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YARD TEMPLATE PLANNING IN A TRANSSHIPMENT HUB: GAUSSIAN PROCESS REGRESSION

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ABSTRACT

A yard template in a container terminal assigns subblocks for containers with the same departing vessel to reduce vessel turnaround time with the decreased number of container rehandling. Because vehicle congestion can significantly affect the vessel turnaround time, a terminal operator carefully determines the yard template considering the complex traffic congestion on the entire container terminal. In this study, we propose an application of a Gaussian Process (GP) to predict the vessel turnaround time under the impacts of vehicle interruption and blocking. Based on the predictions, we determine the yard template with the shortest predicted vessel turnaround time among candidate yard templates. Through simulation experiments, we compare the proposed approach and a baseline model based on a Mixed Integer Programming (MIP). The simulation results show that the application reduces the vessel turnaround time by 6.66% compared with the baseline model.

1 INTRODUCTION

With the rapid growth of the maritime shipping industry, container terminals are motivated to improve their competitiveness (Kim and Günther 2007). Steenken et al. (2004) classify the port operations into quayside and landside operations. The landside consists of several blocks specified bays, rows, and tiers. Export and transshipment containers will be stored in designated storage areas until their reserved vessels arrive. Figure 1 shows a typical configuration of container terminals for transporting the containers between the quayside and the landside.

A yard template is a widely applied concept in a transshipment hub based on a consignment strategy (Han et al. 2008; Jiang et al. 2012; Zhen 2014). The yard template dedicates a storage area to a group of containers with the same departing vessel. The yard template aims to reduce the number of container rehandling, vessel turnaround time, and yard crane travel distance (Zhen 2014). For efficient yard template planning, a terminal operator is eager to consider vehicle congestion which can degrade the synchronization between port operations. Terminal operators can evaluate the yard templates under vehicle congestion based on their historical data, i.e., container flows, yard templates, truck waiting time, and vessel turnaround time.

Gaussian Process (GP) has received attention for its statistical simplicity and flexibility (Wang et al. 2020). The GP is commonly used to predict an objective function expensive to evaluate because the GP model infers the surrogate model of the objective function based on training data (Chen and Liao 2020). In this study, we present the GP model to approximate the vessel turnaround time given the yard templates. We evaluate several candidate yard templates using the trained GP and determine the most potential yard template among the candidate yard templates. To validate our approach, we build a discrete-event simulation to catch uncertain and complex operations in a container terminal, i.e., vehicle interruption, vehicle blocking, and container rehandling of yard cranes. Our simulation experiments indicate that the proposed approach improves the vessel turnaround time by 6.66% and the truck travel time by 5.86% with smaller standard deviations compared to a baseline model based on a Mixed Integer Programming (MIP).

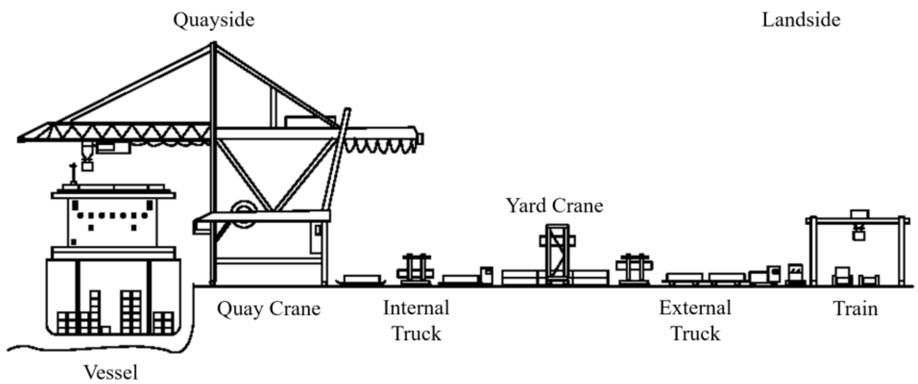

Figure 1: A typical configuration of container terminals modified from Steenken et al. (2004).

Our contributions are summarized as follows: (1) This study introduces a surrogate-model based decision-making for yard template planning in a container terminal; and, (2) We model the GP with the suitable form of the features to predict the vessel turnaround time from the yard templates. We also demonstrate the effectiveness of our approach compared with the baseline model modified from Zhen (2016).

