

Integrated Planning for the Intermodal Container Terminals of the CR Express based on Markov Process



Cuijie Diao, Shujuan Guo, Gang Li, Xiaohan Wang, and Zhihong Jin

Abstract The Belt and Road initiative (BRI) is committed to strengthening the connectivity among countries and building a comprehensive transport network. The China Railway Express (CR Express) as an important part of the BRI has become a new type of intercontinental trade transport mode between Asia and Europe. With the development of the CR Express, China's coastal ports have become the transfer hub connecting the CR Express with other Asian countries. In this paper, an intermodal container terminal system composed of a maritime container terminal and a railway container terminal is studied. The system consists of railway and truck as two kinds of distribution modes, which is considered as the dual-channel supply chain system. This paper explores the Markov process used in that supply chain system to study the intermodal container terminal system. Numerical analysis manifests the influence of the railway distribution rate. The result shows that cooperation strategy can help to make better use of the reserved terminal and reduce the expected storage time. The cooperation strategy is beneficial to both the terminal operators and the consigners.

Keywords Intermodal container terminal · Markov process · Total revenue · Expected storage time

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1 Introduction

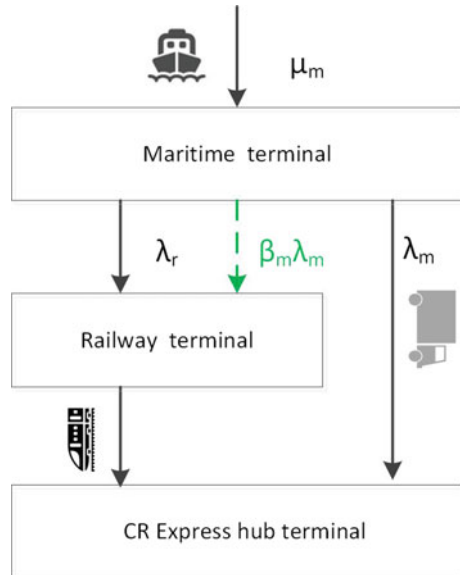
The construction of the strategies of the Belt and Road initiative (BRI) will build a comprehensive transport network and promote the economic development. China Railway Express (CR Express) is an important part of the BRI. With the development of the BRI, the influence of CR Express has gradually extended to Southeast Asia, Japan and South Korea. Coastal ports have become an important node between CR Express and other Asian countries.

This paper studies the intermodal container terminals system in coastal areas is shown in Fig. 1. It is composed by the maritime container terminal and the railway container terminal. The containers will transport to CR Express terminal by train or by truck. Both of the terminals have reserved some storage yard for the CR Express.

The operation of intermodal terminal system is as followed. The system of intermodal terminals will transport containers that arrived at coastal port by sea from maritime terminal to hub terminal of CR Express. The containers arrived at the system are unloaded from the ship in accordance with a Poisson process at constant rates μ_m . The transportation demand by truck arrives at system according to a Poisson process at constant rate λ_m which are satisfied one by one, while the transportation demand by train arrives at system in accordance to a Poisson process at constant rate λ_r . The railway terminal provides batch service and adopts the fixed-length accumulation mode. The train only departs, when the number of containers in the railway terminal has reached the full capacity of the train.

The system of the intermodal terminals has two levels inventories. The containers in the railway terminal transported by railway are transferred from maritime terminal

Fig. 1 The operation of the intermodal terminal system



according to a Poisson process at constant rates λ_r . It is same as the distribution of the transportation demand by train. The intermodal container terminals system is similar to two-echelon dual-channel supply chain system. Therefore, the Markov analysis is explored in this paper to calculate the revenue.

The contributions of this paper to the literatures are as follows. This paper uses the Markov process to model and analyze the intermodal container terminals for CR Express, fewer scholars take terminal as the research object and consider using the Markov analysis method. Firstly, this paper analyzes the impact of railway distribution rate on the total revenue of the intermodal terminal system. Then, the paper assumes that the maritime terminal and the railway terminal can share the information of the volume of containers in the terminal with each other, and evaluates the cooperation strategy of the intermodal transportation system under different demand rate and arrival rate.

