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Optimization Model For Truck Appointment In Container Terminals

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Abstract

Many ports are facing heavy truck congestion in the terminal, which leads to longer truck waiting time and lower operation efficiency. To alleviate congestion and decrease truck turn time in the container terminal, an optimization model for truck appointment was proposed in this paper. In the model, the appointment quota of each period was optimized subject to the constraints of adjustment quota. And a BCMP queuing network was developed to describe the queuing process of trucks in the terminal. To solve the model, a method based on Genetic Algorithm (GA) and Point wise Stationary Fluid Flow Approximation (PSFFA) was designed. GA was used to search the optimal solution and PSFFA was designed to calculate the truck waiting time. Finally, numerical experiments were provided to illustrate the validity of the model and algorithm. The results indicate that the proposed PSFFA method can estimate the queue length accurately and the model can decrease the truck turn time efficiently.

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Keywords: Container terminals, truck appointment, queuing network, genetic algorithm;

1. Introduction

Continuous growth in the volume of containers has placed significant burdens on the landside operations of seaports. Many seaports are facing serious congestion both at gate and in yard due to a large number of trucks arriving at terminal during peak periods. Meanwhile, serious congestion leads to longer truck waiting time, higher air pollution and lower terminal operation efficiency. Therefore, how to decrease the truck turn time in the terminal is an important issue for terminal operator, truck fleet and government regulators.

In response to heavy congestion, ports like Vancouver, Los Angeles and Long Beach have implemented truck appointment system (Morals and Lord, 2006). Using this system, terminal operator limits the maximum number

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of appointment quota during each period. Truckers can make reservations during which period they prefer. International and domestic academics have done research both on the efficiency of truck appointment and truck appointment model. However, truck appointment system is complex and it involves a lot of factors. The length of truck queues is influenced by truck arrivals, the gate service rate and yard service rate. Moreover, the arrival of trucks varies with time, which leads to that the traditional stationary queuing theory can't describe the process of queuing.

In this paper, a model optimizing appointment quota of each period to minimize the truck turn time is addressed. A Baskett Chandy Muntz Palacios (BCMP) queuing network is used to describe the process of trucks at gate and yard. To solve the model, Genetic algorithm and a method based on the Pointwise Stationary Fluid Flow Approximation (PSFFA) are designed. GA was used to search the optimal solution under the constraints of adjustment quota and PSFFA was designed to calculate the truck waiting time. Finally the model is test based on the data of a terminal of Tianjin.

The reminder of this paper is organized as follows. In Section 2, a literature review on approaches to alleviate terminal congestion is provided. Section 3 describes the problem and proposes a truck appointment model. Genetic algorithm and a method based on the PSFFA are designed to solve the model in Section 4. Numerical experiments are conducted in section 5 to illustrate the validity of the methods. Conclusions are provided in Section 6.

2. Literature review

Truck arrival management has gained wide attention recently that much research has done on it. In this section, we review the methods that have implemented to alleviate terminal congestion, including truck appointment method, Vessel Dependent Time Windows (VDTW) and tariff policy.

Since the first implementation of truck appointment method in the port of Vancouver, researchers attempted to analysis its effects. E.g. Zhao and Goodchild (2010) find that the information obtained from truck appointment system can decrease the re-handle rate in yards; Namboothiria and Erera (2008) developed a truck scheduling model and analysis the effect of the truck appointment method on truck scheduling; Huynh and Walton (2008) analysis the effect of the truck management on the truck turn time in the terminal using a simulation model. In practice, the effect of truck appointment method varies with different ports. The research shows that port of Vancouver has an obvious effect while port of Los Angeles while Long Beach did not do well (Giulianoa and O'Brien, 2007).

