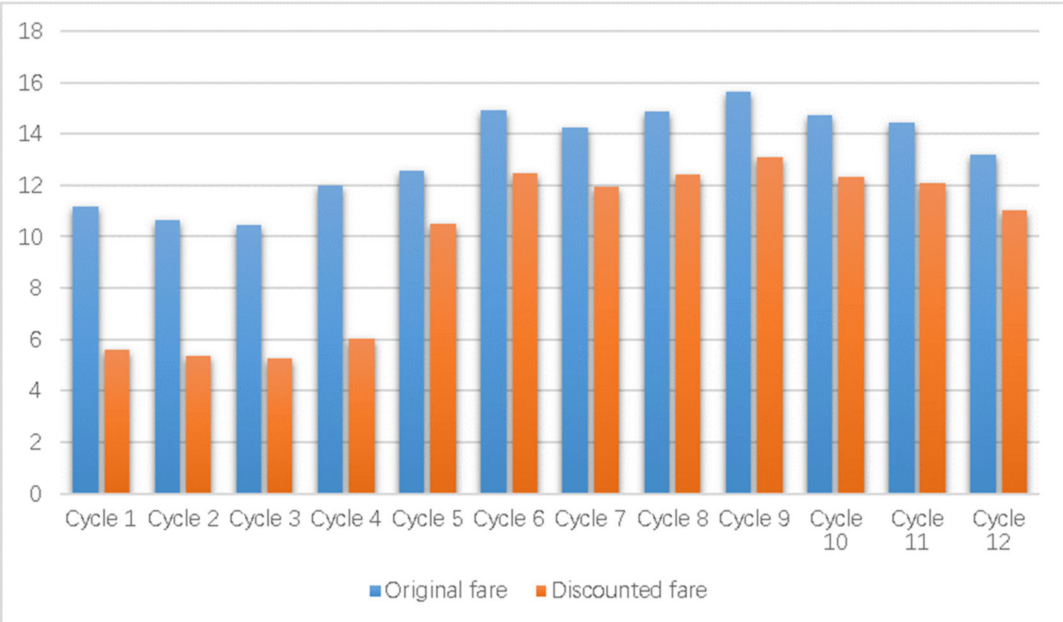

Figure 3. The original fares and the discounted fares at the time of maximum profit

In Figure3, if the fore-four cycles are regarded as the initial period of operation, the original ticket price averaging out to the initial period should be set at 11 yuan; if the last eight cycles are regarded as the stable period of operation, the original ticket price averaging out to the stable stage of development should be set up at 14 yuan. In addition, the movement of discount fares in the graph also reflects the strategy of large discounts in the initial period of operation to attract passengers.

3.3. Discussion: Comparison of Passenger Generalized Cost

After the result of the ticket price is obtained from the pricing model, it is necessary to analyze whether the ticket price is economical from the passenger's point of view, that is, whether the ticket price can minimize the passenger's generalized travel cost. Therefore, this section compares the generalized travel costs of passengers on the same pair of trip end points for customized buses, regular buses, and taxis.

The generalized travel cost of passengers is mainly composed of three parts: travel economic cost, travel time cost and ride comfort factor.

(1) Travel economic cost

For customized buses and regular buses, the travel cost is the actual price of the ticket; for taxis, the travel cost is the fare.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202102_7(2).0008

According to the above pricing model, the initial discount is about 0.5028, and the stable discount is 0.8365. Then it is easy to calculate the travel cost of the customized bus is $\frac{0.5028\times11\times4+0.8365\times14\times8}{12}=9.65$ yuan.

(2) Travel time cost

The first step is to convert a passenger's monthly income into unit time income, so the travel time cost is equal to unit time income λ Times travel time. The passenger's travel time generally includes out-of-vehicle time and in-vehicle time. Out-of-vehicle time includes the time t_1 that from the origin to the boarding point, t_2 that is waiting time, and the time t_3 from the alighting point to the destination. In-vehicle time is the time spent in the vehicle. The unit time value of out-of-vehicle time is different from that of in-vehicle time. Referring to Yin's research (2012), the unit time value of out-of-vehicle time is expressed as 1.5λ, and the unit time value of in-vehicle time is expressed as 0.5λ.

In this paper, we do not set up a specific route for the customized bus in this OD. But based on the flexibility of the custom bus service, the customized bus route in this example refers to the taxi route, and the relevant travel time is also obtained by reasonable floating according to the characteristics of the customized bus service. Based on the survey and experience, the travel time for these three modes is listed in Table 2.