The rest of this paper is organized as follows. The literature review is in Sect. 2. In Sect. 3, an intermodal transportation system model based on Markov process is described including the model assumptions, the operation policy, the Markov process model and the performance measures. In Sect. 4, the numerical analysis is described. Finally, in Sect. 5, the key points are summarized and future research work is mentioned.

2 Literature Review

Many studies have focused on the location of the hub terminal in the future transportation network of CR Express. Wang et al. found the CR Express has its economic transport hinterlands, it is essential to establish a hub-and-spoke transport network and build the transport hubs [1]. From the perspective of freight costs, Jiang et al. applied binary Logit model to compare 5 typical routes of CR Express routes and analyzed the hinterland pattern of CR Express routes. The results show that Chongqing is more likely to become a regional hub of CR Express [2]. Wei et al. studied a logistics network connecting the inland regions by dry ports based on a two-stage logistical gravity model. Dry ports play an important role in the multimodal transport centering on the BRI. Therefore, it is found that the hubs for CR Express will gradually be formed [3].

Some scholars also studied the change of international transport pattern under the influence of the BRI, including the cooperation between the BRI and the original ocean shipping. Wang and Yeo obtained the route from Korea to Central Asia under the BRI with integrated Fuzzy Delphi and Fuzzy methods. The results show that Incheon to Qingdao to Horgos to Almaty is preferred [4]. Sun et al. devised double auction mechanisms for the intermodal transportation service procurement problem under the influence of the BRI and provided several managerial implications [5]. Yang et al. established a bi-level programming model to reconstruct the shipping service network between Asia and Europe by considering the New Eurasian Land Bridge rail services and Budapest-Piraeus railway [6].

Through existing literature, Chan et al. found there is a lack of studies on the BRI from the perspective of logistics and supply chain management [7]. Sheu and Kundu focused on the dynamic and stochastic problems brought by integration of the BRI and international logistic network. A spatial-temporal interaction model combined with Markov chain is used to forecast time-varying logistic distribution flows [8]. The Markov process can also be used to analyze the intermodal terminals system. The model applied in this paper is based on the two-echelon and dual-channel supply chain model proposed by Takahashi et al. which was originally used in the inventory control policy considering production and delivery costs [9].

Some scholars have applied the queuing theory to the research of container truck reservation problem, railway system evaluation, container truck passing capacity at wharf gate and so on. Previous studies have found that the arrival rate of ships and the arrival of transport demand are approximately subject to Poisson distribution. The Markov chain method is suitable for analyzing systems subject to a specific distribution. In this paper, a model of intermodal terminal system is established. The total revenue has been taken as the performance measure, the performance measure is analyzed based on Markov process. This paper considers the two situations of cooperation and non-cooperation and puts forward a reasonable operation strategy.

3 The Model of Intermodal Terminal System

3.1 The Markov Process of Intermodal Terminal System

The Markov process is shown in Fig. 2. The parameters in the figure are explained as follows. S_m and S_r are the maximum inventories of maritime container terminal and railway container terminal reserved for CR Express, respectively. The loading time of train is according to an exponential distribution with mean μ_l . When the number of containers accumulated in the railway terminal reaches the capacity of the train, the containers are loaded to the train and the train will depart.

In the example shown in Fig. 2, $S_m = 9$, $S_r = 6$ and $c = 4$. c is the full capacity of a train. The circles indicate the system state (x, y) , x is the number of containers at the maritime container terminal, and y is the number of containers at the railway container terminal. The explanations of the transition rates in Fig. 2 are as follows. If one container is picked up from maritime terminal to CR Express hub terminal by truck at rate λ_m , the state (x, y) changes to state $(x - 1, y)$. If one container from the ship is unloaded to the maritime terminal at rate μ_m , the state (x, y) changes to state $(x + 1, y)$. If one container is transported from maritime terminal to the railway terminal at rate λ_r , the state (x, y) changes to state $(x - 1, y + 1)$.

There are three scenarios considering the accumulation and transfer state of the system. They are accumulation, acceleration of accumulation scenario and train departure scenarios. The three scenarios are described as follows.