Moreover, some studies focus on the design and implementation of truck appointment method. Huynh and Walton (2008) estimated the maximum number of trucks the terminal could allow taking the terminal operation efficiency into consideration. Guan and Liu (2009) calculated the truck queue length based on the M/Ek/c queuing theory and designed a model to optimize the appointment quota. Many studies estimates the queue length based on stationary queuing theory, but it can't present the characteristic of truck arrival. To solve the problem, a few studies describe the truck queuing using non-stationary queuing theory (Chen, 2011). However, the distribution parameter of truck arrival is worthy of further study.

In china, VDTW is a typical method in truck management. VDTW sets delivery time windows for the vessels loading and unloading. A few studies design a model optimizing the time windows of container trucks coming in or out of port for each vessel (Chen, 2013). This model not only can alleviate terminal congestion, but also decrease the re-handle rate in the yard. But it has a limitation on the delivery time for containers, leading to less flexibility and customer satisfaction. So the ports implementing VDTW are considering truck appointment method.

Tariff policy is another method of terminal management. Through charging the trucks arriving in peak periods an extra fee arriving, truck arrival makes a reduction. Port of Los Angeles and Singapore have implemented this method. Giulianoa and O'Brien (2008) find that the implementation of tariff policy in port of Los Angeles and

Long Beach has decreased the truck arrival in peak hours obviously. Chen (2013) gets the optimal truck arrival through optimized model and gives a charging standard of each time period. There is a large number of studies focus on tariff of roads. But port traffic problem is different from the road (Yang, 2010). Designing tariff policy based on truck arrival is worthy of further studies.

3. Truck appointment model

3.1. Problem description

Truck appointment method usually divides one day into a number of small time periods. The terminal operator announces the maximum appointment quota of each period and then the truckers select one preferred period. But if the selected period is not available, the truckers need to select another until they successfully make an appointment. Truck appointment method can decrease the number of truck arrival during peak hours.

When determine the optimal appointment quota using truck appointment model, terminal operator needs to take the factors affecting truck turn time into consideration. Truck turn time is equal to the total of gate waiting time and yard waiting time plus a fixed value. The terminal system contains gate system and yard system and there is a link between the gate and the yard. So in this paper, a BCMP queuing network is developed to describe the process of trucks in the terminal.

The objective of truck appointment model is to minimize the total of gate waiting time and yard waiting time. Genetic algorithm is designed to search the optimal solution. A method based on Point wise Stationary Fluid Flow Approximation (PSFFA) is designed to calculate the truck waiting time.

3.2. variable definitions

In this model, all input data, derived variables, decision variables are as below:

Input data:

N： index of decisive days, which is determined by the terminal operation characteristics, $N = 7$ days；

t： index of fluid-based modeling time point, where one day is divided into T periods， $t = 1,2...,T$；

P： index of appointment periods, where one day is divided into P periods, $p = 1,2,...,P$， every period length=1440/ P (min)

c_p： Number of gate lanes in service, in time period p , $c_p \le I$ ；

λ_p^g： Number of trucker's preferred arrivals in time period p ；

μ_{it}^g： the processing rate of gate lane i at time point t, where I is the number of gate lanes, $i = 1,2...,I$ ；

μ_{jt}^y： the processing rate of yard zone j at time point t, where J is the number of gate lanes, $j = 1,2...,J$ ；

k：the parameter of Erlang distribution of gate and yard service time；

v：the coefficient of variation of yard service time distribution；

Derived variables：

λ_t^g： Number of truck arrivals at gate at time point t ；

ρ_{it}^g： Utilization rate of gate lane i at time point t ；

l_t^g： Average queue at gate at time point t, which is calculated by the method ；

w_t^g： Average waiting time at gate at time point t, which is calculated by the method;

d_{it}^{g}： discharge rate of gate lane i at time point t；

a_{t}^{g}： One variable of the gate system at time point t；

λ_{t}^{y}： Number of truck arrivals at yard at time point t；

ρ_{jt}^{y}： Utilization rate of yard zone j at time point t；

l_{t}^{y}： Average queue number of trucks at yard at time point t；

w_{t}^{y}： Average waiting time of trucks at yard at time point t；

d_{jt}^{y}： discharge rate of yard zone j at time point t；

$\overline{\lambda}_{p}^{g}$： Appointment quotas in time period p；

3.3. optimization model

In this truck appointment model the objective function is to minimizing the total of gate waiting time and yard waiting time of trucks. Using this optimization model, we can get the optimal appointment quota for every time period. In order to calculate the truck waiting time at gate and yard, a method based on PSFFA is designed.

