Simulation Approach of Container Terminal Modelling

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Abstract: In this paper we have presented an approach that combines the advantages of simulation models and an optimization method related to total cost calculation of an optimal throughput. We have shown that our method is able to generate competitive optimal throughput of CT should be the planning objective since it gives more economical solutions. Computational experiments were conducted to evaluate the performance of the developed models using real data collected from the Korean CTs.

Keywords: Container terminal (CT), Simulation, CT throughput, Performance evaluation, Korean CT.

1. INTRODUCTION

Simulation modelling techniques are being applied to a wide range of container terminal (CT) planning processes and operational analysis of container handling systems. These models have become extremely valuable as decision support tools during the planning and modelling of CT operations.

Simulation of the logistics activities related to the arrival, loading/unloading and departure processes of ship-berth link (SBL) can be carried out for different usages such as design of container yard (CY), increase productivity and efficiency of terminal equipments (quay cranes (QCs), yard trucks (YTs), and yard cranes (YCs)), and analysis of SMs. Simulation of CT transfer operations from the quay to the CY, etc. These logistics activities are particularly complex and very costly since they require the combined use of expensive infrastructure capacities especially berths and CY. CT operations are required to serve containers as quickly as possible. Thus, in order to successfully design and develop CY operations and utilize it as efficiently as possible, it is necessary to develop simulation models (SMs) that will support decision making processes of CT managers. The results, analysis and conclusions given here are intended to provide guidance on achieving time efficiency, raise productivity of CT and accuracy in the modelling and calibration of SMs for Korean CTs.

A CT is a complex system with various interrelated components. There are many complicated decisions that operators or planners have to make. The handling operations in CTs include three types of operations: container ship operations associated with SBL, receiving/delivery operations for external trucks and container handling and storage operations in a CY. Ships are loaded and unloaded where containers are temporarily stored while awaiting a new journey. Inbound containers arrive by ship and QCs transfer containers from ship to a YT. The YT then delivers the inbound container to a YC which may be a rubber tired gantry crane (RTGC) or rail mounted gantry crane (RMGC). The YC picks it off the YT which moves back to the QC to receive the next unloaded container. For the loading operation, the process is carried out in the opposite direction. This is indirect transfer systems where a YT delivers a container between the apron and the CY. RTGCs or RMGCs transfer containers between YTs and yard stacks in the CY.

SM and analysis with ARENA have been developed to CT performance evaluation of Korean CTs. It is shown to provide better results in predicting the actual terminal operations system of the Korean CT. The attained agreement of the results obtained by using SM with real parameters has been used, also, for validation and verification of the applied model. In accordance with that, the correspondence between results and real Korean CT parameters gives, in full, the validity to the applied SM to be used for optimization of processes of servicing ships at existing and new Korean port. Finally, this model also addresses issues such as the performance criteria and the model parameters to propose an operational method that reduces average time that ship spends in port and increases the CT throughput.

The organization of this paper is as follows. Section 2 provides a literature overview. Section 3 presents a brief description of CT modelling procedure and evaluation of SMs. Also, this section gives model validation and simulation results for selected Korean CT. In Section 4 we show cost analysis of optimal CT throughput with case study of KBCT (Korean Busan CT). Finally, Section 5 concludes the paper.
2. LITERATURE REVIEW

SMs have been used extensively in the modeling, planning and analysis of CTs. Many different SMs regarding port operation, especially CTs modeling, have been developed in journal papers (e.g. Borgman et al. (2010), Bruzzone and Signorile (1998), Ding (2010), and so on). These models are coded in different simulation languages that have been used including PORTSIM, Modsim II and III, PCModel, SIMPACK, SIMAN, SIMLIB, SIMPLE++, SLX, SLAM and Visual SLAM, ARENA, AveSim, Witness software, Taylor II, GPSS/H, TermSim, Extend-version 3.2.2, HARAP, MUST, Anylogic, Matlab, FORTRAN, Pascal, Visual BASIC, C, C++, Java etc. Our approach thus attempted to collect all the papers which are within the criteria of the collection across journals of all including ARENA softer (Bruzzone and Signorile (1998), Guldogan (2010), Khatiashvili et al (2006), Kozan (2006), Legato et al. (2009), Lee et al. (2003), Merkuryeva et al. (2000), Park et al. (2009), Park and Dragovic (2009), Sacone and Siri (2009), Tahar and Hussain (2000), Thiers and Janssens (1998), Vis and Harika (2004), Vis and van Anholt (2010), Wanke (2011), Zeng and Yang (2009) among other). Computer algorithms are described in most of the papers to give examples how the SMs are built from sequence of operational procedures which have been conducted to the determination of the CT performance in different environment within various points of view and in heterogeneous cases.

