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Agent-based Truck Appointment System for Containers Pick-up Time Negotiation

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Abstrak

Kemacetan lalu-lintas di area sekitar pelabuhan adalah masalah yang umum terjadi di berbagai belahan dunia. Keterbatasan sumber daya terminal peti kemas untuk melayani jumlah truk yang datang untuk pelayanan peti kemas adalah penyebab utama antrian truk yang panjang. Masalah ini diperparah oleh fluktuasi laju kedatangan truk yang tak terduga, terutama pada saat jam ramai. Sistem reservasi truk telah diperkenalkan di berbagai negara maju, sebagai upaya untuk mengatur laju kedatangan truk yang akan datang. Pada mekanisme sistem reservasi truk yang ada saat ini, keputusan penjadwalan dilakukan secara terpusat dan mengabaikan kepentingan perusahaan truk. Di sisi lain, rekomendasi reservasi yang dikeluarkan oleh sistem reservasi truk dapat berjalan dengan tidak selaras dengan urgensi operasi bisnis perusahaan truk itu sendiri. Untuk memitigasi masalah ini, penelitian ini mengajukan model negosiasi tidak terpusat berbasis agen pada sistem reservasi truk dengan memperhitungkan estimasi waktu tunggu yang harus dihabiskan truk di area terminal peti kemas. Hasil simulasi menunjukkan bahwa dibandingkan dengan mekanisme reservasi terpusat, mekanisme reservasi truk berbasis mekanisme negosiasi multi-agen yang diajukan menghasilkan rata-rata waktu tunggu yang lebih cepat pada berbagai laju kedatangan truk. Sementara untuk total biaya jemput, performa dari mekanisme reservasi truk berbasis mekanisme negosiasi multi-agen menunjukan hasil yang lebih baik pada laju kedatangan truk tinggi. Insentif partisipasi perusahaan truk dalam mekanisme reservasi yang diajukan akan bertambah semakin tinggi pada saat kepadatan layanan tinggi.

Kata kunci*—Sistem Reservasi Truk, Negosiasi, Permodelan Berbasis Agen, Simulasi, Operasi Terminal Peti Kemas*

Abstract

Congestion in the seaports area is a common issue in many parts of the world. The root cause of the long truck queue is the insufficient container terminal resources to service the number of arriving trucks. It is aggravated by the fluctuating truck arrivals, particularly at peak periods. In response, a truck appointment system (TAS) is introduced to manage truck arrival. In the existing TAS mechanism, the appointment scheduling recommendation is constructed in a centralized manner and disregards the concerns of trucking companies. Moreover, such rigid TAS may complicate the business operation of trucking companies that already have a constrained truck schedule. This study proposes a decentralized negotiation mechanism in TAS that allows trucking companies to adjust arrival times by utilizing the waiting time estimation provided by the terminal operator. We develop an agent-based model of a TAS in the container terminal pick-up procedure. The simulation results indicate that compared to the existing TAS mechanism, the negotiation TAS mechanism generates a shorter average truck turnaround time regardless of truck arrival rates. In terms of average pick-up cost, the negotiation TAS mechanism provides better value under high truck arrival rate conditions. The incentive for trucking companies to participate in the negotiations is high at peak periods.

Keywords—*Truck Appointment System, Negotiation, Agent-based Modelling, Simulation, Container Terminal Operation*

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1. INTRODUCTION

Maritime transport is the foundation of global trade and goods supply chain [1], [2]. More than 80% of world merchandise trade by volume is carried by sea [3]. Although the growth in international maritime trade volumes slightly fell from 2018 due to the developments in the world economy, the total volumes reached an all-time high milestone of 11 billion tons. Furthermore, the global maritime trade flow is still dominated by developing countries for both export and import [3].