Objective： $$\min Z = \left(\sum_{t} l_{t}^{g} + \sum_{t} l_{t}^{y} \right) \Big/ P$$

Arrival pattern constraints：

$$\sum_{p} \overline{\lambda}_{p}^{g} = \sum_{p} \lambda_{p}^{g} \qquad \forall p \tag{1}$$

$$\overline{\lambda}_{p}^{g} \geq 0 \qquad \forall p \tag{2}$$

$$\lambda_{t}^{g} = \overline{\lambda}_{p}^{g} \left(P/T \right) \qquad \forall t \in p \tag{3}$$

Equation (1) states that the total number of appointment quotas after optimization should be same to the number of truck arrivals; Equation (2) ensures the number of appointment quotas for each time period is non-negative; Equation (3) calculates the number of truck arrivals at gate at time point t.

Gate system constraints：

$$w_{t}^{g} = l_{t}^{g} \Big/ \sum_{i} d_{it}^{g} \qquad \forall t \tag{4}$$

$$l_{t+1}^{g} = \max\left(l_{t}^{g} + \lambda_{t}^{g} - \sum_{i} d_{it}^{g}, 0 \right) \qquad \forall t \tag{5}$$

$$d_{it}^{g} = \mu_{it}^{g} \times \rho_{it}^{g} \qquad \forall t, \ \forall i \tag{6}$$

$$\rho_{it}^{g} = a_{t}^{g} \big/ c_{p} \qquad \forall t, \ \forall t \in p \tag{7}$$

Equation (4) estimates the truck average waiting time at gate based on the average queue length and discharge rate at time point t; Equation (5) states that changes in the queue length between two time points is equal to arrivals minus departures; Equation (6) calculates the departures of gate lane i at time point t, where the utilization rate of gate lane i at time point t is calculated by equation (7); Equation calculates the average queue length at time point t based on the PSFFA, this method is accurate and fast approximation for non-stationary queues.

Yard system constraints：

$$\lambda_t^y = \sum_i d_{it}^g \tag{8}$$

$$l_{t+1}^y = \max\left(l_t^y + \lambda_t^y - \sum_j d_{jt}^y, 0 \right) \quad \forall t, \forall j \tag{9}$$

$$d_{jt}^y = \mu_{jt}^y \times \rho_{jt}^y \quad \forall t, \forall j \tag{10}$$

$$\rho_{jt}^y = \left(l_{jt}^y + 1 - \sqrt{\left(l_{jt}^y\right)^2 + 2 \times v^2 \times l_{jt}^y + 1} \right) \Big/ 1 - v^2 \quad \forall t, \forall j \tag{11}$$

$$w_t^y \approx l_t^y \Big/ \sum_j d_{jt}^y \quad \forall t, \forall j \tag{12}$$

Equation (8) calculates the number of trucks arriving at the yard zone based on the gate lane discharge rates; Equation (9) states that changes in the queue length between two time points is equal to arrivals minus departures; Equation (10) calculates the departures of yard zone j at time point t, where the utilization rate of yard zone j at time point t is calculated by equation (11); Equation (12) estimates the average waiting time of yard zone j at time point t.

4. Solution of the model

To solve the model, a method based on genetic algorithm and PSFFA is designed. Genetic algorithm is used to search the optimal solution considering the constraints of adjustment quota, calculating the optimal appointment quota for each time period. A method based on Point wise Stationary Fluid Flow Approximation (PSFFA) is used to calculate accurate truck waiting time and queue length in the gate and yard, and the truck total turn time is used as the fitness value of the genetic algorithm.