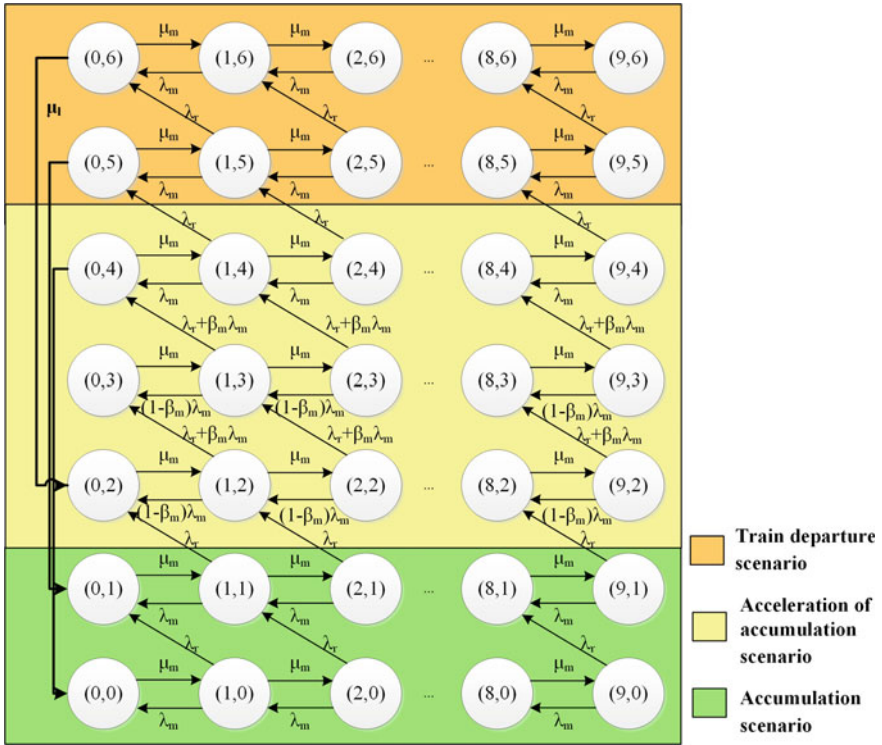


Fig. 2 Markov process of the intermodal terminal system

- Accumulation scenario: If $y < c/2$, the containers are normally accumulated in the railway terminal, the container transported from the maritime terminal to the railway terminal at rate λ_r .
- Acceleration of accumulation scenario: If $c/2 \leq y \leq c$, it means that the train is near to departure. We consider that the maritime terminal and the railway terminal share information with each other. The carriers may notice the train will depart soon. Some proportion of the containers previously planning to transport by truck switch to choose train because of the waiting time will be decreased dramatically. The transfer rate is defined as β_m . The state (x, y) changes to state $(x - 1, y)$ at rate $(1 - \beta_m)\lambda_m$ in this scenario.
- Train departure scenario: If $y \geq c$, there is enough inventory at the railway terminal to ran a train. The containers are loaded to a train at rate μ_l and the state (x, y) changes to state $(x, y - c)$.

3.2 The Generator Matrix of Intermodal Terminal System

To represent the system transitions in a compact form, we arrange the states of the system in the increasing lexicographic order and obtain the generator matrix. The state transitions between systems expressed in matrix form, the general matrix P as follows.

$$P = \begin{matrix} & \begin{matrix} (x,0) & (x,1) & \dots & (x,c/2) & (x,c/2+1) & \dots & (x,c) & (x,c+1) & \dots & (x,S_c-1) & (x,S_c) \end{matrix} \\ \begin{matrix} (x,0) \\ (x,1) \\ \vdots \\ (x,c/2) \\ (x,c/2+1) \\ \vdots \\ (x,c) \\ (x,c+1) \\ \vdots \\ (x,S_c-1) \\ (x,S_c) \end{matrix} & \begin{bmatrix} A-D_0 & C & & & & & & & & & \\ & A-D_0 & & & & & & & & & \\ & & A & & & & & & & & \\ & & & C+D & & & & & & & \\ & & & & A & & & & & & \\ & B & & & & & & & & & \\ & & B & & & & & & & & \\ & & & & & & A-B_0-D_0 & & & & \\ & & & & & & & C & & & \\ & & & & & & & & & A-B_0-D_0 & \\ & & & & & & & & & & C \\ & & & & & & & & & & A_0-B_0 \end{bmatrix} \end{matrix}$$

We have matrices A, A_0, B, B_0, C, D_0 and D as follows.