The high transaction volumes are often not followed by sufficient infrastructure expansion [4], [5]. When the seaports available resource cannot meet the trucks demand for service, negative externalities such as longer turn time and longer queueing time will occur [6]. The accumulation of vehicle within the seaports area consequently affects nearby public road traffic. This seaports congestion issue is common in many parts of the world. As a result of congestion, idling engine time for vehicles in the seaports area will rise and consequently leads to operational inefficiency and higher greenhouse emission. However, simply increasing the seaport's resource capacity with an infrastructure expansion is found to be ineffective [7]. The reason for this is the uncertainty of fluctuating truck arrival rates. There are certain times in a day when several trucks arriving at a similar time, resulting in peak times. In response, an initiative to manage the uncertainty of truck arrival rate is introduced in the form of a truck appointment system (TAS).

TAS was first implemented in Los Angeles and Long Beach seaports in early 2000 [8], [9]. Trucking companies are required to reserve an appointment that is set by the seaport operator before arrival. Intuitively, smoothing peaks with such appointment can reduce congestion. In reality, many trucking companies face difficulties in complying with the appointment system as a result of unsuitable appointments set by the seaport operator [8]. Each trucking companies have various interests and constraints, such as having their truck dispatching plans and schedules, or delivery appointment with other customers. The rigid appointment scheduling assigned by seaport operator is a limitation that may hinder trucking companies from complying with the system [10]. Regarding this limitation, this study proposes a negotiation protocol in TAS, particularly for negotiating truck arrival time.

There is a vast amount of literature regarding TAS to improve container terminal operations [5], [11]. Zhao and Goodchild [12] showed that information sharing in a TAS can reduce waiting times at terminal. Several studies examined the effect of TAS on the scheduling management of drayage trucks. The results show that sufficient access capacity and duration of the appointment windows are critical for trucking companies to maintain high productivity and service levels [7], [13]. Do et al. [14] develop an optimization method for time slot assignments. Huynh [15] studied the performance of container terminal under different appointment scheduling rules using discrete event simulation. Huynh and Walton [16] studied the effect of setting a cap for truck arrivals on truck turn time and crane utilization.

From the mentioned literature, we can see many studies that focus on applying various strategies to improve terminal operation, yet the decision-making perspective of TAS remains unexplored. Moreover, decision-making in many TAS operates in a centralized manner. It does not consider the scheduling problems of the trucking companies in determining the schedule. However, trucking companies have important role in the application of TAS and should be considered in the appointment process. To the best of our knowledge, literature discussing the negotiation mechanism in TAS is very limited [17]. The mentioned study considers the decision-making side of the trucking companies by employing mathematical programming method in a static environment [17]. Considering the dynamic and complex nature of container terminal operations, we opt to employ simulation method [18].

This study proposes a decentralized negotiation model in a TAS. Instead of using mathematical programming [17], we employ a multi-agent system approach [6], [19], [20] to develop the simulation model of TAS in a container pick-up operation. As suggested in [6], [12], [21], information exchange improvement in TAS can improve the operation in container terminal. Therefore, this study aims to present a negotiation protocol that utilizes the estimation of waiting time information provided by container terminal to assist the negotiation process.

2. METHODS

2.1 Problem Description

Container terminal operations consist of marine and landside interface operations. This study focuses on the landside interface operation, precisely the container pick-up procedure carried by drayage trucks in the container terminal area. The pick-up procedure consists of the pre-arrival and on-arrival procedure. A trucking company is required to finish the information exchange formalities before they proceed to the physical execution of picking up a container in the on-arrival procedure [22]. Pre-arrival formalities include the evaluation of the containers' documentation and the approval of the trucking company appointment request. After the document checks, the trucking company may dispatch its truck to the terminal and proceed to the on-arrival procedure. Upon the arrival in the terminal gate, another document check is conducted before the entrance. Once cleared, the operator will notify the position of its container to the truck. If there is another truck in the designated stack, the truck must wait in the designated waiting area before it can move to the container stack. The truck will wait in the stack until yard crane is available to pick-up their container and the queue accumulates as more trucks arrive. This high volume of trucks idling inside the terminal ultimately leads to congestion in the nearby area.