4.1. genetic algorithm

To optimize the model, a method based on genetic algorithm is used to search optimal solution. The total gate waiting time and yard waiting time is used as the fitness value of the algorithm, and it is calculated through equation (14). The steps of the genetic algorithm are as below:

Step 1: coding method and initial population

GA is based on a chromosome. A chromosome is to represent a group number of maximum appointment quota $\left\{ \bar{\lambda}_{11}^g, \bar{\lambda}_{12}^g, \cdots, \bar{\lambda}_{NP}^g \right\}$ of each period. The initial population is produced randomly. Each individual contains a set of $N \times P$ random numbers. The GA parameters are set to be 200 for population size.

Step 2: calculate the fitness value of each individual

Calculate the fitness value of each individual based on the equation (14). If the individual does not subject to the equation (1)-(12), the fitness will be set a huge number M.

Step 3: select and crossover operations

Sequential method is used to determine the probability of selection. The individuals are divided into two parts based on the constraint conditions. Number the individuals based on the fitness value from smallest to the largest. Calculate the number of the individuals under constraints, and then add m to the number of the individuals inadequate to the constraints. The probability is calculated as follows:

$$p_i = \frac{1}{N}\left[\eta^+ - (\eta^+ - \eta^-)\frac{i-1}{N-1} \right] \tag{13}$$

N represents the size of the population, i is number of the sequence, $1 \le \eta^+ \le 2$, $\eta^- = 2 - \eta^+$ in general, $\eta^+ = 1.5$, $\eta^- = 0.5$

New individuals of high fitness value are generated through crossover operation, and excellent genes from the parents are gathered through crossover.

Step 4: mutation

The parameter is set to 0.1 for mutation probability.

4.2. queue length estimation

The queue length is calculated based on the non-stationary PSFFA method. Fig.1 shows the process of PSFFA method:

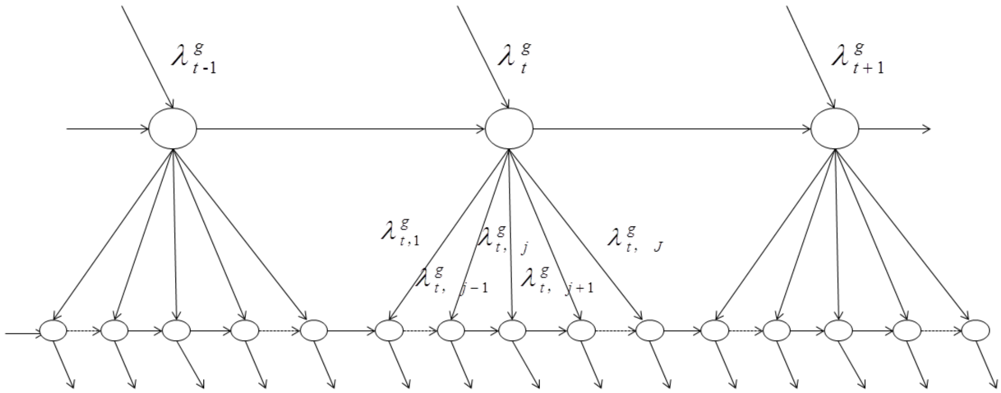

Fig.1 the process of PSFFA method

$$l_t^g = \frac{\left(a_t^g\right)^{c_p+1}}{\left(c_p-1\right)!\left(c_p-a_t^g\right)^2}\left\{\sum_{n=0}^{c_p-1}\frac{\left(a_t^g\right)^n}{n!}+\frac{\left(a_t^g\right)^n}{\left(c_p-1\right)!\left(c_p-a_t^g\right)}\right\}^{-1}\left\{\frac{1+\frac{1}{k}}{2}+\frac{\left(1-\frac{1}{k}\right)\left(1-\frac{a_t^g}{c_p}\right)\left(c_p-1\right)\sqrt{4+5c_p-2}}{32a_{tj}}\right\} \tag{14}$$

Equation (14) is used to calculate the queue length of trucks. Each time point t is divided into a number of J small time points. Then stationary approximation can be used in each small time point. The number of arrivals in each small time point is estimated through equation $\lambda_{t\tau} = \lambda_t / J$. It is too complex to estimate ρ^g_{it} , so a bisection method is used. The steps are as follows:

Step 1: start with input two variables, $a = 0$ $b = 1$;

Step 2: set $\rho'_{it} = (b + a)/2$, and then calculate the queue length with equation (14).

