12-2017

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Ketki KULKARNI

Khiem Trong TRAN

Hai WANG
Singapore Management University, haiwang@smu.edu.sg

Hoong Chuin LAU
Singapore Management University, hclau@smu.edu.sg

DOI: https://doi.org/10.1109/WSC.2017.8248029

Citation

KULKARNI, Ketki; TRAN, Khiem Trong; Hai WANG; and LAU, Hoong Chuin. Efficient gate system operations for a multi-purpose port using simulation optimization. (2017). *2017 Winter Simulation Conference: Las Vegas, NV, December 3-6: Proceedings*. 3090-3101. Research Collection School Of Information Systems.
Available at: https://ink.library.smu.edu.sg/sis_research/3911

Proceedings of the 2017 Winter Simulation Conference
W. K. V. Chan, A. D'Ambrogio, G. Zacharewicz, N. Mustafee, G. Wainer, and E. Page, eds.

EFFICIENT GATE SYSTEM OPERATIONS FOR A MULTIPURPOSE PORT USING SIMULATION-OPTIMIZATION

Ketki Kulkarni
Khiem Trong Tran
Hai Wang
Hoong Chuin Lau

Fujitsu-SMU Urban Computing & Engineering Corp. Lab
Singapore Management University
71 Stamford Road
178895, Singapore

ABSTRACT

Port capacity is determined by three major infrastructural resources namely, berths, yards and gates. The advertised capacity is constrained by the least of the capacities of the three resources. While a lot of attention has been paid to optimizing berth and yard capacities, not much attention has been given to analyzing the gate capacity. The gates are a key node between the land-side and sea-side operations in an ocean-to-cities value chain. The gate system under consideration, located at an important port in an Asian city, is a multi-class parallel queuing system with non-homogeneous Poisson arrivals. It is hard to obtain a closed form analytic approach for such a system. In this paper, we describe an application of simulation techniques in analyzing the performance of gate operations. Further, we develop an optimization model that is integrated with simulation techniques to suggest efficient lane management policies for an outbound gate system.

1 INTRODUCTION

The management of a port involves a complex ocean-to-cities value chain. Figure 1 shows the overview of the value chain. On one side there are vessels (ships) carrying cargo to and from the city, while on the other side are multitude of vehicles moving this cargo on land. The work described in this paper is part of a port simulation effort developed in collaboration with a multipurpose port in an Asian city. The gate system (refer *2* in Figure 1) is an important link in maritime port operations. With increasing trade in cargo shipments globally, ports worldwide are striving to maximize their capacities at berths and yards. However, those efforts remain futile, if not supplemented with adequate planning at the gate system to handle the increased movement of cargo through the gates. This project aims to identify efficient lane management policies that minimize operational costs as well as waiting time for the customers (cargo carrying vehicles). The port earns revenue for every unit weight or volume of cargo it handles successfully. The more capacity it provides, the more potential revenue it earns. However, while aiming to increase revenue, the port authorities do not want to increase customer wait time. Also, opening additional lanes is not necessarily an efficient solution, since it increases operational costs. An efficient management policy is important to run the system with minimum resources while meeting the service requirements.

Freight vehicles carrying cargo vary from large 18-wheeled prime movers to closed container lorries and cement carriers, and goods vans of all sizes. Vehicle arrival rate is different across the day. The gate has a different set of lanes dedicated for inbound and outbound traffic, physically separated by a partition. At both the inbound and outbound sections of the gate, vehicles are subjected to two checks: a port check and an immigration check. The gate system is a multi-class (multiple vehicle types), multi-server (two

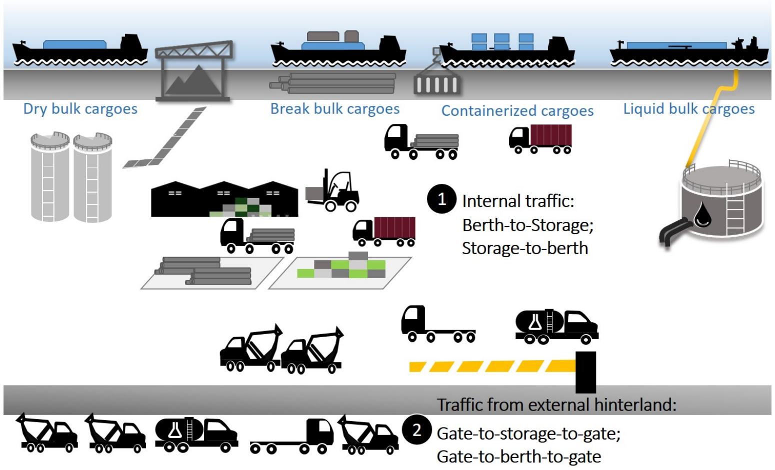

Figure 1: Maritime port optimization at a glance.

check points per lane), parallel (lanes operating in parallel) queuing system with non-homogeneous Poisson customer arrivals. The automated system at the outbound gate provides service time, vehicle and cargo type information for each entering and exiting vehicle, but does not cover the government check point. In order to gauge the capacity of the gate system, it is important to capture the time spent by each vehicle at the gate. Due to the uncertainty involved in the immigration check, this estimation is non-trivial. The outbound gate also experiences large queues during heavy demand seasons, which block internal roads in the port. The next section describes the gate system under study in detail.