The remainders of this paper are as follows. Chapter 2 reviews the related literature. Chapter 3 introduces the yard template in a transshipment hub and the application of the GP for yard template planning. Simulation results of the GP and baseline models are presented in chapter 4. Chapter 5 gives conclusions and future research.

2 LITERATURE REVIEW

The containers can be allocated by individuals or groups (Carlo et al. 2014). Bazzazi et al. (2009) individually allocate the storage areas of containers based on their types, i.e., different sizes, empty containers, and refrigerated containers. Guldogan (2010) suggests an integrated policy considering the workload balance between yard cranes. The individual containers were distributed or clustered based on their departure dates. Park et al. (2011) propose a two-stage approach to allocate storage areas for containers. They select a block for each container based on yard cranes' workloads and select a specific location based on the proposed weighted function. Storage space allocation can be analyzed on different levels according to the storage space unit: yard section, yard block, yard sub-block, yard bay, and individual slot (Fibrianto et al. 2020; Jin et al. 2016). Ku et al. (2010) allocate storage areas at the block level concerning the workload of each block.

A transshipment hub commonly utilizes a consignment strategy to allocate storage areas for containers. This strategy stores export and transshipment containers which will be loaded onto the same departing vessel at the same assigned storage locations. Further details about consignment strategy can be described in Chen et al. (1995) and Davies and Bischoff (1999). A yard template is a widely applied concept in a transshipment hub based on a consignment strategy (Moorthy and Teo 2006). Yard template planning aims to determine the best yard template to minimize the vessel turnaround time by reducing travel time and the number of container rehandling of yard cranes. Given the yard template, Lee et al. (2007) propose a storage space allocation strategy to minimize the total number of crane shifts. Han et al. (2008) formulate a Mixed Integer Programming (MIP) model to optimize a yard crane allocation problem given the yard template used in Lee et al. (2007). Jiang et al. (2012) propose two space-sharing methods to improve the storage utilization of a yard template. Zhen et al. (2011) investigate an integrated MIP model and its heuristic algorithm to optimize a yard template with a berth template.

Vehicle congestion is one of the important issues considered in yard template planning. Vehicle congestion prevents vehicles from traveling freely in a container terminal (Roy 2016). The commonly applied strategy to mitigate vehicle congestion is to balance workloads between yard blocks. Jeong et al. (2012) develop a heuristic to balance the workload in each block and validate their proposed heuristic via simulation experiments. To mitigate vehicle congestion, Lee et al. (2007) also propose a high-low workload procedure that aims to prevent two high-workload subblocks from being a neighborhood. The high-low workload is placed as one of the constraints in a mathematical model. Zhen (2016) proposes a MIP model to minimize the total expected travel time based on travel time estimation under vehicle congestions.

3 PROBLEM STATEMENT

3.1 Yard Template in a Transshipment Hub

The transshipment hub treats transshipment activity as a major activity. The transshipment hub implements the consignment strategy to allocate the storage areas for the containers. The consignment strategy strives to store the export and transshipment containers with the same port of destination (POD) at the same subblocks. Figure 2 shows the transshipment hub with a consignment strategy. There are subblocks dedicated to specific vessels. The allocation of the subblocks for vessels in the transshipment hub with the consignment strategy is called yard template planning.