Step 3: if $L'_t < L_t$, set $a = \rho'_{it}$, then return to step 2; but if $L'_t > L_t$, set $b = \rho'_{it}$, and then return to step 2;

Step 4: stop until $L'_t = L_t$ or $\left|L'_t - L_t\right| \le \varepsilon$, ε is a minimum.

5. Case study

5.1. data collection

This paper tests the proposed optimization model using the data provided by a container terminal in Tianjin. Software arena is used to fit distribution of service time of gate lanes and yard lanes. The result shows that the fitting distribution is Erlang with four parameters. The service rate of gate lanes is 0.75 trucks per hour and the service rate of yard lanes is 0.55 trucks per hour. So the gate system can be described in a M (t)/ E (4)/7/∞/∞/FCFS queuing theory and the yard system can be described in a M(t)/E(4)/4/∞/∞/FCFS queuing theory.

5.2. result analysis

- accuracy test of PSFFA method

The queue length is calculated based on the equation (14) using the data of a container terminal, and then calculate the waiting time through the equations mentioned in the model. The turn time is the sum of gate waiting time, yard waiting time and a fixed value. The turn time comparison between actual and PSFFA method is as Fig.2:

The result shows that the average turn time before using optimization model is 60.01 minutes; the maximum turn time is 115.57 minutes. The square deviation between actual turn time and estimated turn time is 1.3 minutes. So the PSFFA method can describe the characteristics of truck queuing in the container terminal accurately.

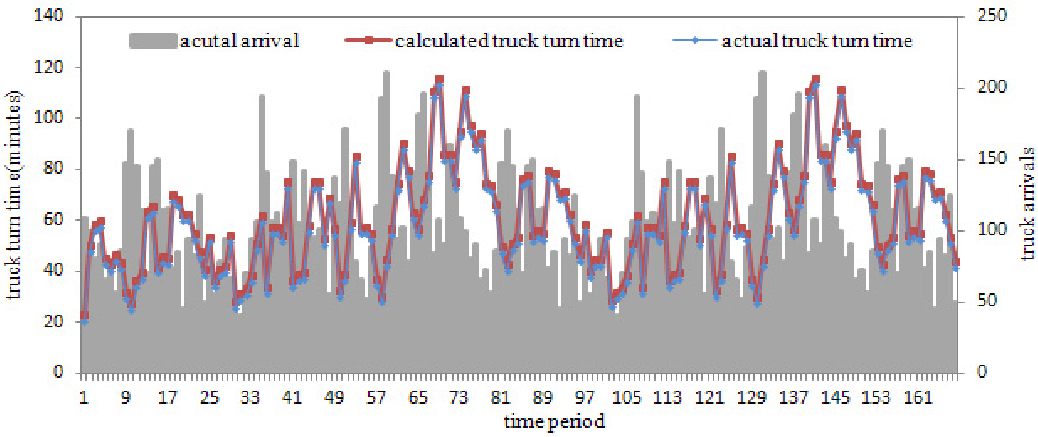

Fig.2 the turn time comparison between actual and PSFFA method

This paper calculated truck waiting time at the gate and in the yard separately to describe the implementation of BCMP queue network. The result is as shown in Fig.3:

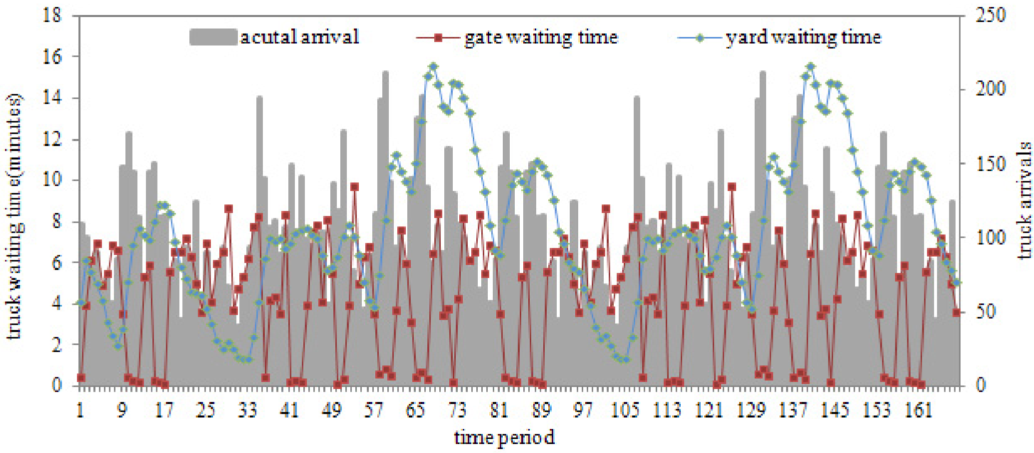

Fig.3 the truck waiting time at gate and in the yard

The result shows that: the average truck waiting time at the gate is 4.37 minutes and the average truck waiting time in the yard is 7.63 minutes. Heavy congestion accrues both at gate and in the yard, leading to long truck turn time in the terminal.

- accuracy test of optimization model

An optimization model is developed to alleviate the congestion in the container terminal. This model can estimate an optimal group number of appointment quotas, and then again calculate the waiting time using the optimal appointment quota. In this paper, the parameters are set to 200 for population size and 0.05 for mutation rate.

Fig.4 shows the comparison between actual arrivals and optimized arrivals. The result shows that after optimizing, the arrival flow of trucks tends to be more stationary and steady.

Fig.5 shows the variation of turn time after using optimization model. The result shows that the truck turn time decreases from 60.01 minutes to 50.19 minutes, the maximum truck turn time decreases from 115.58 minutes to 90.21 minutes. This illustrates the model can decrease the truck waiting time obviously.

