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SIMULATION-BASED ANALYSIS OF HANDLING INBOUND CONTAINERS IN A TERMINAL

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ABSTRACT

The continuing growth of marine container transport, as well as, the complexity in the analysis of terminal port operations has created an ideal area for applying computer simulation. This paper focuses on the handling of incoming containers transported on trucks in an "All-Straddle-Carrier" system. All major processes are reproduced by the simulation model. Input data includes parameters of space, speed and arrival frequency in a generic format, so that the model is adjustable to any situation. Analyzing the model for periods of model time ranging from a day to a week can give insight to the service level provided by any given port configuration. The simulated system can be used as a planning and a process improvement tool. In the development of the simulation model an object-oriented environment is used. It proves quite effective, resulting in a reliable and adjustable model.

1 INTRODUCTION

During the past few decades, general cargo–handling technology changed dramatically with the introduction of containers. The amount of general cargo handled with containers has steadily been increased. Nowadays, the majority of general cargo traffic moves by containers. The annual growth rate of container traffic is estimated to be about 9% and is anticipated to continue growing. As Ryan (1998) quotes, by 2010 it is predicted that 90% of all liner freight will be shipped in containers.

Container terminal ports are required to service ships as quickly as possible. Besides Ship-To-Shore (STS) operations, the mainland connection is also critical and the offered service level may provide key leverage against competition. Optimizing the balance between the customer's need for quick servicing and economical use of equipment is the main port management problem. The container terminal port in itself includes a multitude of interacting factors (personnel, varying ship and truck arrival patterns, various kinds of cargo-handling equipment); therefore, it is not the ideal environment for the application of an analytical and deterministic model. The randomness and complexity of the problem make the processes of a terminal port interesting ground for applying simulation modeling.

There are four basic types of container handling equipment: trailers, flatcars, gantries, and straddle-carriers. These types of equipment can be used in different combinations. Many average size ports in the Mediterranean Sea commonly use the **All-Straddle-Carrier** system option.

Several researchers used mathematical modeling or simulation to analyze various problems concerning commercial harbor operations and planning. Castilho and Daganzo (1993) used mathematical algorithms to examine different stacking techniques to the export and import areas of a container terminal. They studied the interdependence among storage space, equipment and labor. Shabayek and Yeung (2001) applied a queuing theory in Hong Kong's container terminal and improved the model's accuracy by the inclusion of seasonal effects. Pathak (1995) describes the simulation of a private bulk cargo port in India in order to provide a realistic optimized design. Mosca, Giribone and Bruzzone (1992) used simulation to check the efficiency of an automatic flatcar system servicing a rail-mounted crane. Makris (1998) studied the container terminal of the port-city of Thessaloniki, Greece, using two general simulation models of the simplified operating processes, one for ship and another for truck servicing. The commercial models are used for day-to-day operational needs and not for mid-term planning, the main purpose for building this specific model.

Most studies concerning port planning and simulation focus on the service of ships rather than trucks. The reason for this bias is that ship's downtime costs and customer demands are higher and more pressing than their terrestrial counterparts. This does not mean that optimizing truck servicing and equipment utilization is of no importance. Since a terminal's performance is judged on the overall performance of its individual components, this bias is not justified.

This paper describes the building and use of a discrete-event simulation model of the real life detailed processes concerning the inbound container handling in an All S/C terminal (Figure 1). The custom-made model was calibrated

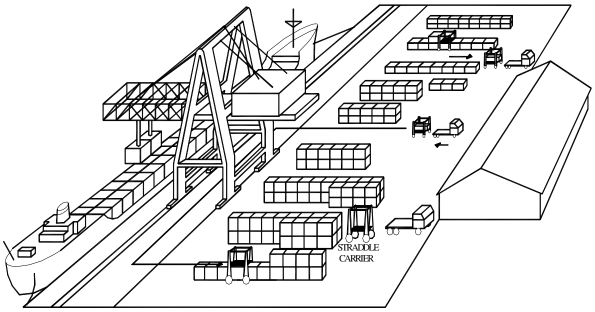

Figure 1: Sketch of an All-Straddle Carrier System

and adjusted to the characteristics of Thessaloniki's container terminal, a medium size Mediterranean facility. Issues regarding stacking yard layout, stacking techniques, optimized equipment use and equipment utilization factor were investigated and proposed for increasing the operational profit margin and improving service level. General conclusions can also be drawn and the simulation model's agility allows it to be used with other port configurations as well.

2 PROBLEM DEFINITION

2.1 Typical Terminal Layout

The use of Straddle-carriers, for handling containers on the route from a truck to the STS-gantry and vice versa requires similar patterns of terminal layout. As a consequence of cargo handling practices (custom clearance, inability to match arrival of containers and demand of trucks), containers remain in the terminal for a period of time ranging from hours to weeks. Thus, an adequate storage space is needed in the form of stacking yards (outlined areas for stacking containers).