2 OUTBOUND GATE SYSTEM DESCRIPTION

This section describes gate system at the port. There are five lanes in the outbound gate system as illustrated in Figure 2. Laden vehicles use 4 out of the 5 lanes while one lane is dedicated to empty vehicles.

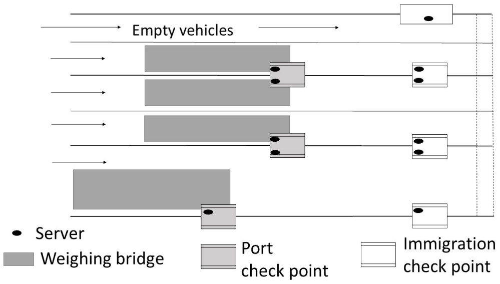

Figure 2: Layout of lanes at outbound gate.

There are two check points in each lane, corresponding to the port check and the immigration check. One of the lanes is wider than other lanes, to accommodate wider vehicles. In Figure 2, the arrows show direction of traffic flow. Within each lane, the grey rectangular blocks depict areas where vehicles halt for weight check. The location of the servers for each of the two checkpoints is indicated by the bordered boxes between lanes. The grey boxes show the port checkpoints and the white ones indicate the immigration checkpoints. The black oval symbols within these boxes indicate the servers at each checkpoint. Next, the various checks that the vehicles undergo before departing from the port into the city are described. Table 1 shows the various checks that each type of vehicles has to undergo at the outbound gate. To maintain confidentiality, the data in this paper is masked. There are 3 main types of vehicles observed at the gate, referred to as *A*, *B* and *C*. Vehicles not belonging to either of the three types are clubbed under the category of *others*. As is observed, some vehicles are subjected to more stringent checks due to the nature of the cargo they carry. Type A vehicles have more flexibility compared to other vehicles, since their cargo is fixed.

Table 1: Outbound gate checks.

Check Point	Check Type	A	B	C	Other vehicles
Port check	Cargo count	×	×	✓	×
	Weight	✓	✓	✓	×
	Driver identification	✓	✓	✓	✓
	Vehicle identification	✓	✓	✓	✓
Immigration check	Cargo inspection	×	✓	✓	✓
	Relevant papers	✓	✓	✓	✓
	Customs check	×	✓	✓	✓

These characteristics are important predictors of the expected service time for the vehicles. Appropriately dispatching vehicles to lanes could possibly bring down the time in system for vehicles and increase the overall cargo handling capacity of the gate system. The next section describes some of the prior work in this field, specially focusing on those works that involve simulation based approaches.

3 RELATED WORK

This section describes some of the previous efforts in gate operations management using simulation based approaches. The key takeaways from each of the researches as mentioned and the differences with the current work are listed.

Yue, Chun, and Lin (2006) present a simulation-optimization framework for the planning of a gate system at a container terminal. They consider costs involved in building a new lane along with auxiliary facilities, since structural changes to the gate layout are under consideration. Further, the service rates at the servers are dependent on the choice of lane and not on the type of vehicle being served. The authors consider a queuing system where all the vehicles using either the entrance or the exit lanes join a single queue. The solution methodology involves a simulation model that evaluates the plan suggested by a Genetic Algorithm (GA) based optimizer and conducts a performance analysis. For the port gate system considered in our paper, structural changes are not permitted. Further, the service times of each server depend not only on the choice of lane, but also on the vehicle type. Lastly, the system under consideration is a parallel system of queues, where separate queues are seen before each server.

Guan and Liu (2009) present an optimization model for obtaining a lane operations policy. This work addresses the efficient lane management problem in a purely analytic manner using a multi-queuing model and $M/E_k/S$ approximation formulas. Authors consider gate operations costs, labor costs and truck operation costs. The authors focus on issues for inbound trucks and quantify truck waiting cost. Maguire et al. (2010) present a detailed review of literature related to port gate system operations. The authors discuss various systems used at the gate, the different kinds of automation technology employed as well as mathematical models used to study the operations. Maria et al. (2013) use simulation based techniques to compare gate operation strategies for a container port. They compare five scenarios that differ in the hours of operations and restrict commercial demand to certain times of the day. These scenarios are bench-marked against a baseline scenario obtained through historical data. The authors show the usefulness of simulation in deciding operational strategies without actually having to experiment with the real customers. Although this work deals with lane management in terms of operating hours, they do not focus on a more detailed lane policy problem of restricting access to lanes by vehicle types.