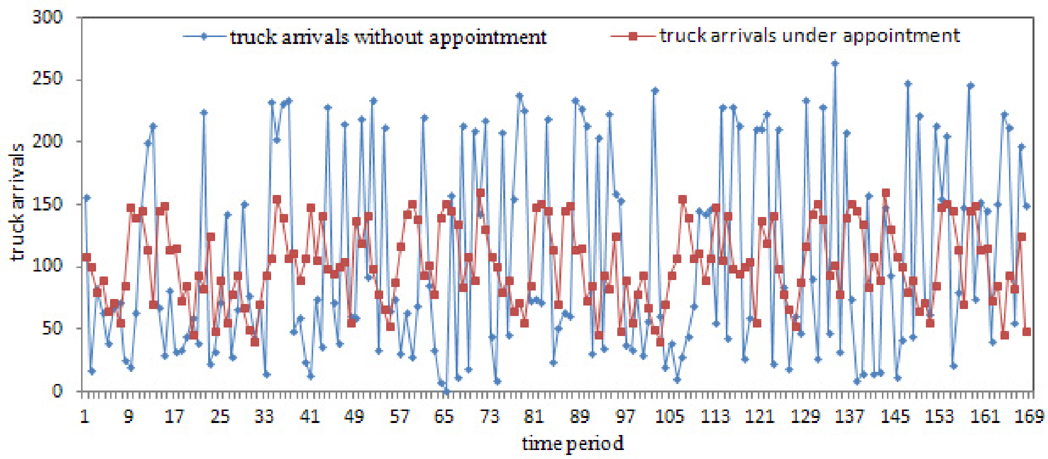

Fig.4 comparison between actual arrivals and optimized arrivals

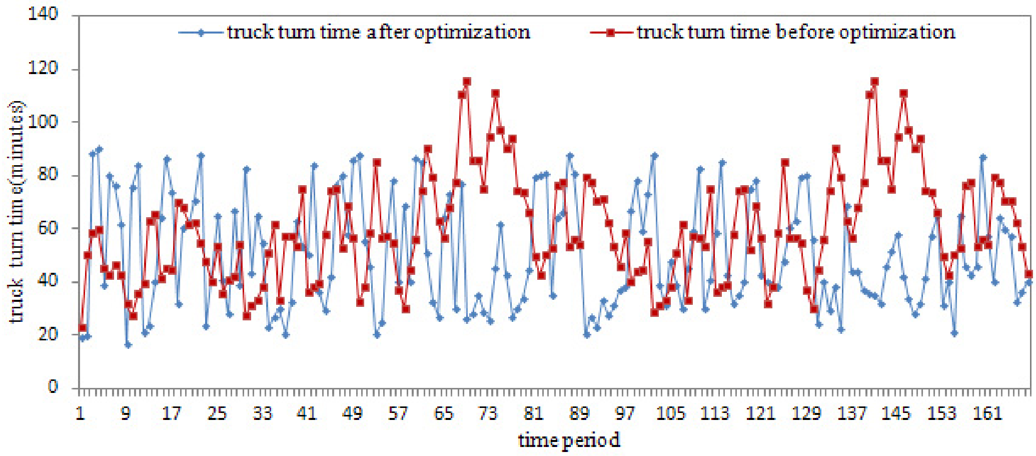

Fig.5 the variation of turn time after optimizing

5.3. sensitive analysis

The length of appointment time period is a very important factor affecting truck waiting time based on PSFFA method. This section sets different length of appointment time period to estimate the truck turn time separately. The length of appointment time period concludes 0.5 hours, 1 hours, 2 hours and 3 hours. The result is as Fig.6:

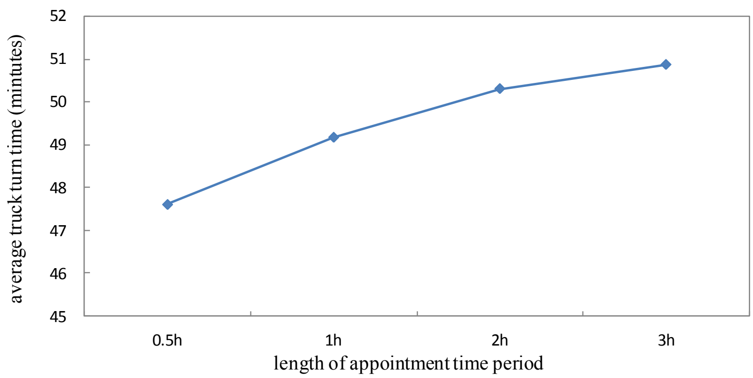

Fig.6 the impact of length of appointment time period on truck turn time

The result shows the smaller the length of appointment time period, the shorter the truck turn time. But punctuality is another factor considered in implementing truck appointment system. Trucks may not arrive at the gate on time during very small length of appointment time period because of traffic jam. So setting the truck turn time at an acceptable value, can improve truck arrival punctuality and leave the terminal operator more time to handle some emergencies.

6. Conclusions

This study develops a truck appointment model to alleviate the gate congestion. The objective is to minimize the truck turn in the terminal. A Baskett Chandy Muntz Palacios (BCMP) queuing network is used to describe the process of trucks at gate and yard. To solve the model, Genetic algorithm and a method based on the Pointwise Stationary Fluid Flow Approximation (PSFFA) method are designed. Numerical results indicate that the proposed truck appoint model can decrease truck turn time efficiently. And the length of appointment time period has an impact on the accuracy approximation of truck waiting time.

Further research could be directed towards (a) distinguishing pick-up and drop-off trucks when calculating truck turn time; (b) considering terminal extra scheduling cost due to truck delays in appointment period when determining the length of appointment period.

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