A typical morphology of such a port comprises two more or less independent areas. The Export Area deals mostly with the service of container ships; it includes the gantries and the export stacking yards, which accommodate the containers to be loaded on ships. The Import Area is used for the containers carried by trucks. Import containers arrive at the yard in large batches and in a predicted fashion, but depart one by one in an unpredictable order. Each area uses dedicated straddle-carriers to function.

Trucks pass through the terminal's gate and park in specific truck pads waiting to be serviced. Figure 2 gives a schematic view of the above.

2.2 Typical Import Area Functions

The Import Area functions represent a multitude of interdependent operations from straddle-carrier and truck movements to the various ways of container handling management and working shifts.

a. *Inbound containers.* Ships arrive at the port either at defined schedules or erratically. The containers are unloaded by gantries and then transported to the Import Area Stacking Yards by straddle-carriers of the Export Area (see Fig.2, routes D) and stacked.
b. *Container demand and truck service*. The passing of a truck through the gate signals the necessary operations for servicing it. If it is empty, a non-occupied straddle-carrier (S/C) may move to the place in the stacking yards where the demanded container is stored (see Fig. 2, route A). The S/C will transport the container to the pad where the truck awaits and will load the truck, which will then proceed to the exit gate.

   The loaded trucks can be unloaded either in the truck pads by a S/C, which carries the container to the Export Area stacking yards (see Fig. 2, route B1) or directly by an STS-gantry (see Fig. 2, route C). In this case, if the truck delays for any reason, this would imply a delay to the ship, which, in turn, means costly penalties for the port authority.

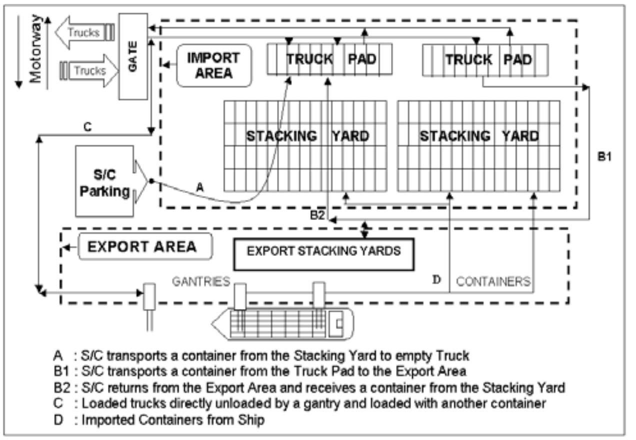

Figure 2: Typical Terminal Layout and Processes

A limited number of trucks can enter the terminal area each time, so a queue of trucks may evolve outside the gate. Internal waiting queues are also formed. Trucks are serviced on a load category priority basis. Loaded trucks are given priority. Otherwise, trucks form a FIFS (First-In-First-Serve) queue in their pad positions.

In order to retrieve a specific container, a straddle-carrier may need to move overlaying containers. Two carriers are not allowed to operate simultaneously in the same or neighboring rows of a stacking yard. The same straddle-carrier that unloads a truck will fetch the container possibly demanded by the truck from the import area stacking yard (combined movement, see Fig. 2, routes B1 and B2).

c. *Shifts and Reshuffling*. A typical workday of a container terminal can be divided into two or three shifts. Each shift has 7.5 hours of continuous work with a half an hour break during shift change. The case analyzed in this paper uses two shifts in the Import Area and trucks are served for a continuous 12-hour period.

    At the end of a workday a reshuffling scheme can be employed. Containers are stacked again in order to accomplish:

- Minimum yard height. This method, known as "simple reshuffling" simply dictates that every available place in the yard is filled before a second container tier is formed.
- A 2-2-1 arranging scheme, in which the yard is reshuffled, so that two places with two containers are followed with a place with one container. This pattern is proposed, because it reduces the essential carrier movements when attempting to reveal any given container. In the end of the workday all stacking yards are arranged this way.
- A scheme, where top containers will be demanded first. This method relies on a day-to-day planning to be put in practice. Transport companies are expected to notify port authorities a day before the container is requested. This way, at the end of each workday, the containers that will be asked for the next day are put on top.

d. *Finding demanded containers*. This process can be approached either on a "manually managed" basis or by a "computer organized management system". The applied approach critically affects the procedures followed and the way the system can be simulated.

    The **manually managed** approach is used in the port case analyzed in this paper. In order to achieve acceptable truck servicing times, truck drivers are informed from the shipping agencies of the exact container position. By entering the terminal, the driver parks as near as possible to the given coordinates and not on a standard pad position (there are no officially designated pads). The driver should then inform by himself the operator of a nearby S/C.