More recently, excellent investigations of simulation modelling on CT operations have been done by Petering (2010 and 2011) where we have identified new research trends and significant increase of the knowledge using discrete-event SMs. It should also be pointed out, that there are a few concepts of integrating simulation and optimization to modelling CT operations in port given by Bruzzone and Signorile (1998), Legato et al. (2009 and 2010), Sacone and Siri (2009), Zeng and Yang (2009), Longo and Mirabelli (2008) and Longo (2010). Good simulation-based optimizations for CT operations have been done by these authors. Simulation optimization models consider the stochastic factor in CT and can tackle the practical assigning and scheduling problem efficiently.

Bruzzone and Signorile (1998) developed a collection of simulation tools and used genetic algorithms to make strategic decisions and scheduling for resource allocation and CT organization. Key issues of the application of modelling and simulation for the management of the Malaysian Kelang CT are discussed in paper by Tahar and Hussain (2000). Merkuryeva et al. (2000) considered simulation of containers processed at the Baltic CT in Riga as a basic simulation research, and then its complementing by a metamodelling study is discussed. Vis and van Anholt (2010) studied the effect of different types of berth configurations on vessel operation times at container terminals and also created SMs for each type of berth in which all relevant logistics processes required for unloading and loading a vessel have been implemented. Guldogen (2010) investigated the effect of different storage policies on the overall performance of a CT in the port of Izmir. Wanke (2011) considered SBL by SM with case study which assessed the impact of different berth allocation problems on main performances including demurrage costs. Ding (2010) presented a SM to estimate the throughput capacities of a CT under different combination patterns of the types of arriving vessels.

One can conclude that CT operations have been adequately analyzed and modelled by using different SMs. Various SMs in the field of optimizing CT planning are applied more and more in world CTs.

3. SIMULATION MODELLING

The objective of this section is to develop SMs to analyze the CT performance. This analysis includes the integration of container berth and CY simulation planning within CT. Combined planning approaches for different decision levels are expressed here. Implementation of the presented procedure leads to the creation of a simulation algorithm that captures CT performance well.

A simulation tool, ARENA 12.0, is used for developing the SMs and integration of berth and CY simulation, as well as analyzing the results (Kelton et al. 2003, Park et al. (2006 and 2009, Park and Dragovic (2009)). This simulation consists of specific models which have been further considered by the effective utilization of their integration.

Berth simulation model: Instead of the existing method for the calculation of berth performance, this study has built a new SM for berth performance analysis based on the real data. This SM can present a more practical way of calculating berth performance, suggesting more diverse evaluation indicators and making it possible to check up the quality aspect of services at the CT. Ship operation usually begins with the ship’s arrival to the port anchorage area. Depending on the state of congestion, or priority of the arriving ship, the latter may have to wait in the anchorage area. After berthing, containers are unloaded/loaded from/on the ship. Finally, when service is completed, the ship leaves the port.

QC assignment rule: Berthing location is based on the berthing plan that is linked to the QC operation policy and CY operation strategy. It is obviously that the berthing location of a ship has to consider the QC assignment rule. Therefore, the calculations of the lifts per ship call (LPC) are done on the data collected by CT. Then the ships are categorized in four classes according to the LPC.

Ship berthing: Ship berthing is one of the problems faced by the planners at the port. There are some cases that the priority of berthing can be decided according to the contract made between shipping company and CT.

A SM is proposed in Fig. 1 for representing the processes relevant to ship and container movement inside a CT. This model is designed by ARENA block diagrams. It is developed by defining the CT entities and by describing the sequences of activities to be performed by the transient entities included in the SM.
Fig. 1. Berth SM and CT current performance in ARENA.

The main function of the model builder is to create a discrete-event SM of the CT system and the actual data in the database. This model is designed following the object-oriented approach that was central to ARENA’s development with the hierarchical architecture so that the system is data-driven.

CY simulation model: The capacity of CY is closely related to the size of CY, the mutual relationship among YCs, YT, external trucks and container turnover. The small size of CY can intensify the traffic congestion, causing reloading, lowering the productivity of YCs and eventually delaying the container handling of both external trucks and YT.

The developed SM analyzes the change of inventory level in the CY, thus showing how this level is changing according to the ships’ arrival time distribution, handling volume by ship, loading/unloading productivity of berth, and carrying in/out containers at the CT gate. The results of these analyses can provide important information for calculating the required CY area.

Fig. 2. Integration model of berth and CY simulation in ARENA.