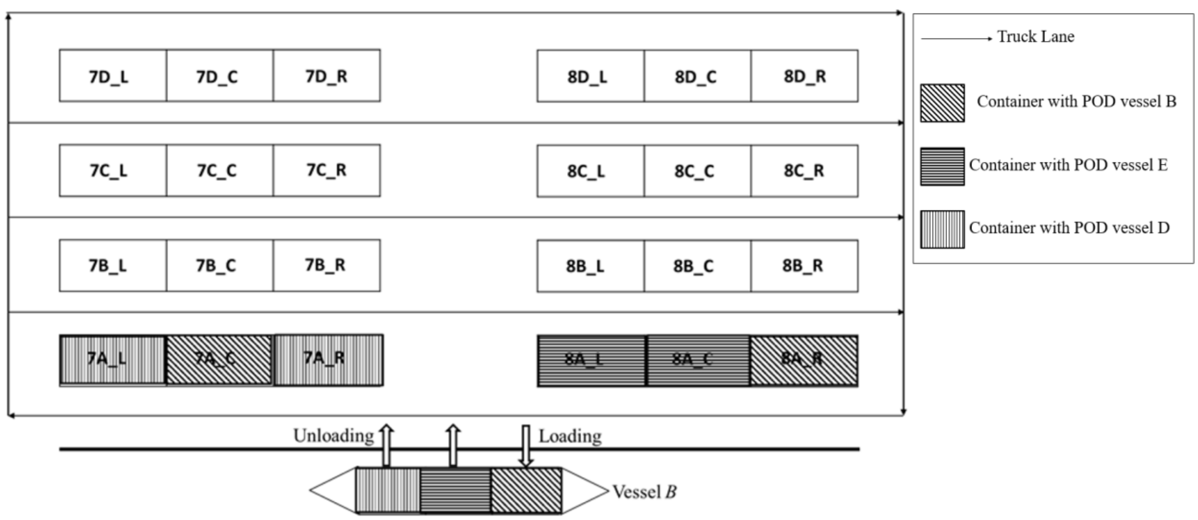

Figure 2: A container terminal with the consignment strategy.

The performance of the yard template can be measured by the total travel distance, total travel time, vessel turnaround time, etc. We are interested in the vessel turnaround time as the major performance measurement because the container terminal with a lower vessel turnaround time mostly attracts shipping liners. The vessel turnaround time consists of the required time for vehicles to travel to their containers, cranes to handle their containers, and the other variabilities presented in the container terminal, i.e., the empty travel and rehandling of yard cranes and vehicle congestions. Therefore, minimizing turnaround time indicates the minimization of the compound of turnaround time (travel time, handling time of crane, etc).

Equation (1) shows the expected total travel time modified from Zhen (2016). The total travel time TV is calculated by multiplying the total number of loading and unloading containers on the routes in each period ($\eta^L_{i,j,p}$ and $\eta^U_{i,j,p}$) and the required time for vehicles to travel in each route ($t_{i,j}$). To consider vehicle congestion, Zhen (2016) estimates $t_{i,j}$ in advanced and use the travel time information as a parameter in the yard template optimization. Following is the model without congestion provided by Zhen (2016) with modifications regarding the link i, j:

Parameters:

A	Set of routes
$A_{v,k}{}^{U}$	Subset of routes that comprise the unloading route from the location of vessel v berthed to the subblock k
$A_{v,k}{}^{L}$	Subset of routes that comprise the loading route from the location of vessel v berthed to the subblock k
P	Set of periods (indexed by p)
P_v	Subset of periods when Vessel v has loading/unloading activities at port
K	Set of subblocks (indexed by k)
K_v	Set of candidates subblocks, from which some subblocks are selected and assigned to Vessel v
N_e	Pair of neighbor subblocks
$\mathbb{N}$	Set of all the pairs N_e
B_g	Group of the subblocks that belong to the same block
$\mathbb{B}$	Set of all the blocks
r_v	Number of subblocks needed to be assigned to Vessel v
V	Set of vessels (indexed by v)
V_v	Subset of vessels, onto which some containers unloaded from Vessel v will be loaded in future
$n_{v',v}$	Number of containers that are unloaded from Vessel v', stored in the yard, and then will be loaded onto Vessel v in the future, $v \in V'$
$t_{i,j}$	Travel time for the route (i, j)
H_{LB}	Lower bound that a high workload can take
H_{UB}	Upper bound that a high workload can take
C_{YC}	Capacity of a YC (Yard Crane) in a period
Y_{YC}	Maximum amount of YCs that can work simultaneously in a block

Decision variables:

$\beta_{v,k} \in \{0,1\}$	Set to one if subblock k is assigned to Vessel v and zero otherwise
$\zeta_{k,p} \in \{0,1\}$	Set to one if subblock k has a high workload in Period p and zero otherwise.
$\eta^{L}_{i,j,p}$	Number of loaded containers going through Link (i, j) in Period p
$\eta^{U}_{i,j,p}$	Number of unloaded containers going through Link (i, j) in Period p
$\omega^{L}_{k,p}$	Number of containers loaded from Subblock k in Period p
$\omega^{U}_{k,p}$	Number of containers unloaded to Subblock k in Period p