To mitigate such issue, TAS is introduced. The essence of TAS implementation is the management of truck arrival. In a TAS, the maximum number of trucks allowed to enter the gate during a time window is predetermined, and once the maximum capacity for a specific time slot is reached, no more pick-up request will be approved [16]. We refer to this mechanism as rigid TAS (RTAS). The appointment procedure in RTAS scheme is presented in Figure 1. From a terminal operator point of view, an RTAS enables the operator to manage container pick-up activities according to current resource availability. The truck arrival can also be distributed evenly throughout the day under ideal conditions.

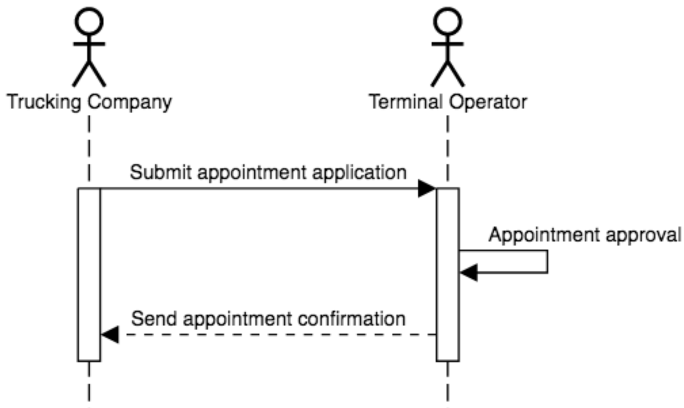

Figure 1. *RTAS Appointment Reservation Mechanism*.

Although the benefit of TAS is promising for both terminal operators and trucking companies, it poses a challenge in the implementation [13]. For the trucking companies that already have a constrained truck schedule, TAS may complicate their business operation. The rigidness of standard TAS causes problems such as low participation from the trucking companies side [8], [10]. Previous studies suggest that with real-time information about workload and congestion from terminal operator, trucking company can minimize congestion

[6], [17]. Considering this, we propose a TAS with a negotiation protocol, which incorporates the consideration concerning the workload and congestion of the container terminal.

2. 2 Solution Proposition

We propose the implementation of negotiation protocol in a TAS environment. Inspired by the decentralized decision-making model [17], this protocol considers the decision-making problem independently for each trucking company and the terminal. In contrast with a centralized RTAS, a decentralized TAS with negotiation protocol enables the trucking companies to adjust the arrival time with their own preferable time schedule. We refer this mechanism as negotiation TAS (NTAS). Figure 2 shows the appointment procedure in the NTAS scheme proposed in this study.

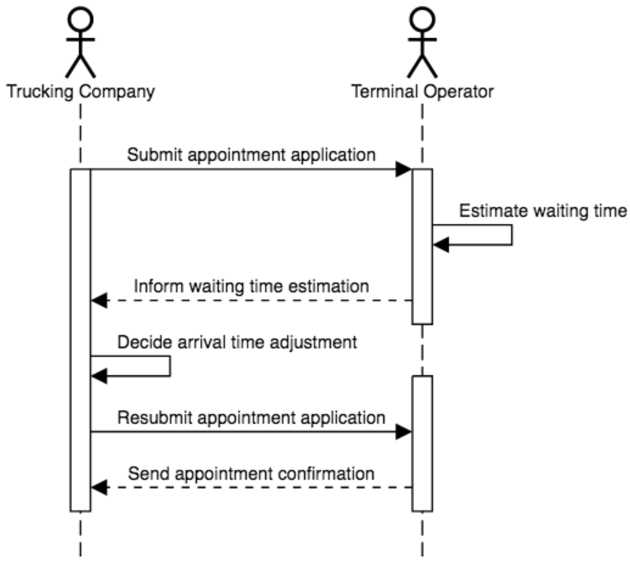

Figure 2. *NTAS Appointment Reservation Mechanism.*

We consider a TAS where the mandatory pre-arrival procedure is finalized at the beginning of every session k prior to on-arrival procedure. A representative agent that is responsible for a single appointment of trucking company j is always paired with single truck i, and we refer this pair as truck ij. Prior to arrival, a truck ij sends a proposal for container pick-up at its most preferred time θ_{ij}. The terminal operator is assumed to possess real-time information about the average truck turnaround time w_t. Equation (1) presents the calculation for the average truck turnaround time.