There are four types of container handled in CT: import, export, transshipment containers handled in the same terminal and transshipment containers handled in other terminal. In Fig. 2 is shown the container flow that includes full, empty, reeper, oversized and dangerous containers and are generated in SM module.
Integration of berth and CY simulation: At the CT, the integration of berth and CY simulation presents a challenging problem for the operations level. This integration concept is based on berth and CY occupation rate, ship’s waiting time ratio (average waiting time of ships/average service time of ships ratio, see more (Dragović et al. (2006 and 2011)) and appropriate subsystems throughput. Here, we propose an integrated SM that also takes into account the CY performances generated by the berth template. The basic structure of the SM is shown in Fig. 2 which illustrates integrated processes, also. The objective is, on the one side, to minimize waiting time ratio associated to the ships serviced, on the other side, to maximize terminal throughput generated by the berth and CY occupation rate. The SM provides detailed ARENA architecture modules of the problem presented in Fig. 2, as well as sub-model integration. Experimental strategies are performed on realistic instances provided from Korean CT.

3.1 Results

We have carried out the extensive numerical work for the high/low values of the Korean CTs model characteristics. Our numerical experiments are based on different parameters of various Korean CTs characteristics that are presented in Tables 1, 2 and 3. The ships were categorized into the following four classes according to the LPC: under 1,000 LPC; 1,000 – 1,999 LPC; 2,000 – 2,999 and over 3,000 LPC.

Table 1. Data summary of four CTs, 2008

<table>
<thead>
<tr>
<th>Input data</th>
<th>HBCT</th>
<th>KBCT</th>
<th>PNC</th>
<th>HJNC</th>
</tr>
</thead>
<tbody>
<tr>
<td>pdc</td>
<td>1 year</td>
<td>1 year</td>
<td>1 year</td>
<td>1 year</td>
</tr>
<tr>
<td>ns</td>
<td>1758</td>
<td>1848</td>
<td>1010</td>
<td>786</td>
</tr>
<tr>
<td>eb-ut</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>ab-ut</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>ls</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>cc</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>twh</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>nwh</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>ncs</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>LPC</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

Note: O - Data provided; pdc - Period of data collection; ns - No. of ships; eb-ut - Estimated berthing/unberthing time; ab-ut - Actual berthing/unberthing time; ls - Length of ship in m; cc - Carrying capacity in TEU; twh - Total working hours per QC; nwh - Net working hours per QC; ncs - No. of QCs per ship; HBCT - Hutchinson Busan CT; KBCT - Korean Busan CT; PNC - Pusan New CT and HJNC Hanjin New CT.

Table 2. Simulation input values by CT

<table>
<thead>
<tr>
<th>CT</th>
<th>Ship’s arrival time distribution</th>
<th>LPC distributions for four classes of ships</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBCT</td>
<td>-0.5 + LOGN(5.94, 8.14)</td>
<td>15 + 984 * BETA(1.54, 1.46)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1e+003 + WEIB(126, 1.21)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.00e+003 + EXPO(359)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRIA(3e+003, 3.12e+03, 4.00e+00)</td>
</tr>
<tr>
<td>KBCT</td>
<td>-0.001 + EXPO(4.75)</td>
<td>3 + 996 * BETA(1.38, 1.25)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1e+003 + 988 * BETA(0.772, 1.38)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2e+003 + 950 * BETA(0.543, 0.888)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3e+003 + WEIB(41.8, 0.626)</td>
</tr>
<tr>
<td>PNC</td>
<td>-0.001 + GAMM(9.25, 0.938)</td>
<td>-0.001 + 996 * BETA(1.09, 1.25)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1e+003 + 987 * BETA(0.839, 1.41)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.02e+003 + EXPO(461)</td>
</tr>
<tr>
<td>HJNC</td>
<td>-0.001 + EXPO(8.18)</td>
<td>10 + LOGN(777, 689)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.01e+003 + 987 * BETA(0.737, 1.21)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NORM(2.32e+003, 204)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.06e+003 + 244 * BETA(0.112, 0.112)</td>
</tr>
</tbody>
</table>

Table 3. Simulation input values by CT

<table>
<thead>
<tr>
<th>CT</th>
<th>h_{tn}</th>
<th>n_b</th>
<th>n_c</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBCT</td>
<td>1+ER(1.14, 0.91)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>KBCT</td>
<td>LOGN(1.97, 0.32)</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>PNC</td>
<td>1+2.85*BETA(9.36, 20.71)</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>HJNC</td>
<td>9+LOGN(13.6, 34.6)</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: h_{tn} - Handling time per container (based on total work hour); n_b - No. of berths; n_c - No. of QCs per berth.

For purposes of the SMs validation and verification, the results of SM were compared with the actual measurement. Several statistics and parameters were used as a comparison between simulation output and real data. The values presented in Figs. 3 and 4 and consist of CT throughput and the facilities performance indicators. On the basis of actual operation and simulation results comparison, the accuracy ratio is in the range of 93.3% to 99.7% related to throughput and number of calling ships.