Mohammad (2013) documents a PhD thesis towards using agent-based approaches to study container terminal operations. In particular, chapter 3 discusses modeling approaches to address terminal gate

Table 2: Classification of literature survey.

Authors	Multiple vehicle types	Structural changes	Lane management	Simulation model	Case study
Yue, Chun, and Lin (2006)	×	✓	×	✓	Container terminal
Guan and Liu (2009)	×	×	✓	×	Container terminal
Maguire, Ivey, Golias, and Lipinsk (2010)	×	×	×	×	Review paper
Maria, Sotirios, Mihalis, Patrick, and Eleftherios (2013)	×	×	✓	✓	Container terminal
Mohammad (2013)	×	×	×	✓	Container terminal
Vadlamudi (2016)	✓	×	✓	✓	RORO port
Proposed paper	✓	×	✓	✓	Bulk port

congestion. The authors propose an approach where depots aim to minimize congestion at seaport terminal gates by using real-time gate congestion information provided to them. The authors further demonstrate through experiments how truck wait time can be successfully minimized by distributing the demand more uniformly over the operational hours. This work does not consider multiple truck types. Also, one of the key differences with the work proposed in our paper is that the vehicles do not get to choose when to come to the port. The arrival rates are fixed, regardless of the congestion levels. Vadlamudi (2016) present a master's thesis on gate operations. The thesis reviews multiple papers that have used simulation for studying gate systems. They also address the problem of traffic through outbound gate system. However, only a single lane system in considered. Further, the various operational policies involve changing hours of operations at the gate. The analysis is also carried out to help plan a future gate system, by using future demand predictions and various automated systems. Although this work involves multiple truck types and scenario analysis using simulation, the single lane structure makes it significantly different. Since our work involves multiple lanes, lane policies involve not just hours of operations, but also choice of number of lanes open.

From the literature survey, useful insights were obtained on ways to analyze gate operations systems. Over the years, simulation has found much importance in this field. Table 2 compares the previous work with the proposed work based on various criteria such as use of simulation model, types of vehicles considered and whether lane management problem is addressed. From the table, it seen that the work closest to ours is Vadlamudi (2016). However, as described earlier, this thesis considers a single lane system for the outbound gate, as opposed to the multi-lane system considered by this paper. One of the major differences in the work proposed in this paper with most of the previous work is the high vehicle mix faced by the port. Our work considers a system where structural changes (such as increasing lanes) are not permitted, port cannot control arrival patterns of vehicles and the gates are open 24 hours. In the context of this paper, lane management policy is defined as **schedule of opening, closing or restricting of lanes to particular vehicle types**. This paper presents a simulation-optimization based approach to analyze a gate operations system with multiple lanes and multiple kinds of vehicles and uses scenario analysis to identify efficient lane management policies. Next, the modeling framework along with the simulation and optimization models is described.

4 SIMULATION-OPTIMIZATION FRAMEWORK

The gate system under consideration involves multiple lanes operating in parallel. Each lane has two check points, which can be called as servers in a queuing system. Each server can serve a single vehicle at a time. The customers of this system are the various vehicles. It is important to model the different customer classes accurately, so that an optimal lane management policy can be obtained. Each lane of the queuing system under consideration can be denoted $M(t)/M/1$, where $M(t)$ indicates Poisson arrivals with a time-dependent parameter $\lambda(t)$, M indicates exponential service time and 1 is the number of parallel servers. It is noted that each lane has two different servers, which are sequential and different. The queues in the actual system are limited by space. If the queue before the first server is full, the vehicle is forced to wait either on one of the internal roads or in the parking space. If the queue before the second server is full, the vehicle is forced to wait at the first server. The queue before the first server is limited to 10, while the queue between the two servers is limited to 3 vehicles. The modeling of the customer classes is as follows.

4.1 Modelling vehicle classes

Based on historical data, we observe that the vehicles can be divided into 4 main categories: Types *A, B, C* and *others*. The first three classes usually account for more than 90% of the traffic.

Table 3: Parameters for simulation.

$\lambda_A(t)$	Average type A arrivals in time step t
$\lambda_C(t)$	Average type C arrivals in time step t
$\lambda_B^w(t)$	Average wide ($> 3.5m$) type B arrivals in time step t
$\lambda_B(t)$	Average regular type B arrivals in time step t
$\lambda_o(t)$	Average *other* arrivals in time step t
μ_A	Service rate for type A
μ_C	Service rate for type C
μ_B	Service rate for type B
μ_o	Service rate for *others*

The remaining traffic usually consists of goods vans, private cars and smaller pick-up trucks. The historical data of arrivals is sorted into these 4 categories. The type B class is further divided into two types based on their size: $<= 3.5m$ and $> 3.5m$. Upon analyzing the sorted data, it is observed that arrivals follow a non-homogeneous Poisson process. The arrival rates are defined for a 24 hour cycle. The service rate at both servers follow the same distribution across the 24 hour period. However, different vehicle categories have different rates. It is also observed that the service rates are independent of the choice of lane and remain consistent for the same service across lanes. Also, the service rates for all type B is similar, regardless of their size. The parameters in the simulation model are listed in Table 3. There are 24 time steps considered, one for each hour of the day. Next, the process of building the model in Java is described, along with the model flow.