$$w_t = \frac{\sum_{i=1}^{i}\sum_{j=1}^{j}(t_{ij}^{d} - t_{ij}^{a})}{q_t} \tag{1}$$

where:

i	index for an appointment made by trucking company
j	index for the type of trucking company (i.e. TC1, TC2, and TC3)
t	index for time interval
q_t	number of trucks serviced at time t
w_t	average truck turnaround time at time t
t_{ij}^{d}	time truck ij depart from the terminal
t_{ij}^{a}	time truck ij arrive at the terminal

We formulate individual truck's expected waiting time e_{ijk} in equation (2). Coefficient of variance σ represents the variation in the expected waiting time. After the operator receives the proposal, expected waiting time and workload will be estimated.

$$e_{ijk} = \sigma w_t \tag{2}$$

where:

k index for a session
e_{ijk} expected waiting time of truck ij at session k
σ coefficient of variance of expected waiting time

The waiting time estimation formula is presented in equation (3). It accounts for the current average truck turnaround time and the number of appointments made in session k to predict the waiting time in the following hour.

$$\varphi_{ijkt} = w_t + \frac{\sum_{i\in k}\sum_{j\in k}\sum_k e_{ijk}}{r_k + 1} \tag{3}$$

where:

φ_{ijkt} waiting time estimation provided by the terminal operator for truck ij at time t during session k
r_k number of appointments made at session k

The estimation φ_{ijkt} is then informed to the trucking company as a response to the appointment application. Then, the trucking company may utilize that information to decide the time adjustment for the proposal. The decision logic to obtain arrival time adjustment Δ_{ij} is presented in equation (4). Note that the time adjustment value is subject to be limited by the earliest b_j^l and latest b_j^u time adjustment tolerance.

$$\Delta_{ij} = X_{ijkt} - e_{ijk}; \quad b_j^l \le e_{ijk} \le b_j^u \tag{4}$$

where:

Δ_{ij} arrival time adjustment for truck ij
b_j^l earliest possible (lower) time adjustment tolerance of truck company j
b_j^u latest possible (upper) time adjustment tolerance of truck company j

Then, the adjusted arrival time λ_{ij} is formulated as in equation (5). Truck ij then resubmits its modified appointment application to the terminal operator. The appointment process ends after the terminal operator sends appointment confirmation.

$$\lambda_{ij} = \theta_{ij} + \Delta_{ij} \tag{5}$$

where:

λ_{ij} adjusted arrival time for truck ij
θ_{ij} most preferred arrival time for truck ij

Finally, we formulate average pick-up cost Y_t in the equation (6) as the second performance measurement. In essence, it is a combination of truck turnaround time and inconvenience cost. In contrast with truck turnaround time, the pick-up cost is employed to measure the benefit of adjusting time arrival. This measurement represents the trucking companies' point of view of TAS performance [17].

$$Y_t = \frac{\sum_{i=1}^{i}\sum_{j=1}^{j}(t_{ij}^d - t_{ij}^a + |\lambda_{ij} - p_{ij}|)}{q_t} \tag{6}$$

2. 3 Model Implementation

To evaluate our proposal, we conduct agent-based simulations. We adopt a reference model [19] and extend the model to meet our needs. The reference model is used to capture the real-world situation of the on-arrival pick-up procedure in the container terminal and analyze the emerging properties. We refer to [19] for the simulation parameters; thus, we will not repeat the details of the model parameterizations here. In Figure 3, we portray the user interface dashboard of the agent-based simulation model.