Objective function:

$$minimize\ TV = \sum_{p \in P} \left(\sum_{(i,j) \in A^L} t_{i,j} \eta^{L}_{i,j,p} + \sum_{(i,j) \in A^U} t_{i,j} \eta^{U}_{i,j,p} \right) \tag{1}$$

Subject to:

$$\sum_{v \in V} \beta_{v,k} \leq 1 \qquad \forall k \in K \tag{2}$$

$$\sum_{k\in K}\beta_{v,k}=r_v \qquad \forall v\in V \tag{3}$$

$$\eta^L_{i,j,p}=\sum_{v\in V,k\in K|(i,j)\in A^L_{v,k},p\in P_v}\beta_{v,k}\left(\sum_{v'\in V}n_{v',v}\right)\Big/(r_v\cdot|P_v|) \qquad \forall(i,j)\in A,\forall p\in P \tag{4}$$

$$\eta^U_{i,j,p}=\sum_{v'\in V,k\in K|(i,j)\in A^U_{v',k},p\in P_{v'}}\sum_{v\in V}\beta_{v,k}\left[n_{v',v}/(r_v\cdot|P_v|)\right] \qquad \forall(i,j)\in A,\forall p\in P \tag{5}$$

$$\omega^L_{k,p}=\sum_{v\in V|p\in P_v}\beta_{v,k}\left(\sum_{v'\in V}n_{v',v}\right)\Big/(r_v\cdot|P_v|) \qquad \forall k\in K;\forall p\in P \tag{6}$$

$$\omega^U_{k,p}=\sum_{v'\in V|p\in P_{v'}}\sum_{v\in V}\beta_{v,k}\left[n_{v',v}/(r_v\cdot|P_v|)\right] \qquad \forall k\in K;\ \forall p\in P \tag{7}$$

$$\zeta_{k,p}H_{LB}\le\omega^L_{k,p}+\omega^U_{k,p}\le\zeta_{k,p}(H_{UB}-H_{LB}) \qquad \forall k\in K\,;\forall p\in P \tag{8}$$

$$\sum_{k\in N_e}\zeta_{k,p}\le 1 \qquad \forall N_e\in\mathbb{N};\forall p\in P \tag{9}$$

$$\sum_{k\in B_g}\left(\omega^L_{k,p}+\omega^U_{k,p}\right)\le C_{YC}.Y_{YC} \qquad \forall B_g\in\mathbb{B};\forall p\in P \tag{10}$$

$$\beta_{v,k}\in\{0,1\} \qquad \forall v\in V{:}\,\forall k\in K \tag{11}$$

$$\zeta_{k,p}\in\{0,1\} \qquad \forall k\in K;\forall p\in P \tag{12}$$

$$\omega^L_{k,p},\omega^U_{k,p}\ge 0 \qquad \forall k\in K;\forall p\in P \tag{13}$$

$$\eta^L_{i,j,p},\eta^U_{i,j,p}\ge 0 \qquad \forall(i,j)\in A;\forall p\in P \tag{14}$$

The objective function (1) minimizes the total travel time TV. Constraint (2) ensures each subblock to be occupied only by one vessel. Constraint (3) ensures that subblocks r_v assigned to vessel v. Constraint (4) and (5) ensure the number of the loaded and unloaded containers in each route (i,j) in each period, respectively. Constraint (6) and (7) calculate the number of loaded and unloaded containers in each subblock in each period, respectively. Constraint (8) ensures that the workload of loading and unloading requests is either high-workload or low-workload in each period in each subblock. Constraint (9) prevents two high-workload subblocks from being a neighbor in each period. The total workload on each block is limited by the constraint (10). The workload in each block does not exceed the yard crane (YC) capacity in each period. Constraint (11), (12), (13), and (14) are the variable domains.