4.2 Simulation model building

Figure 3 shows the overview of the simulation model logic built using Java libraries. Java is chosen because it is open source, freely available and has a set of simulation libraries for queuing models. Vehicle arrivals are triggered using arrival events. Each vehicle is informed of the set of accessible lanes. The default strategy used by vehicles is to pick the lane with the shortest visible queue length, which is the queue at the first check point at the gate. Once a vehicle is generated using arrival event, it selects a queue to join and is added to it if the queue limit is not reached. At the queue, the vehicle checks for available server, which is modeled as a resource. If server is available, the vehicle is removed from the queue and server status is changed to busy. If server is not available, the vehicle waits to receive notification of server being

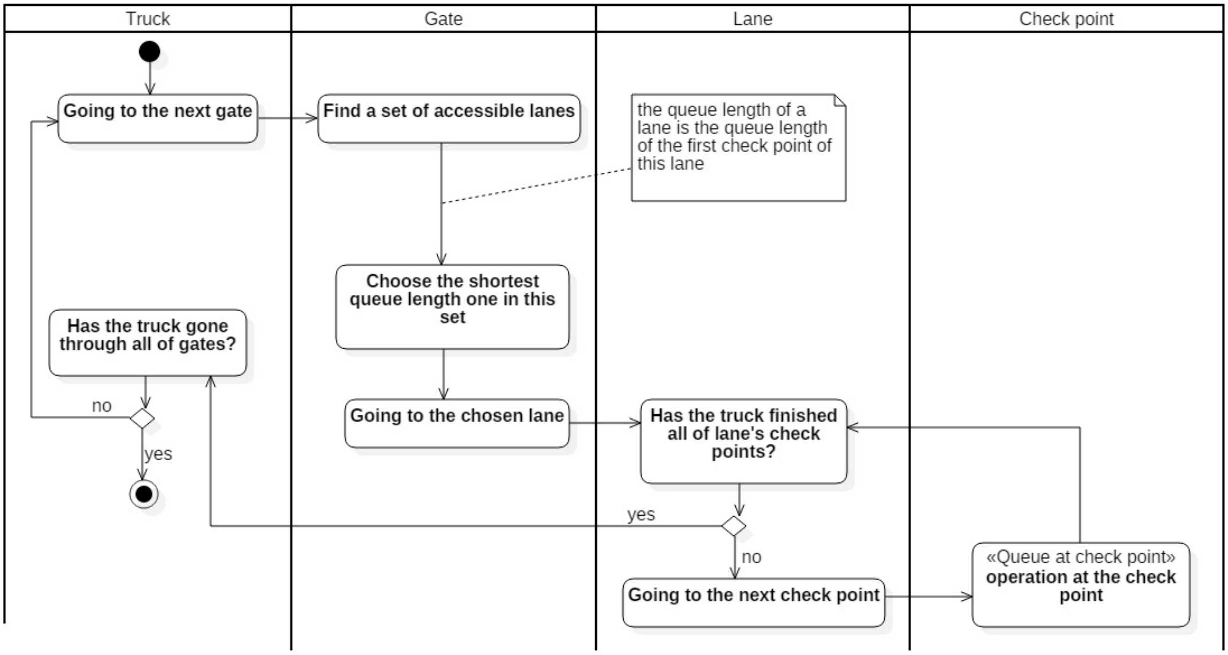

Figure 3: Gate simulation operations overview.

freed. Once the vehicle completes the first check, it joins the queue for the second check. Upon completion of each check, the vehicle checks to see if it has completed the required number of checks for leaving the gate. Once this condition is met, it is allowed to exit the gate. The model allows for a multi-gate system, where a vehicle might need to visit more than one gate. For the current project, this multi-gate feature is not used. Although all lanes appear similar, there are minor differences in their attractiveness to vehicles. To maintain data confidentiality, the lane numbers will be masked in the remaining discussion in this paper. The 4 lanes used for laden vehicles will be referred to as *W, X, Y* and *Z*. The underlying lane features that decide the probability of a vehicle picking a lane have been captured in the simulation model by implementing the following:

- All vehicles check for Lane W before other lanes.
- For equal queue lengths, vehicles choose Lanes W or X over Lanes Y-Z.
- All laden vehicles with higher dimension cargo ($> 3.5m$) are assigned Lane 1.

The optimization model and its integration with the simulation model is described next.