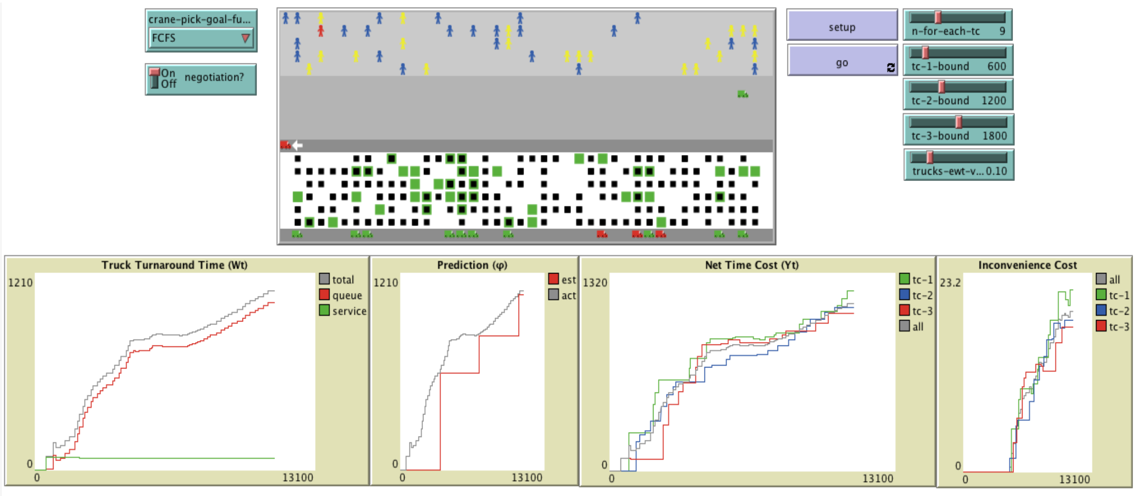

Figure 3. *The User Interface of Agent-based Simulation Environment.*

For this study, we implement several customizations. First, we model a single yard layout with a single crane. The container yard consists of 40 bays of containers with six container row stacks and a maximum height of four stacked containers. Second, we introduce an agent that acts as a representation of trucking companies. This agent will interact with the terminal operator in the pre-arrival procedure regarding the appointment process. Each agent has their preferred arrival time and expected wait time, which are used as a basis for decision-making in the negotiation. The appointment process occurs at the beginning of each session, which we define as ten sessions with 60 minutes duration for a working day.

2. 4 Experiment Design

The main emphasis of this study is to evaluate the impact of NTAS application on the truck turnaround time (see Equation 1) and the pick-up cost (see Equation 6) under different truck arrival rate condition (see Figure 4). We treat the existing RTAS mechanism as the benchmark case. Truck turnaround time is a general performance assessment for a container terminal operation, while pick-up cost is employed to portray the benefit of early or late arrival for trucking companies.

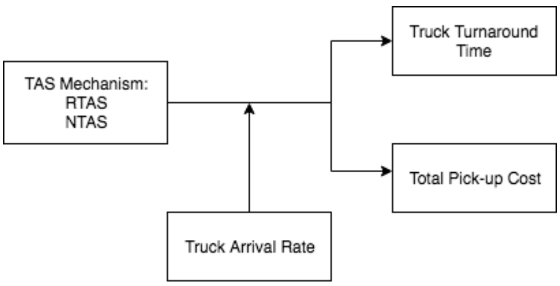

Figure 4. *Research Conceptual Model.*

We model three types of independent trucking companies with different upper and lower bound time adjustment tolerance: 10 minutes, 20 minutes, and 30 minutes. A 10% variance constant is employed to model the expected wait time variability of each independent trucking companies. Four constant truck arrival rates are tested: 6, 7, 8, and 9 trucks per hour. These rates are applied for each individual trucking companies. We run a 2*4 scenario in total, and each scenario is replicated 30 times. The first two sessions are regarded as a warm-up period and were omitted for the analysis. Table 1 presents the details of the simulation variable configuration.

Table 1. *Variable Configuration*

Variable	Values
TAS Schemes	Rigid TAS (RTAS), Negotiation TAS (NTAS)
Truck Arrival Rate / Hour	6, 7, 8, 9
TC Upper/Lower Time Adjustment Tolerance	10 min (TC1), 20 min (TC2), 30 min (TC3)
Expected Wait Time Variance	± 10%
Crane Strategy	First come first served
Simulation Length	10 Hours (36000 ticks)
Total Sessions	10 Sessions
Session Length	1 Hour (3600 ticks)
Warm-up Period	2 Sessions (7200 ticks)
Replication	30

3. RESULTS AND DISCUSSION

The simulation results of our proposed solution are presented in Table 2. As shown, under all truck arrival rate conditions, the average truck turnaround time is lower in the RTAS mechanism. A similar result can also be seen for the average truck queueing time as well. However, we note insignificance differences for the average truck service time in both mechanisms.