Table 2. The travel time of the three travel modes between the OD

Travel modes	Out-of-vehicle time(min)			In-vehicle time(min)	Travel time(min)
	t_1	t_2	t_3	t_4	
Customized bus	1.5	5	0.5	28	35
Traditional bus	5	25	3	45	78
Taxi	0	0	0	25	25

Consider that the average salary per person in the region is about 7,000 yuan per month, then the unit time income is $\lambda=\frac{7000}{22\times8\times60}=0.66$ yuan per minute. Therefore, the unit time value of out-of-vehicle time is $0.5\lambda=0.5\times0.66=0.33$ yuan per minute, and the unit time value of in-vehicle time is $1.5\lambda=1.5\times0.66=0.99$ yuan per minute.

So the formula for travel time cost (F) is:

$$F=0.5\lambda\left(t_1+t_2+t_3\right)+1.5\lambda t_4 \tag{5}$$

(3) The comfort cost

According to the questionnaire survey, the scores of passengers on comfort degree of three modes of travel are given in Table 3.

Table 3. Passengers satisfaction with the comfort of travel modes

	Very dissatisfied	Dissatisfied	General	Satisfied	Very satisfied
Traditional bus	6	37	41	14	2
Railway	0	8	23	40	29
Taxi	0	6	44	35	15
Private car	0	4	15	33	48
Customized bus	0	5	30	47	18

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202102_7(2).0008

In accordance with the scoring standard of "very dissatisfied = 1, dissatisfied = 2, general = 3, satisfied = 4, very satisfied = 5", the average score of each mode of travel comfort was calculated and recorded as ζ, the impact factor of riding comfort. Then according to the rule that each score represents "-0.5 yuan", the impact of ride comfort can be converted into the comfort cost, as shown in Table 4.

Table 4. The comfort cost after conversion

Travel modes	The impact factor of comfort ζ	The comfort cost
Customized bus	3.78	-1.89
Traditional bus	2.69	-1.36
Taxi	3.59	-1.80

(4) Traveler' s preferences

By investigating the preference of passengers for travel cost, travel time cost and comfort in the generalized travel cost, the generalized travel cost can be more accurately quantified, as shown in Figure4.

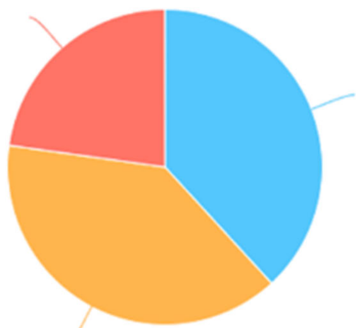

Figure 4. Phase analysis of arrangement

Therefore, the preference parameter of passengers to travel economic cost is ε_1=0.38, to travel time cost is ε_2=0.39, and to comfort is ε_3=0.23.

(5) Generalized travel cost calculation

After the above analysis, travel economic cost, travel time cost and ride comfort cost are respectively multiplied by their passenger's preference coefficient and then added together to get the value of the passenger's travel cost in a broad sense. The generalized travel cost calculation for the three modes of travel is shown in Table 5.

Table 5. Calculation for generalized travel cost of passengers with three modes of travel

Travel modes	Travel economic cost	Travel time cost	The comfort cost	Generalized travel cost
Customized bus	9.65	30.03	-1.89	16.11
Traditional bus	2	55.44	-1.36	22.07
Taxi	45	24.75	-1.80	26.34

As can be seen from Table5, the generalized travel cost of passengers on a customized bus is minimal. In addition, although the regular bus fare has a great advantage, but its travel time cost

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202102_7(2).0008

is relatively high. It is obvious that taxi is the most expensive in the broad sense because of its high travel cost.

Through the calculation of an example, if the customized bus line adopts the dynamic pricing strategy, which sets different fares in different development periods and is supplemented by discounts, the ticket price can take into account both the interests of operating enterprises and the interests of passengers. On the one hand, it guarantees the profits of operating enterprises, and can bring about 110,000 yuan a year for operating enterprises; On the other hand, the passenger's generalized travel cost is the smallest among several feasible travel modes.

4. CONCLUSION

First of all, this paper puts forward that the operation period of one customized bus line should be divided into the initial period and the stable period, and the corresponding discount and preferential system should be adopted in each period to form dynamic pricing strategy. Based on this pricing strategy, it builds a model to achieve the overall profitability of operating enterprises.

Secondly, this paper assumes that there are customized buses in the pair of OD, which from the port-adjacent industrial area to the main urban area. Then, the paper calculates the fare by the model of period-dividing pricing strategy, and compares the result that the generalized travel cost is the least among the alternative travel modes.

Finally, the above example demonstrate the feasibility of the dynamic pricing model and the necessity of creating a customized bus route between the selected pair of OD.

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