4.3 Optimization formulation

The objective of the optimization model is to reduce operating costs without adversely affecting the time in system for each vehicle. The model aims to reduce the total number of *lane-hours*, which is the summation of the hours in which each lane is open. Unlike the simulation model, the optimization model treats all lanes as equal. It is noted that the optimization model is not a standalone model, but needs inputs from the simulation model. The index n indicates the iteration from which the parameters are obtained. The parameters, decision variables and the mathematical model are described next.

Parameters

I	Set of all lanes
J	Time steps, j=1,...,24
β_j^n	Cost function for time period derived from (n-1)th simulation iteration j
w_j^{n-1}	Average time in system in time period j obtained from (n-1)th simulation iteration
w^*	Threshold for vehicle time in system

Decision variable

x_{ij}^n	1 when lane i is open in time period j and 0 otherwise

$$\min \sum_{i \in I, j \in J} \beta_j^n x_{ij}^n \quad (1)$$

$$\sum_{i \in I} x_{ij}^n \geq 1, \quad \forall j \in J \quad (2)$$

$$\sum_{i \in I} x_{ij}^n \leq I/2, \quad \forall j \in J, |\beta_j^n| < 2 * w^* \quad (3)$$

$$x_{ij}^n \in \{0,1\} \quad (4)$$

Expression 1 gives the objective function, which is to minimize the number of lane-hours. Constraint 2 ensures that at least one lane is open in any given hour. Constraint 3 limits the total number of open lanes to half the available lanes, if the additional time in system for vehicles is less than twice the acceptable time in system. The values for parameters w_j are obtained through simulation. It is noted that successive w_j are not independent of each other. As shown in Equation 5, the time in gate system for vehicles is a function of the number of lanes open in a given hour. Equation 6 gives the cost function used in this optimization model. It is defined as the difference between the specified threshold of average time in gate system for all vehicles and the observed values of average time in system at every hour in previous iteration. For a given time period k, if $w_k << w^*$, then β_k, which is the cost coefficient of the decision variables in the objective function, will take on a high positive value. It will encourage the model to drive multiple $x_{ik} = 0$. Alternatively, if $w_k >> w^*$, then β_k will be a large negative number, driving the model to keep more lanes open by setting $x_{ik} = 1$.

$$w_j^n = f(x_{ij}^n) \quad \forall i \in I \quad \forall j \in J \quad (5)$$

$$\beta_j^n = w^* - w_j^{n-1}, \quad \forall j \in J \quad (6)$$

4.4 Simulation-optimization approach

The integrated modeling approach applied in this paper is based on the works of Kulkarni and Venkateswaran (2014). The proposed simulation and optimization models do not work as standalone models, but interact with each other over multiple iterations to obtain the *best* lane operations schedule.

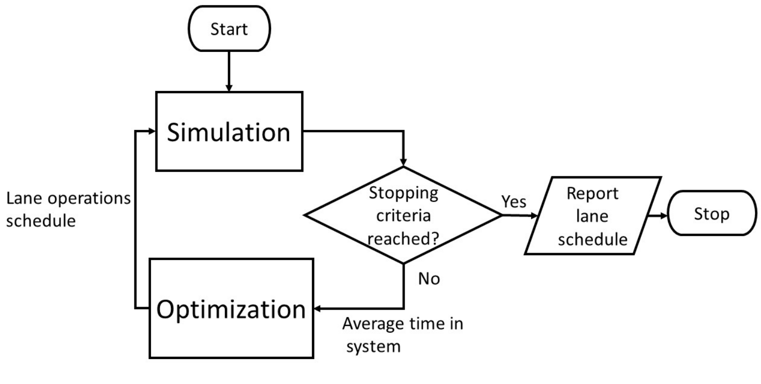

Figure 4: Interactive simulation-optimization approach.

Figure 4 shows the simulation-optimization scheme. The simulation model runs first, providing feedback to the optimization model (average time in system). The optimization model uses the feedback to generate the next of inputs (lane schedule) for the simulation model. This process continues till a pre-specified stopping criteria (such as number of iterations) is reached, after which the best schedule is reported. Algorithm 1 shows the steps involved in the interactive model. Initially, the simulation model runs with all lanes open for all hours. The average time in system is noted for each hour. The optimization model runs with the time in system input from simulation, generating a new schedule of opening and closing lanes over the 24 hour period. This schedule is compared with the previous best schedule for number of lane-hours required, while the average time in system is checked against the set threshold value w^*. After completing the specified N iterations, the best schedule is reported. The next section describes the data collection process and some preliminary analysis on the data.