$$A = \begin{matrix} & \begin{matrix} (0,y) & (1,y) & (2,y) & \dots & (S_m-1,y) & (S_m,y) \end{matrix} \\ \begin{matrix} (0,y) \\ (1,y) \\ (2,y) \\ \vdots \\ (S_m-1,y) \\ (S_m,y) \end{matrix} & \begin{bmatrix} -\mu_m & \mu_m & & & & \\ \lambda_m & -(\mu_m+(1-\beta_m)\lambda_m+\lambda) & & & & \\ & \lambda_m & -(\mu_m+(1-\beta_m)\lambda_m+\lambda) & & & \\ & & \ddots & \ddots & & \\ & & & -(\mu_m+(1-\beta_m)\lambda_m+\lambda) & & \\ & & & & -(\mu_m+(1-\beta_m)\lambda_m+\lambda) & \\ & & & & & \lambda_m & -((1-\beta_m)\lambda_m+\lambda) \end{bmatrix} \end{matrix}$$

$$D = \begin{matrix} & \begin{matrix} (0,y+1) & (1,y+1) & (2,y+1) & \dots & (S_m-1,y+1) & (S_m,y+1) \end{matrix} \\ \begin{matrix} (0,y) \\ (1,y) \\ (2,y) \\ \vdots \\ (S_m-1,y) \\ (S_m,y) \end{matrix} & \begin{bmatrix} 0 & & & & & \\ & \beta_m\lambda_m & & & & \\ & & \beta_m\lambda_m & & & \\ & & & \ddots & & \\ & & & & \ddots & \\ & & & & & 0 \\ & & & & & & \beta_m\lambda_m & 0 \end{bmatrix} \end{matrix}$$

$$D_0 = \begin{matrix} & \begin{matrix} (0,y) & (1,y) & (2,y) & \dots & (S_m-1,y) & (S_m,y) \end{matrix} \\ \begin{matrix} (0,y) \\ (1,y) \\ (2,y) \\ \vdots \\ (S_m-1,y) \\ (S_m,y) \end{matrix} & \begin{bmatrix} \beta_m\lambda_m & & & & & \\ & \beta_m\lambda_m & & & & \\ & & \beta_m\lambda_m & & & \\ & & & \ddots & & \\ & & & & \beta_m\lambda_m & \\ & & & & & \beta_m\lambda_m \end{bmatrix} \end{matrix}$$

$$B = \begin{matrix} & \begin{matrix} (0,y-c) & (1,y-c) & (2,y-c) & \dots & (S_m-1,y-c) & (S_m,y-c) \end{matrix} \\ \begin{matrix} (0,y) \\ (1,y) \\ (2,y) \\ \vdots \\ (S_m-1,y) \\ (S_m,y) \end{matrix} & \begin{bmatrix} \mu_l & & & & & \\ & \mu_l & & & & \\ & & \mu_l & & & \\ & & & \ddots & & \\ & & & & \mu_l & \\ & & & & & \mu_l \end{bmatrix} \end{matrix}$$

$$B_0 = \begin{matrix} & \begin{matrix} (0,y) & (1,y) & (2,y) & \dots & (S_m-1,y) & (S_m,y) \end{matrix} \\ \begin{matrix} (0,y) \\ (1,y) \\ (2,y) \\ \vdots \\ (S_m-1,y) \\ (S_m,y) \end{matrix} & \begin{bmatrix} \mu_l & & & & & \\ & \mu_l & & & & \\ & & \mu_l & & & \\ & & & \ddots & & \\ & & & & \mu_l & \\ & & & & & \mu_l \end{bmatrix} \end{matrix}$$

$$C = \begin{matrix} (0,y) \\ (1,y) \\ (2,y) \\ \vdots \\ (S_m-2,y) \\ (S_m-1,y) \\ (S_m,y) \end{matrix} \begin{bmatrix} (0,y+1) & (1,y+1) & (2,y+1) & \cdots & (S_m-2,y+1) & (S_m-1,y+1) & (S_m,y+1) \\ 0 & & & & & & \\ \lambda_x & 0 & & & & & \\ & \lambda_y & 0 & & & & \\ & & \ddots & \ddots & & & \\ & & & \ddots & \ddots & & \\ & & & & 0 & & \\ & & & & & \lambda_x & \\ & & & & & & 0 \\ & & & & & & \lambda_x & 0 \end{bmatrix}$$