3.2 Traffic Congestion in a Transshipment Hub

Vehicle congestion is inevitably caused by time-variant operations in a large-scale material handling system, i.e., a container terminal (Fazlollahtabar and Saidi-Mehrabad 2015; Vis 2006). Vehicle congestion can be classified into vehicle interruption and blocking. Vehicle interruption occurs when trucks encounter during travel (Zhen 2016). The interrupted truck should decelerate to keep a safety distance between the trucks. Vehicle blocking occurs when the downstream truck has to wait until the upstream truck releases its transfer request (Chen et al. 2007). Figure 3 illustrates examples of vehicle interruption and blocking, respectively. In Figure 3 (a), the vehicle interruption is observed when truck B enters the truck lane where truck A is traveling. Truck B forced truck A to decelerate or stop to avoid a collision. In Figure 3 (b), the vehicle blocking is observed when downstream truck A gets blocked from upstream truck B handling its transfer request. Truck A has to wait until tuck B completes its transfer request. Because vehicle interruption and blocking can be comprehensively considered in yard template planning, we build a discrete-event simulation to reflect both effects on yard template planning.

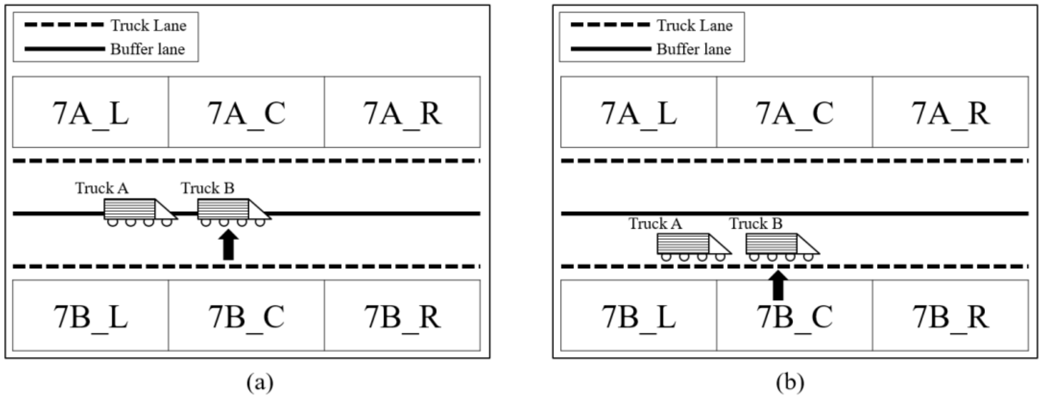

Figure 3: The examples of vehicle congestion: (a) vehicle interruption; and (b) vehicle blocking.

3.3 Gaussian Process Regression for Yard Template Planning

Because a typical container terminal simulation includes a lot of container handling equipment with their complicated operations, the simulation requires a large amount of time to mimic the operational algorithms (i.e., scheduling of trucks and cranes) and reflect congestions between the equipment. GP is commonly used to predict an expensive objective function and can estimate posterior distributions over possible candidates based on a covariance function. The GP is also widely used when there are difficulties in constructing the closed-form equations describing vehicle congestion in the yard as a derivative-free optimization known as a grey-box problem. The grey-box problem is distinguished by the lack of closed-form equations with unknown constraints and objectives. A surrogate model (or metamodel or response surface model) is used to analytically approximate the underlying equations (Boukouvala et al. 2016). The readers can refer to Bhosekar and Ierapetritou (2018) and Rios and Sahinidis (2012) for a depth review regarding surrogate modelling and derivative-free optimization, respectively.

Vehicle congestion is a kind of variability in the system. Although the variability of the system is random, the variability can be pictured through its distribution (Hopp and Spearman 2011). Fortunately, the consequences of both congestions are logged in the historical data, i.e., yard templates and vessel turnaround time. We propose the GP-based approach to interpolate the distributions of the vessel turnaround time in yard template planning. Table 1 shows the example of the pre-processed historical data. The numbers of loading and unloading containers in each subblock are regarded as input vector $x = \{x_1, x_2, \ldots, x_d\}$ where d is the dimension of x. The trained GP model obtains the predicted turnaround time ($\widehat{TT}$) for each candidate.

Table 1: Example data of the pre-processed historical data.