Algorithm 1 Simulation-optimization

```
Run simulation with all lanes open $\forall j \in J$. Note $w_j^0$. Set Iteration counter n=0, $x_{ij}^n = 1 \quad \forall i \in I \quad \forall j \in J$, $X^{best} = x_{ij}$.
while $n < N$ do
    Run optimization model with $w_j^n$. Note $x_{ij}^{n+1}$.
    If $w_j^n \leq w^* \quad \forall j$ and $\sum_{ij} x_{ij}^{n+1} < \sum_{ij} x_{ij}^n$, $X^{best} = x_{ij}^{n+1}$.
    Run simulation model with $x_{ij}^{n+1}$.
return $X^{best}$.
```

5 DATA COLLECTION AND ANALYSIS

The automated system at the gates can collect data such as vehicle type, type of cargo, weight, driver details, time of entry and exit. This allows to obtain near accurate arrival patterns for each type of vehicle across days and even years. However, the immigration check point does not come under the purview of port management. A survey was designed to estimate the service time for the immigration check and to understand the physical layout of the gate. Volunteers collected data over one working week (5 days) related to service times, wait times in queues and physical layout of the gate system.

Table 4: Impact of preceding vehicle type on average time (sec) in immigration queue.

Current Vehicle	Preceding vehicle type All	 *A*	 *B*	 *c*
A	27.12	20.76	32.04	**48.44**
B	52.74	30.02	69.98	**82.8**
C	58.26	27.08	76.96	**93.54**

The form used for the data collection survey carried out at the port gate is described next. The first part of the form notes the lane number and observation slot (afternoon or morning). The first two columns specify class of the current vehicle and the vehicle ahead of it in the queue. The survey form includes a column for noting the type of vehicle preceding the current vehicle to study any impact the order of vehicles might have on time in system. The last four columns in the form note the time spent at various places in the system: the queues and the two servers as well as the total time in system. Table 4 shows the impact of type of preceding vehicle. The last column in the Table 4 clearly shows that having a *C* type vehicle ahead of the current vehicle in the queue increases the time spent by the current vehicle.

6 COMPUTATIONAL EXPERIMENTS

This section presents the results of computational experiments carried out using the standalone simulation model as well as the integrated simulation-optimization framework. The main role of the simulation model is to evaluate schedules while accounting for stochastic arrival and service rates. As mentioned in Section 4.1, $\lambda(t)$ and μ represent the various arrival rates and service rates. Table 5 shows the sample inputs for arrival rates. Various profiles are created to represent peak and non-peak demand for different days of the week. For each vehicle type, average arrivals $\lambda(t)$ are specified for every hour of the day. These are used as parameters for corresponding exponential distributions, that define the arrival pattern. Each experiment is carried out for over 10000 replications within each iteration to factor in the stochastic elements (arrival and service rates) and run for a virtual run time of 30 days.

Table 5: Sample arrival input to simulation.

Profile	Vehicle type	0	1	2
Monday-Off peak	A	12.42	8.45	7.54
Monday-Off peak	B	0.92	0.78	0.87
Monday-Off peak	C	1.84	0.93	1.36
Monday-Off peak	O	2.2	1.52	1

As mentioned earlier, of the five lanes available at the outbound gate, four lanes are available for cargo laden vehicles. For the experiments described in this paper, the demand pattern used corresponds to “off-peak” conditions. The first set of experiments studies different policies for combating the effects observed Table 4.

6.1 Analyzing impact of type C vehicles using simulation

From the previous section, it is observed that the presence of a type *C* before a vehicle adversely affects the time in queue. Using simulation, different policies are experimented with, suggesting lane allocation for type *C*. Table 6 describes the scenarios experimented with, along with the corresponding legend entry (in subsequent figures). First, we test the efficacy of new policies by checking the average time in system for all vehicles in each scenario. Figure 5 plots these times for the 4 cases.

Table 6: Scenario description.

Legend	Scenario description
No ban	Baseline scenario; three lanes open, all vehicles allowed in all lanes
ban W	Type C vehicles banned from Lane W, allowed in Lanes X and Z
ban X	Type C vehicles banned from Lane X, allowed in Lanes W and Z
ban W,X	Type C vehicles banned from Lanes W and X, allowed only in Lane Z

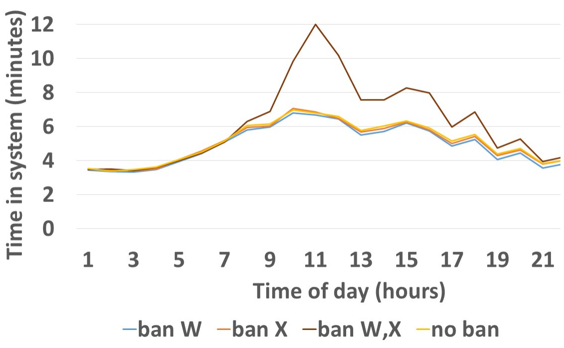

Figure 5: Average time in system.