Berth simulation results: The results obtained using SM with corresponding values of real parameters has also been used for CT performance evaluation. In case of KBCT, current occupancy ratio is estimated to be 50%. However, this is not an appropriate result. As well as CTs consist of four and more berths, the occupancy ratio would increase up to 65% within permissible ship’s waiting ratio. The SM results for considered CTs shown in Figs. 3 and 4 are as follows: the throughput per berth is 510,190 TEU for HBCT; 517,298 TEU for KBCT; 545,674 TEU for PNC and 395,803 TEU for HJNC, respectively. Furthermore, the level of waiting ratio is between 1.3 and 6.1 for all CTs and average number of QC per ship is from 2.28 for HJNC to 2.87 for HBCT. Thus, the main result is the average total time that ship spends in port and varies from 12.0 to 15.3 hours, respectively. The validation of the SM was done by generating CT appropriate capacity and performance from the model at a certain berth throughput level and making comparisons with actual statistics of real CTs parameters.

Fig. 3. Validation data for SM accuracy.

CY simulation results: The existing calculation methods for CT optimal throughput are mainly based on the berth capacity. Because of this, if the container handling volume is greater then the designed capacity, that will indicate the congestion at CY. The high density of CY worsens not only the productivity of a CT, but also increases its logistics costs by containers re-handling into the ODCY (off dock CY).
According to the results in Fig. 4, the average CY occupancy ratio is between 60% - 65% for smoothing containers workflow without constraints at CT. The CY occupancy ratio of 60% is for manned YC while 65% is for automated YC. Based on this opinion, if the logistics volume is generally maintained at the same level, then CT will be more efficient. The impact of the SM is defined by comparing the key performance measures of simulation to those of the real data of considered CTS. Fig. 4 presents appropriate CTS capacities which are determined with the value of appropriate throughput per berth or CY. The objectives were to carry out CT capacity estimation and performance evaluation related to average occupancy rate and ship’s waiting ratio. The SM was to find appropriate berth and CY throughput, as well as a specific throughput can be achieved.

The cost analysis model for ship waiting and backlogged cargo is based on the model from Park et al. (2006) and the opinions of managers in charge working in the KBCT (MR 2009). According to the financial information published in 2009 (MR 2009), the cost items in this analysis have been divided into two: fixed cost and variable cost and the analysis has been done on the assumption that ship waiting/backlog-related costs take place when the CT is operated over its optimal throughput. Furthermore, by comparing its ship waiting/backlog-related costs with gross sales, we have tried to prove the economic validity of this analysis.

**Estimation of Total Costs:** The cost increase caused by ship waiting and backlog brings heavy burden not only on the shipping companies and customers, but also on the society. KBCT ship waiting and backlog-related costs are shown in Fig. 5. In the case of KBCT, its optimal throughput has been calculated to be from 485,361 to 567,753 TEU as a result of the SM.

To determine the CT capacity, the SM takes a lower bound and an upper bound of the capacity. The current throughputs of considered CTS are the lower bound and the capacities of a CTS subsystem are the upper bound. Berth throughput is the upper bound for HBCT, KBCT and PNC while is the lower bound related to HJNC.

In suggesting the optimal throughput of CT, cost analysis including service cost of CT, waiting cost of ship and containers, gives evidence to the terminal operators to make a decision of how many containers should be handled within permissible waiting ratio in terms of optimal capacity. Next Section needs to incorporate a cost analysis of the CT. This analysis ought to focus especially on the CT cost as their proper facility utilization. The results have revealed that simulation technique is a very effective method to estimate the relationship of berth capacity and ship’s waiting ratio at the considered CTS.

### 4. COST ANALYSIS

This section has tried to analyze the problems originating from ship’s waiting and backlogged cargo by means of KBCT. In case that there is any difficult item in analyzing this CT, we have tried to adopt the cases common to many other terminals. The important criteria of this analysis, i.e. the criteria of optimal throughput of a CT, are based on the outputs derived from the SM developed in the Section 3 and results explained in subsection 3.1.
550,000 TEU, the corporate profit of KBCT increases slightly, but the social costs increases sharply to a huge amount.

5. CONCLUSIONS

A simulation approach is explained here, combines the advantages of SMs and an optimization based on relationship between improvement of service facilities and ship’s waiting costs. Our contribution is twofold: SMs development and analysis of the integration of container berth and yard simulation planning within CT, and an iterative combination of SM and a method for estimating the optimal throughput per berth or terminal, as well as determining the handling capacity of CY. As a result of our research, it has been found out that KBCT optimal throughput and maximum profit are realized when the waiting ratio of ships is from 3% to 5%.

REFERENCES