Ship code	Call sequence	Date	Period	Number of loading containers						Number of unloading containers						Turnaround time (TT)
				7A_L	7A_C	7A_R	7B_L	7B_C	7B_R	7A_L	7A_C	7A_R	7B_L	7B_C	7B_R	
A	1	07/26/2022	2	0	0	0	0	10	0	7	21	31	3	0	0	2097.39
B	1	07/26/2022	3	0	0	5	0	0	0	3	1	2	2	2	1	3507.02
D	3	07/31/2022	3	0	0	0	0	0	0	7	0	0	0	0	0	3507.02
A	4	08/01/2022	1	0	0	0	0	10	0	20	0	0	20	0	0	5348.34
C	6	08/01/2022	2	0	20	0	10	0	0	24	0	0	0	7	0	4405.29
D	4	08/01/2022	3	70	0	0	0	0	0	0	0	0	0	0	0	4823.43

We denote the testing input, total turnaround time, and unknown total turnaround time as X_*, y, and y_*. For example, if there are three historical data with training input $X = \{x_1, x_2, x_3\}$ and training target $y = \{y_1, y_2, y_3\}$. We are interested in a prediction of the testing target $y^* = \{y_4\}$ given the historical data and testing input $X_* = \{x_4\}$. Gaussian process is a distribution which is finite jointly Gaussian (Mackay 1998). Thus, we can infer the posterior distribution over objective functions $\{f^*\}$ from the prior distribution $\{f_1, f_2, f_3\}$ using Gaussian process. Based on the definition of Gaussian process adapted from Rasmussen

(2003) and Schulz et al. (2018), the joint probability of the observed data (X, X_*, y), and posterior function f_* can be calculated as

$$[\, y, f_*] \sim \mathcal{N}\,(0, [\, K(X, X) + \sigma_n^2\, I\; K(X, X_*)\; K(X_*, X)\; K(X, X_*)]),$$
$$p(f_* \,|X_*, X, y) = \mathcal{N}\,(f_*, \mathrm{cov}(f_*)),$$

where

$$f_* \triangleq E[f_* \,|X, y, X_*] = K(X_*, X)[K(X, X) + \sigma^2 I]^{-1} y,$$
$$\mathrm{cov}(f_*) = K(X_*, X_*) - K(X_*, X)[K(X, X) + \sigma^2 I]^{-1} K(X_*, X).$$

We obtain the total turnaround time y_4. The kernel function $K(x_i, x_j)$ infers the posterior distribution. In this study, we use Radial basis function kernel as

$$K(x_i, x_j) = \sigma^2 exp\,(-\,\|x_i - x_j\|/2\lambda^2).$$

Based on the constructed surrogate model, we use a fixed-budget ranking and selection (R&S) algorithm to obtain the most potential candidate. The fixed-budget R&S aims to allocate the given number of samples to select the best candidate (Hong et al. 2021). We use a static budget allocation procedure under the assumption that the outputs are uniformly distributed (Chen and Ryzhov 2019). We determine the most potential yard template with the shortest expected turnaround time ($\widehat{\widehat{TT}}^{*}$) from the fixed-budget R&S. Figure 4 shows the flowchart of the proposed approach.

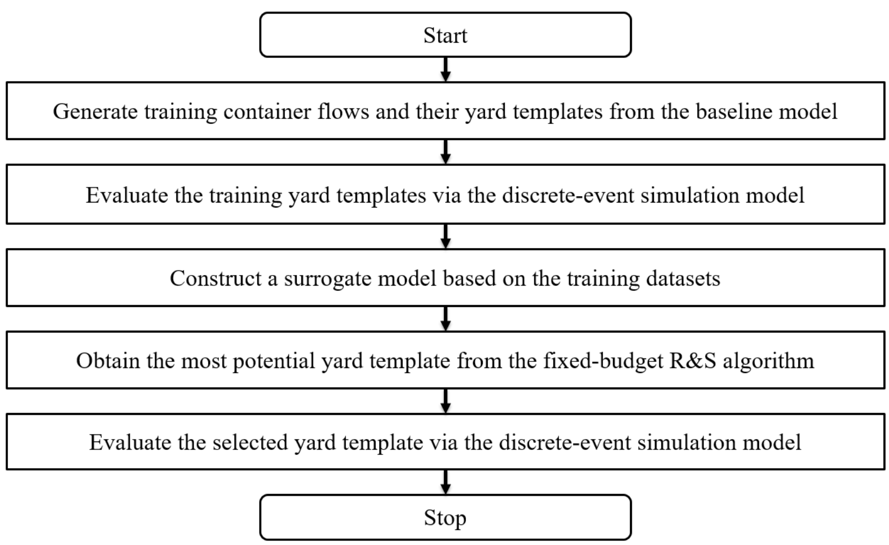

Figure 4: Flowchart of the proposed approach.