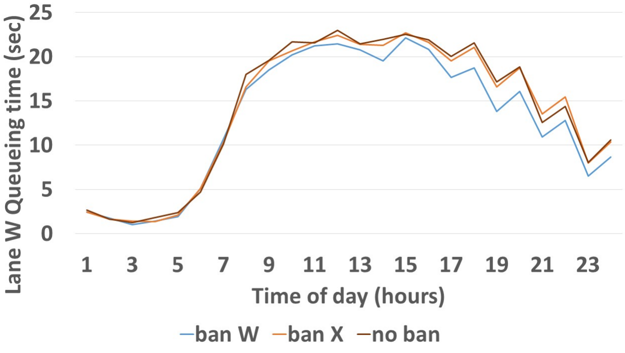

Figure 6: IC queue time in Lane W.

It is observed that the average time in system tends to get worse by reserving a single lane for type C (ban W,X scenario). However, banning type C from one out of three lanes does not affect the overall time in system. In fact, the “ban W” scenario performs marginally better than the “no ban” scenario. Figures 6-8 further compare the waiting time in immigration queues for all vehicles in each lane. Figure 6 shows the wait time at immigration for Lane W, while Figures 7 and 8 show the queue wait times at immigration in lanes X and Z. It is interesting to note that banning type C vehicles in Lane W seems to yield better results than banning these vehicles in Lane X. As discussed in Section 4.2, although all lanes appear similar, there are minor differences which make them more or less attractive to vehicles. An important takeaway from these experiments is that although some scenarios give similar average time in system, reallocation of lanes is able to reduce customer wait time in some lanes. The next set of experiments uses the simulation model for estimating the capacity of the gate in terms of number of served vehicles in a 24 hour period.

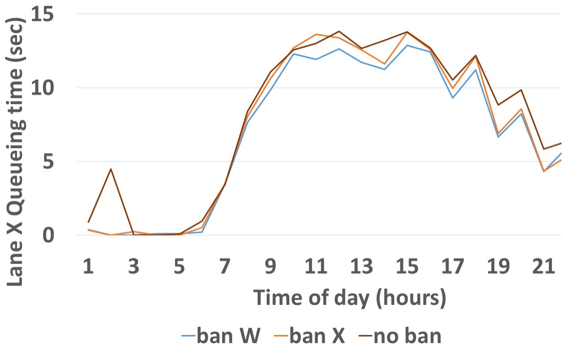

Figure 7: IC queue time in Lane X.

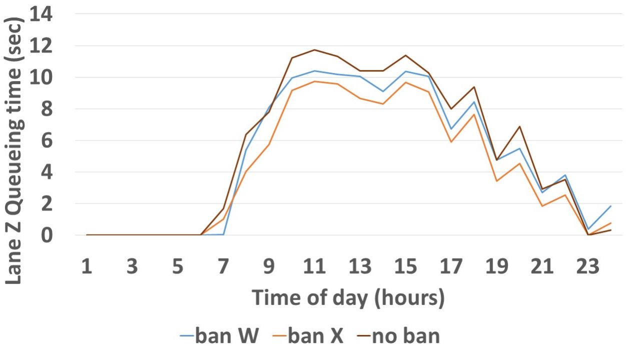

Figure 8: IC queue time in Lane Z.

6.2 Estimation of gate capacity using simulation

Figure 9 shows the experiments performed to estimate the gate capacity given its current demand pattern. The capacity also depends on accepted wait time. The increased demand patterns are generated while retaining the expected mix of vehicles observed over the years. It is observed that the gate system can support upto **3920** vehicles by keeping all 4 lanes open and with an average time in system less than 10 minutes. This is roughly 1.5 times the current demand. The plot in dotted line is plotted on secondary vertical axis (on the right). In the next set of experiments, lane policies with varying number of open lanes are explored. Simulation-optimization framework is used to identify an optimal lane management schedule for a given threshold value of average time in system.

Table 7: Expected number of served vehicles.

Demand	Served vehicles
1x	2614
1.5x	3920
2x	5232
2.5x	6546

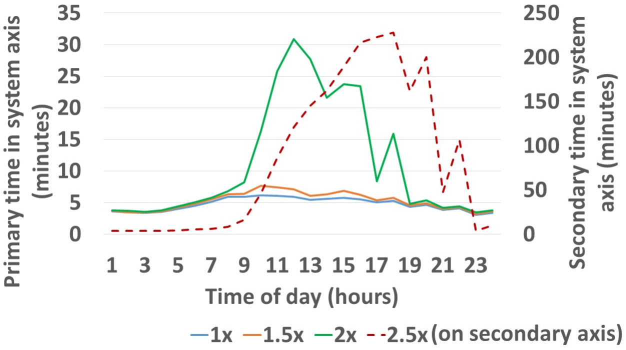

Figure 9: Time in system for increased demand.

6.3 Lane operation schedule using simulation-optimization

Figure 10 shows three scenarios with different number of open lanes for the identical (original) demand pattern. Table 8 shows that throughput remains similar regardless of whether 2, 3 or 4 lanes are open.