Let π_{xy} be the steady-state probability of the state with the number of containers at the maritime container terminal x , the number of containers at the railway container terminal y . The steady state probability π is defined as $\pi = [\vec{\pi}_0, \vec{\pi}_1, \dots, \vec{\pi}_n, \dots, \vec{\pi}_{S_y}]$, where $\vec{\pi}_n = [\pi_{0n}, \pi_{1n}, \pi_{2n}, \dots, \pi_{S_m-1,n}, \pi_{S_m,n}]$, $\forall n \geq 0$. Based the standard solution method to obtain the steady state probability of Markov process, the steady state probability matrix π obtained by solving the equations $\pi \cdot P = 0$ and subject to the constraint that the sum of the all probability of matrix π is equal to 1. In this paper, GTH algorithm is used to get the steady-state probability by solving the $\pi P = 0$ and $\pi e = 1$.

3.3 Performance Measure

The main performance measure used in this paper is the total revenue of the maritime terminal and railway terminal. It consists of the container operation revenue, the transfer revenue, and the train operation revenue. The revenue is calculated with the steady-state probability $\vec{\pi}_n$. Let i present the terminals. $i = 1$ represents maritime terminal and $i = 2$ means railway terminal.

Let tsq_i be the container storage quantity at terminal i . tsq_i is calculated by (1).

$$tsq_1 = \sum_{x=0}^{S_m} \sum_{y=0}^{S_r} x \pi_{xy}, \quad tsq_2 = \sum_{x=0}^{S_m} \sum_{y=0}^{S_r} y \pi_{xy} \tag{1}$$

Let CST_i be the unit container operation revenue at terminal i . Ctr_i is the container operation revenue at terminal i is calculated using

$$Ctr_i = CST_i \times tsq_i \tag{2}$$

Let ttq be the container transfer quantity at the port to the railway terminal. ttq is obtained by (3).

$$ttq = \sum_{x=0}^{S_m} \sum_{y=c/2}^c \beta_m \lambda_m \times \pi_{xy} \tag{3}$$

Let CSP be the unit container transfer revenue at the railway terminal. Container transfer revenue C_{tra} is calculated using

$$C_{tra} = CSP \times ttq \quad (4)$$

Let $vnum$ is the number of trains to departure, which is obtained by (5).

$$vnum = \sum_{x=0}^{S_m} \sum_{y=c}^{S_r} \mu_l \pi_{xy} \quad (5)$$

Let CPR be the train operation revenue per number of train and the train operation revenue C_{opt} is calculated using

$$C_{opt} = CPR \times vnum \quad (6)$$

Finally, the total revenues under the accumulation modes are calculated using (7) as follows.

$$TC = Ctr_1 + Ctr_2 + C_{tra} + C_{opt} \quad (7)$$

The other performance measures such as expected storage time in the system W , and terminal utilization U , can be calculated using Little's Law. Let W_1 and W_2 be the expected storage time in the system and the railway container terminal, respectively. W_1 and W_2 are obtained by (8)

$$W_1 = (tsq_1 + tsq_2)/\mu_m, \quad W_2 = tsq_2/\lambda_r \quad (8)$$

Let U_1 and U_2 be the utilization of maritime container terminal and the railway container terminal, respectively. U_1 and U_2 are obtained by (9).

$$U_1 = tsq_1/S_m, \quad U_2 = tsq_2/S_r \quad (9)$$

4 Numerical Analysis

In this section, there are three main research questions. The first question is the impact of railway distribution rate α on the total revenue of the system. The second question is the impact of cooperative strategy on the total revenue of the system. The third question is the impact of cooperative strategy on the utilization and waiting time of the system.

The full capacity of the train is $c = 40$. The container transport by truck to railway transfer rate β_m was set 0.5. The capacities of maritime terminal and railway terminal are $S_m = S_r = 60$.

The cost parameters considered in this paper are set as follows. The loading time of containers on the train follows an exponential distribution with $\mu_l = 5$. The unit

container operation revenue at maritime and railway terminals are $CST_1 = 5$ and $CST_2 = 5$, respectively. The unit container transfer revenue is $CSP = 15$. The unit train departure revenue is $CPR = 150$.