4 SIMULATION EXPERIMENTS

We use Technomatix© Plant Simulation 12 as simulation software to validate the output of the baseline model and the proposed approach. We generate 100 planning horizon data. Each planning horizon is 7 days with 3 periods each day. For each planning horizon data, there are unique datasets of containers along with each incoming vessel. We divide 100 datasets into 80 training datasets and 20 testing datasets. We solve the baseline model using IBM ILOG CPLEX Optimization Studio 12.8 built on python by DOcplex library. We set the budget of the fixed-budget R&S as 100. We conducted simulation experiments over 20 different container flows with the yard templates from the baseline model and proposed approach, respectively.

We build a simulation based on the Busan Port Terminal (BPT) in Korea. The specifications of container handling equipment and yard configuration are similar to the real container terminal. The BPT has 8 blocks and each block has 3 subblocks. The size of each block is around 420x25*m* with the height of stacking seven containers. A rail-mounted gantry crane (RMGC) is deployed in each block. The speed of the RMGC is 3*m/s* and the trolley speed of RMGC is 1*m*/s. The lock/unlock time for RMGC to release the container was set to 5 seconds. There were 2 berths with 8 cranes in each berth. The handling time of each QC is set as fast as possible to minimize the variability of vessel turnaround time because we didn't deal with QC scheduling in this study. The upper aisle in each block is dedicated to internal trucks and the lower aisle is dedicated to external trucks. The speed of internal trucks was set to 16*m/s*. The simulation covered tactical planning and operational planning. Although this study only deals with the yard template which belongs to tactical planning, operational planning was provided in the simulation. To avoid bias, the operational planning strategies to validate the baseline model and the proposed model are identical.

To solve the baseline model in the considered layout, we obtain the parameter from Zhen (2016) as the default. The number of subblocks assigned to each vessel r_v is dependent on the number of vessels in the experiment. For example, if the number of vessels is 8 then the r_v is three because the number of subblocks in the considered layout was 24. We set A, $A_{v,k}^{U}$, and ${A_{v,k}}^{L}$ based on the BPT's configuration. We also define the parameters regarding subblocks ($K, K_v, N_e, \mathbb{N}, B_g$, and $\mathbb{B}$) as shown in Figure 2. We assume that a yard crane is dedicatedly assigned to a yard block ($\mathrm{Y_{YC}} = 1$). The maximum number of containers that can be handled by yard crane C_{yc} was set 240. For the "high-low workload" procedure, H_{LB} and H_{UB} are set to the range [100,200] respectively.

We assess the accuracy of the GP to predict the vessel turnaround time of yard templates from the baseline model. We randomly shuffle the training and testing datasets as much as 50 and 30, respectively. A dataset consists of 21 (7×3) data because the number of planning horizons and the number of periods for each planning horizon are set as 3 and 7. We report the normalized root mean square error (RMSE) according to the different sizes of training datasets with 20 repetitions. The RMSE of the GP is reduced according to the increased sizes of the training datasets. The average RMSE is 0.0143 when the number of training datasets is set as 50. Figure 5 illustrates the boxplots for the normalized RMSE.

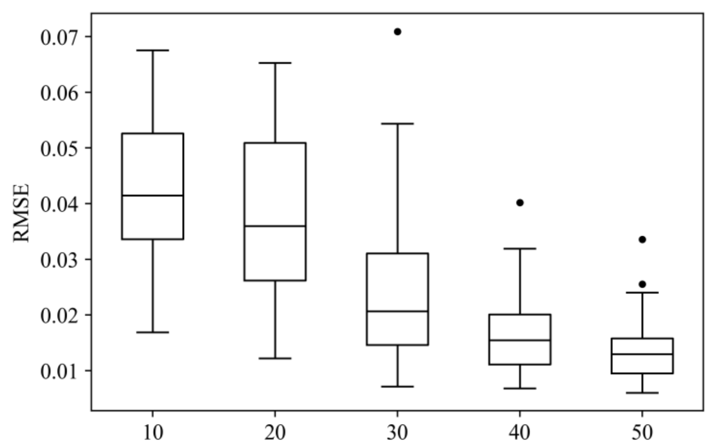

Figure 5: Boxplots for the normalized RMSE with different sizes of training datasets.