Particularly, there is no real advantage of keeping 4 lanes open over 3 lanes, since the pattern for time in system is similar. It is inferred that an *optimal* lane policy would include different number of lanes open in each time slot, since the arrival rates vary with time. Next we use the simulation-optimization model to determine an efficient lane operation schedule such that the average time in system for all vehicles is at most 25 minutes. Total of 5 iterations are performed and the best schedule obtained is reported.

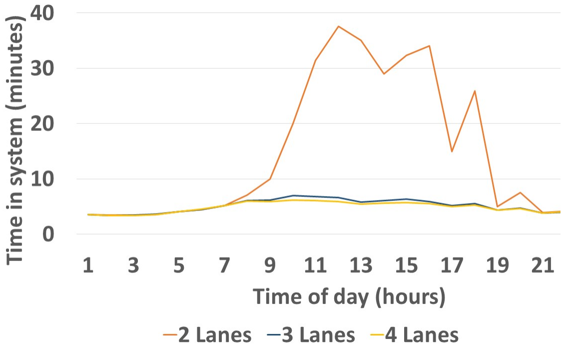

Figure 10: Avg time in system for all vehicles.

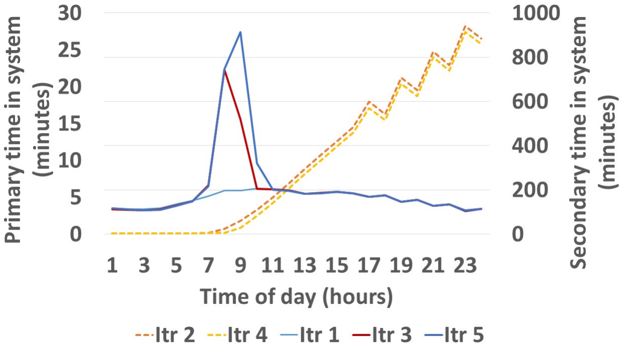

Figure 11: Iteration (Itr)-wise time in system.

Table 8: Average time in system vs open lanes.

Open lanes	Served vehicles
1	1728
2	2618
3	2616
4	2618

Table 9: Lane-hours in each iteration.

Iteration (Itr)	Lane-hours
1	96
2	73
3	25
4	70
5	26

Table 9 shows the required lane-hours for the schedules suggested in each iteration. Figure 11 shows the average time in system obtained at the end of each simulation-optimization iteration (Itr). The plots in dotted lines are plotted on secondary axis. Iteration 1 (Itr 1) is the baseline scenario, where all four lanes are open for the entire 24 hour period, giving a total of 96 lane-hours. It is seen that iteration 3 (Itr 3) results in a schedule that ensures that average time in system is below the specified threshold at any given time with much lesser lane-hours (25). Hence, the simulation-optimization method allows the user to effectively operate the lanes, while meeting desired service requirements.

7 CONCLUSION

This paper described a simulation-optimization based study carried out on the outbound gate system of a multipurpose port. Firstly, a simulation model was used to analyze trends observed in collected data and suggest policies to address different vehicle types. Next, the simulation model was used to estimate gate capacity using current demand patterns. Finally, a simulation-optimization framework was used to obtain an efficient lane management schedule. The paper presents one approach of developing a simulation-optimization model for efficient lane management. Ongoing and future work involves working on more complex cost functions for the optimization model and use of other feedback measures such as time in queue and service time. Future research will also be directed towards addressing multi-class customers of the queuing system.

ACKNOWLEDGMENTS

This research is funded by the National Research Foundation Singapore under its Corp Lab @ University scheme and Fujitsu Limited as part of the A*STAR-Fujitsu-SMU Urban Computing and Engineering Centre of Excellence

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AUTHOR BIOGRAPHIES

KETKI KULKARNI is a Research Fellow of Fujitsu-SMU Urban Computing and Engineering Corporate Lab. She holds a Ph.D. in Industrial Engineering and Operations Research from Indian Institute of Technology Bombay, India. Her research interests include discrete-event simulation, operations research, and their applications in transportation, logistics, and manufacturing. Her e-mail address is ketkivk@smu.edu.sg.

KHIEM TRONG TRAN is a Research Engineer at Fujitsu-SMU Urban Computing and Engineering Corporate Lab at the Singapore Management University, Singapore. His research interests include simulation and machine learning. His email address is tktran@smu.edu.sg.

HAI WANG is an Assistant Professor of Information Systems at the Singapore Management University. His research interests include stochastic analysis and optimization of complex systems, especially in urban transportation and logistics context, high dimensional data inference, and health-care analytics. His email address is haiwang@smu.edu.sg.

HOONG CHUIN LAU is Professor of Information Systems and Director of the Fujitsu-SMU Urban Computing and Engineering Corp Lab at the Singapore Management University. His research in the interface of Artificial Intelligence and Operations Research has contributed to a variety of complex problems in logistics and transportation. He currently serves on the editorial board of the IEEE Transactions on Automation Science and Engineering. His e-mail address is hclau@smu.edu.sg.