4.1 Effects of the Railway Distribution Rate

The impact of railway distribution mode preference rate α on the total revenue is studied. α is set to 0.1, 0.2, ..., and 1.0. $\alpha = 1$ means all containers are transported by the railway to the CR Express hub terminal and no containers are transported by the truck. In this section, the following parameters are fixed as follows. (μ_m, λ) is set at (15, 13).

Figure 3 shows the total revenues in different value of α . With the increase of the railway transportation preference rate, container operation revenue of maritime is almost the same. The container operation revenue of railway and train departure revenue increase as α increases. The transfer revenue increases first and then decrease as the value of α increases, because of the demand transport by train and the accumulation of containers in the railway terminal increase. In total, the total revenues increase as the value of α increases. Therefore, it is suggested for consigner to choose the railway mode.

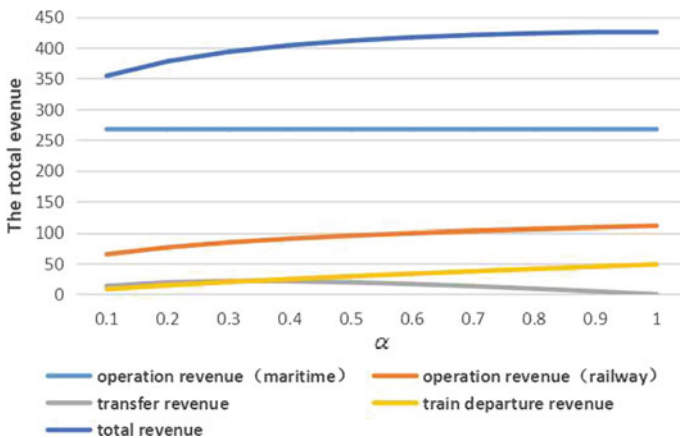


Fig. 3 The total revenue of different transportation mode preference rates

Table 1 The difference of the total revenues between with and without cooperation

(μ_m, λ)	The total revenue	
	With cooperation	Without cooperation
(15, 13)	416.96	402.10
(25, 20)	461.21	434.50
(40, 30)	511.57	467.97
(60, 45)	578.93	510.31

4.2 Total Revenues in the Situation of with Cooperation and Without Cooperation Between Two Terminals

The scenarios of two terminals with and without cooperation under different arrival rate and demand rate are compared. In the strategy without cooperative that the maritime terminal and railway terminal work separately.

It can be seen from Table 1 that the cooperation strategy can generate more total revenue regardless of the transportation demands. However, when the transportation demand is small as (15,13), the revenue difference between with cooperation strategy and without cooperation strategy is small. When the transportation demand is large as (60,45), the revenue difference between with cooperation strategy and without cooperation strategy is large.

4.3 Analysis of the Average Storage Time and the Utilization

The average storage time of different arrival rate μ_m and total demand rate λ is shown in Fig. 4. The average storage time of the railway terminal and the system with cooperation is no more than that without cooperation in all demand cases. The cooperation can help to reduce the waiting times and speed up the turnover. It is beneficial to promote consigner to choose railway transportation, which is more environmental and economic.

The utilization of different arrival rate μ_m and total demand rate λ of the maritime terminal and the railway terminal is shown in Fig. 5. With the increase of the transportation demand, the utilization rate of the maritime terminal increases to near the maximum inventories. Under the situation of cooperation, the intermodal terminal system can be better utilized and the reserved railway terminal can be more utilized.