Table 2 shows that the proposed model improves the average turnaround time and travel time over 20 experiments by 6.66% and 5.86% compared with the baseline model. The proposed model obtains the turnaround time in the range between 43.64 h and 75.91 h while the baseline model provides the turnaround time in the range between 43.54 h and 58.53 h. The proposed model decreases the stand deviations of the vessel turnaround time and truck waiting time by 37.46 % and 32.01 %. The proposed model provides consistent and reliable yard templates relatively. The experiment results indicate the proposed model identifies the correlation between vehicle congestion and the yard templates. The baseline model without a congestion estimation couldn't reflect the impacts of vehicle interruption and blocking.

Table 2: Experiment results of simulation with vehicle interruption and blocking.

Instance	Total vessel turnaround time (h)			Total truck travel time (h)		
	Baseline model	Proposed model	Gap	Baseline model	Proposed model	Gap
1	43.94	44.13	-0.43%	171.95	173.99	-1.19%
2	49.38	47.91	2.98%	195.23	183.84	5.84%
3	48.37	50.62	-4.65%	184.51	207.85	-12.65%
4	75.91	44.22	41.75%	279.09	169.87	39.13%
5	58.48	45.02	23.03%	232.91	181.83	21.93%
6	57.27	54.71	4.46%	223.13	219.08	1.82%
7	54.18	50.64	6.53%	207.49	197.50	4.81%
8	43.64	45.93	-5.25%	172.23	182.41	-5.91%
9	50.05	52.87	-5.64%	193.46	202.07	-4.45%
10	50.98	48.72	4.43%	200.62	190.19	5.20%
11	56.71	45.73	19.37%	215.96	178.70	17.25%
12	52.14	55.09	-5.65%	207.38	215.83	-4.08%
13	56.66	48.61	14.20%	222.65	185.11	16.86%
14	53.00	49.40	6.78%	206.77	197.35	4.56%
15	51.11	51.12	-0.01%	201.59	207.80	-3.08%
16	45.09	43.54	3.43%	175.94	168.93	3.98%
17	46.35	44.04	4.99%	181.47	174.52	3.83%
18	48.86	46.07	5.73%	186.68	177.78	4.77%
19	60.90	58.53	3.89%	231.35	215.82	6.71%
20	51.06	56.99	-11.60%	200.83	220.87	-9.98%
Average	52.70	49.19	6.66%	204.56	192.57	5.86%

5 CONCLUSIONS

A yard template in a container terminal assigns subblocks for containers from the same departing vessel to reduce the number of container rehandling and the vessel turnaround time. Although the preliminary studies propose analytical models to determine the yard template, these analytical models still encounter difficulties in predictions of the vehicle congestions on an entire container terminal because the problem is identified as a grey-box problem with a lack of exact constraints. The historical data in the transshipment hub motivated us to identify the effectiveness of vehicle congestion in yard template planning. Because a surrogate model is suitable to statistically approximate the grey-box problems. We propose an application of the GP for yard template planning. The GP applied in this study predicts the total vessel turnaround time of the candidate yard templates. Based on the predictions, we determine the most potential yard template with the shortest turnaround time.

Furthermore, this study extends the notion of congestion in the yard template presented by Zhen (2016) with the blocking situation in the congestion consideration. Over the presence of blocking and interruption congestion, the proposed model determines the suitable yard template reducing the total vessel turnaround time by 6.66% compared to the baseline model. The experimental results indicate that the proposed model obtains reliable yard templates with the decreased vessel turnaround time as well as the truck travel time.

This study investigates a new way to deal with yard template planning considering uncertain factors in a transshipment hub. The key to this study is the collaboration of a large-scale high-fidelity simulation and the surrogate model. There is further room for future improvements in terms of optimization applications. We will discuss the more sophisticated sampling algorithms such as maximum expected improvement (MEI) and maximum entropy sampling (MES) than the fixed-budget R&S with the static budget allocation procedure used in this study. Future research can investigate a surrogate model-based decision-making in various large-scale manufacturing systems, i.e., semiconductor manufacturing facilities, automobile manufacturing plants, and order picking systems.

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