Table 2. *Truck Turnaround Time, Queueing time, and Service Time.*

Truck Arrival Rate	Average Truck Turnaround Time		Average Truck Queueing time		Average Truck Service Time	
	RTAS	NTAS	RTAS	NTAS	RTAS	NTAS
6	347.51	335.83	276.52	264.72	70.99	71.11
7	464.95	452.88	393.89	381.94	71.06	70.94
8	877.04	765.69	805.74	694.56	71.30	71.13
9	1750.78	1367.64	1679.52	1296.29	71.26	71.35

In Figure 5, we portray the performance comparison of RTAS and NTAS mechanisms in terms of truck turnaround time, truck queueing time, and truck service time. Note that truck turnaround time is a summation between the truck queueing time and truck service time. As expected, the NTAS mechanism leads to faster truck turnaround time and shorter queuing time. This indicates the effectiveness of our proposed NTAS solution.

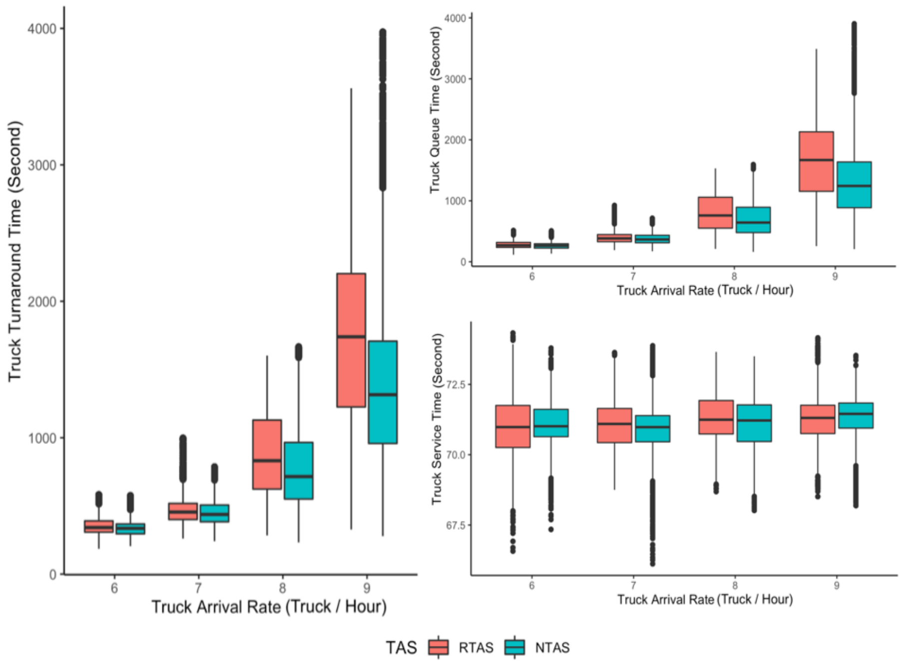

Figure 5. *The Impact of RTAS and NTAS Mechanisms on Truck Turnaround Time.*

We can also remark similar results under medium truck arrival rate (i.e. 8 trucks per hour). Interestingly, higher truck arrival rate leads to higher standard deviation value under medium to high truck arrival rate (i.e. 8 and 9 trucks per hour). Nevertheless, the average truck turnaround time is significantly lower under NTAS under high truck arrival rate conditions. This result is aligned with [6], [12], [17] that showed simple real-time information regarding current container terminal's workload could indeed be utilized by trucking companies to minimize truck turnaround time.