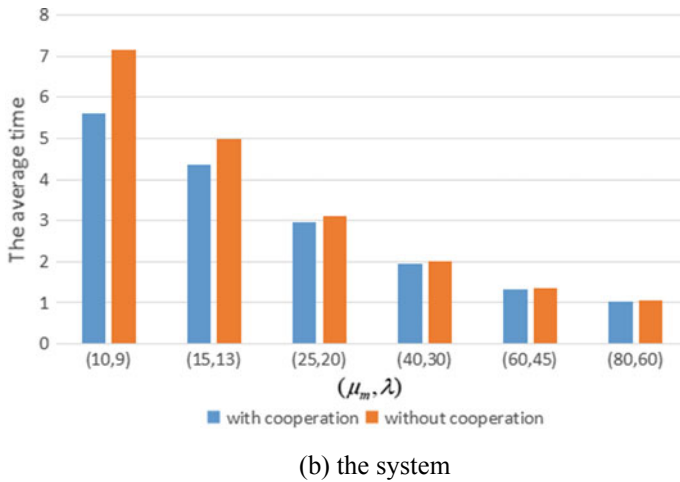
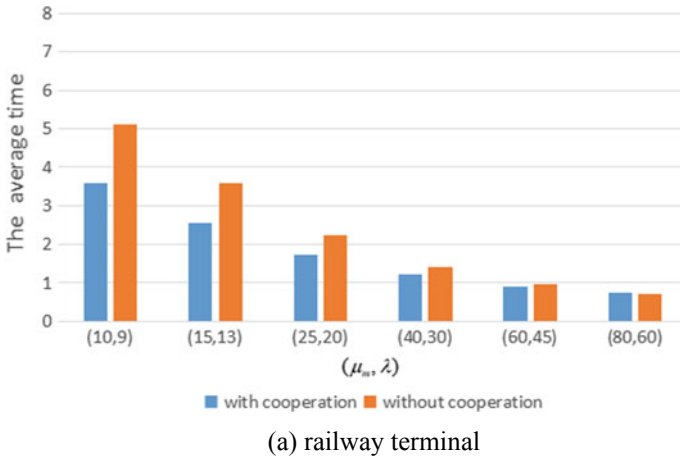
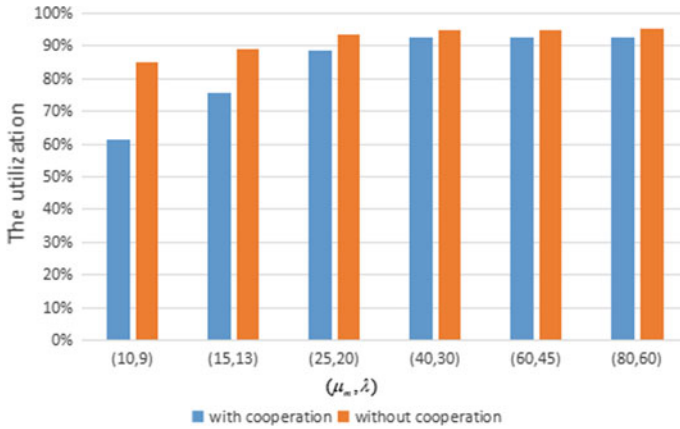


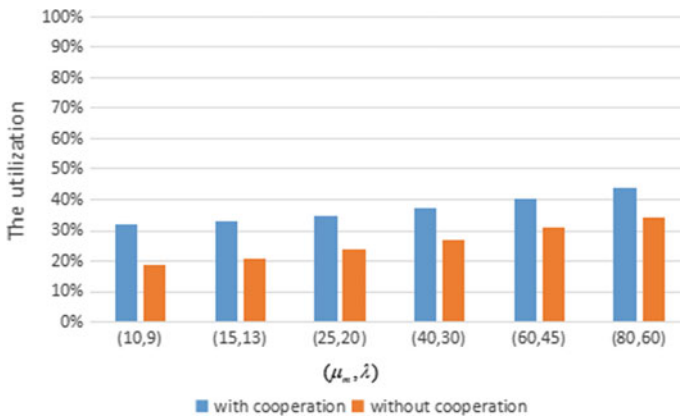
Fig. 4 The average storage time of different arrival rate μ_m and total demand rate λ of railway terminal and the intermodal terminal system

5 Conclusion

In this paper, the model based on Markov process is applied to carry out the impact of railway distribution rate on the total revenue of the intermodal transportation system, and the impact of cooperative strategy on the total revenue and operation of the system under different arrival rate and demand rate. Previously, few scholars have tried this method to the research of intermodal terminal. Numerical analysis shows that the strategy with cooperation will yields higher revenue for both terminals. The cooperation can help to make better use of the reserved terminal and reduce the waiting times of consignees, it suggested for consigner to choose the railway mode.



(a) maritime terminal



(b) railway terminal

Fig. 5 The utilization of different arrival rate μ_m and total demand rate λ of the maritime terminal and the railway terminal

For future research, our work can be extended to include batch arrivals and batch service which are more according with the actual situation of maritime terminal and railway terminal. For the system, different railway accumulation modes can be considered, this paper only considers the fixed-length mode, in fact, most of China’s railway terminals use fixed-time mode.

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