To analyze the benefit of NTAS for the trucking companies, we present the average pick-up cost result in Table 3. The pick-up cost is the total of truck turnaround time and inconvenience cost, which reflects the difference between trucks' adjusted time and preferred time. The NTAS mechanism generates a higher average pick-up cost than RTAS mechanism under low to medium truck arrival rates (i.e. 6, 7, and 8 trucks per hour). The gap of average pick-up cost between RTAS and NTAS decreases as the truck arrival rate increases. Under high truck arrival rate conditions (i.e. 9 trucks per hour), NTAS mechanism provides lower pick-up cost than RTAS mechanism. As shown, the additional inconvenience cost occurred in NTAS mechanism can make up for the truck turnaround time reduction compared to RTAS mechanism (see Equation 6). This indicates that the incentive for participating in NTAS mechanism is high when the container terminal is crowded. Figure 6 shows a visual representation of Table 3.

Table 3. *Pick-up Cost.*

Truck Arrival Rate	Average Pick-up Cost		Average Pick-up Cost (TC1)		Average Pick-up Cost (TC2)		Average Pick-up Cost (TC3)	
	RTAS	NTAS	RTAS	NTAS	RTAS	NTAS	RTAS	NTAS
6	347.51	458.17	342.67	459.58	346.80	455.09	353.13	459.93
7	464.95	578.08	461.81	582.34	470.68	573.85	462.51	577.46
8	877.04	902.66	869.00	908.74	880.59	909.26	880.64	889.03
9	1750.78	1521.83	1753.70	1515.16	1744.20	1521.97	1752.84	1526.11

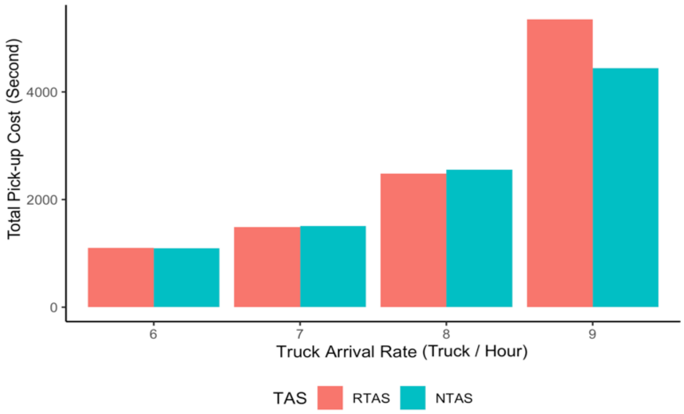

Figure 6. *The Impact of RTAS and NTAS Mechanisms on Average Pick-up Cost.*

4. CONCLUSIONS

This study proposes a decentralized negotiation protocol (NTAS) for reserving appointments of containers pick-up operation. We evaluate the proposed NTAS mechanism and compare it with the existing rigid TAS (RTAS) mechanism in terms of the truck turnaround time and pick-up cost metrics under different truck arrival rates. The results of the simulation evaluation are stated as follow:

1. NTAS mechanism leads to shorter truck turnaround time under any truck arrival rate than RTAS mechanism. A shorter truck turnaround time reflects a more efficient operation in a container terminal system. In terms of truck turnaround time, both terminal operators and trucking companies can obtain a clear benefit from NTAS implementation.
2. The average pick-up cost is slightly higher in the NTAS mechanism compared to RTAS mechanism under low to medium truck arrival rate (i.e. 6, 7, and 8 trucks per hour). However, under high truck arrival rate (i.e. 9 trucks per hour), the average pick-up cost is lower in NTAS mechanism. This result shows that the benefit of NTAS increases as the workload of the container terminal increases.

5. RECOMMENDATIONS

This study has several limitations. First, the generation of the truck's appointment requests are randomly generated. Truck arrival is not set to a specific scheduling decision rules. Thus, further studies that combine different scheduling decision rules, other than reactive random rule, with our proposed NTAS can be explored. Second, the waiting time estimation provided by the container terminal operator to the truck companies is rather simplistic. The terminal estimates the future waiting time based on the average trucks' waiting time in that day. For future research, the applications of a predictive model is recommended to obtain a more accurate of the trucks waiting time predictions. Furthermore, myriad research approaches that can improve the operation of container pick-up coordination using decentralized-based truck appointment system can also be further explored.

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