    In a **computer organized management system**, the gate personnel, the carrier operators and a general supervisor of the operations communicate through an on-line system. This system is of course applied to all terminal operations but here only the Import Area processes are analyzed. The system registers and tracks all containers inside the terminal's area. A database is continually updated with container identification number, time of arrival, custom status and stacking coordinates. This way, the system is capable of informing, with minimum delay, the straddle-carrier's operator with the coordinates of the containers in demand as well as the position of the relevant trucks in the pad. Proximity and availability of all straddle-carriers is considered when a task is assigned. Each truck, when it passes the gate, is given a truck pad place proximate to the stacking yard location of the demanded container; meanwhile the gate personnel informs the system's operator with the container identification number and truckload in order to assign a straddle-carrier to service it.

The two approaches differ drastically in terms of applying a simulation. Although, both systems follow almost the same operations flow chart, manual operation is heavily relied on the human factor (drivers need to find the containers themselves, S/C operators are given only general instructions, and decisions are made on the spot). Furthermore, the lack of specific truck pads makes the layout less accurate. All these make the parameterization of such a model a difficult task demanding a great amount of specific measurements to be gathered and statistically analyzed. The computer organized management system on the other hand is straightforward, both in terms of processes and layout, and thus can be simulated directly (without arbitrary adjustments).

2.3 Objectives

The primary objective of this paper is to create a credible and agile model capable of simulating several working days of a container terminal's Import Area. This model was used to assess the current situation of the case study terminal and demonstrate the potential for operational improvements. In particular, the model helped to:

- Give insight to the dynamics of the Import Area functions of the case study's container terminal and quantify efficiency parameters like Truck Turnaround (or Cycle) Times (TCT) and equipment utilization.
- Demonstrate the benefits from installing and using a computer organized yard management system to the terminal under consideration.
- Provide some estimates of traffic load limits and required number of straddle-carriers for ensuring acceptable service levels in the case study terminal.

- Suggest efficient ways of utilizing the terminal's space under current conditions or future expansion plans.

3 SIMULATION ENVIRONMENT

Simulation of Import Area operations is a discrete-event problem. To custom build such a model a flexible yet specialized software package is needed. Extend, version. 3.2.2 for PCs developed by Imagine That Inc. of San Jose, CA., fulfilled this need. Its object oriented basis provided an agile spine for the creation of the model as well as adequate animation capabilities, ease of use and customization. A similar problem was addressed successfully by Angelides, Phelps and Himel (1997) using the same package. They created a model of offshore pipelaying operations for planning and executive control purposes.

In the Extend environment, models are structured by individual objects assembled and connected, known as "blocks". Each block represents a specific physical entity or operation and may create, modify or represent information. All blocks have associated dialogs to enter the values and settings for every simulation run. Dialogs also display the output of the simulation runs. Connections between the blocks are materialized through predefined item input and output connectors, value input and output connectors, and the lines between connectors. A visual representation of the above is given in the next section.

Blocks are stored in libraries and can be used in other related models. Block functions are coded via a C-clone programming language. This feature enables users to create custom blocks, best suiting the needs of particular simulation problems. For simplicity, model subsystems comprising many blocks can be represented by one hierarchical block with the required input and output connectors. Extend's scripting language offers the capability of introducing animation features in the model, for better monitoring the whole operation.

4 THE MODEL

4.1 User Interface – Data Input

The simulation model uses custom-made blocks to represent the areas and processes of Stacking Yards, Truck Pads and intermediate routes of straddle-carriers. Vital parts of a simplified model (with only 2 Stacking Yards) can be seen in Fig. 3. The stacking yard offers a depiction of all container rows along with the height of each container stack. The truck pads show a sketch of places available, places occupied (by trucks), and trucks currently served. The movements of a straddle-carrier are also represented upon arrival to or departure from a block. Because animation by itself is not sufficient for validation or verification purposes, each time an event occurs in a block it issues a text trace report with time and activity information.

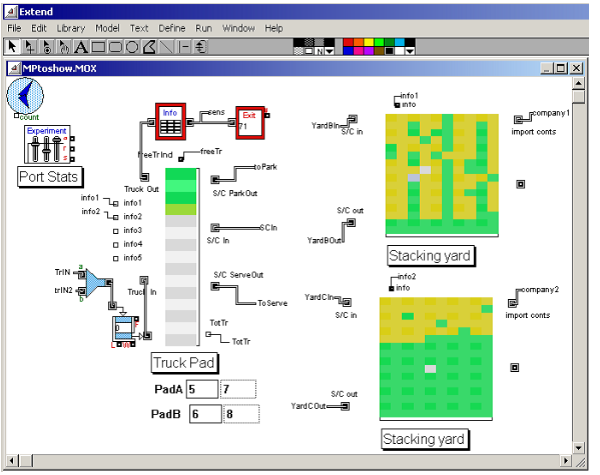

Figure 3: Vital Blocks in the "Extend" Environment

The user provides the data needed to run the model according to the layout and characteristics of the studied terminal. As input the user may specify:

- Number and dimensions of stacking yards and truck pads.
- Distances between each truck pad to all stacking yard rows.
- Arrival distributions for trucks depending on load status.
- Shift pattern.
- Yard filling rate. In order to prevent stacking yards from overflowing and to ensure realistic stacking yard coverage, an upper limit coverage factor is applied.
- Straddle-carrier average speeds (inside and outside the stacking yards).
- Duration for system operations like spotting containers, loading trucks, retrieving containers from stack, straddle-carrier and truck turning times. These values can be given as constants, as a combination of minimum, most probable and maximum values, or as results of a probability distribution chosen by the user, depending on the data available for the terminal to be modeled.
- General port organization methods, i.e., reshuffling, computer organized yard management system and combined straddle-carrier movements.

4.2 Output

Besides a trace text report that is used mainly as a debugging and verification tool, all the important results are summarized in the "statistics block dialog box", which opens automatically when a simulation run ends (see Fig. 4). This block contains the critical information that allows conclusions to be drawn over the efficiency and capacity of

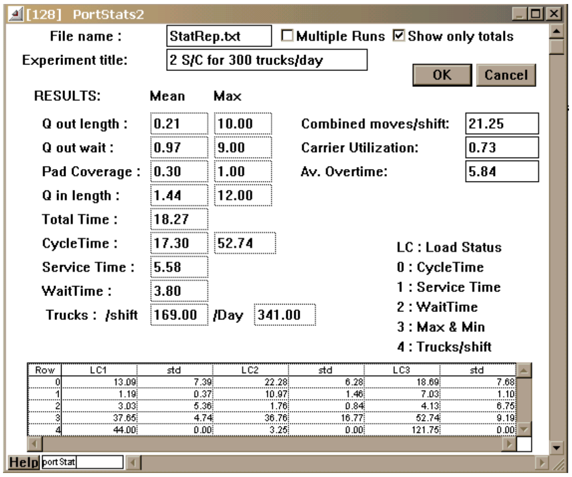

Figure 4: Statistics Block Dialog Box (Simulation Results)

the examined terminal's configuration. Results of serial experiments can also be recorded and presented.

4.3 Structure and Functions

The model is structured in sections as presented in Fig. 5.

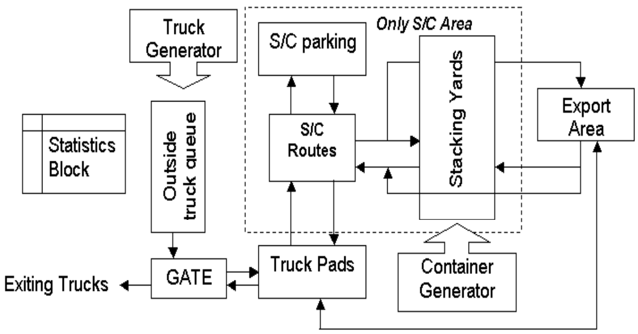

Figure 5: Overall Simulation Model Architecture

Trucks, straddle-carriers and containers move as separate or attached items (loaded truck or Straddle-carrier handling a container). Blocks delay items according to the activity performed.

Truck Generator. Trucks arrive at the gate according to user-defined probabilistic distributions. Trucks are characterized by load categories (see Table 1). Demanded containers are communicated through identification numbers.

Container Generator. Containers are introduced in the simulation run assigned with four attributes: company, departure index number, arrival time, and identification number. There is an initial preheating model running time before truck arrivals in order to fill up the stacking yards to a realistic percentage of their capacity. The number of containers correlates to the number of truck arrivals. The two rates match, otherwise either the yards will constantly be full or very close to be empty.

Gate and Outside Truck Queue. Trucks are allowed to pass through as long as there are available places in the pad. Otherwise, a queue is formed. Truck passage can also be blocked during shift changes and for a period of time before the end of the workday. The phenomenon of trucks arriving before gate opening, thus creating a morning queue, can also be simulated.

Truck Pads. This block holds the trucks waiting to be serviced, searches for straddle-carriers and informs available straddle-carriers of their next assignment. Finally, it calculates truck loading maneuvers and it delays straddle-carriers accordingly. This calculation is based on adding the time needed for a S/C to come to the truck, position itself above truck's trailer, load or unload it and then move out.

Stacking Yards. Stacking yard blocks provide a generated truck item with the data of the container assigned to this truck. It is a random operation based on the departure index number of each stacked container. These blocks also supervise container stacking, perform reshuffling activities if required, calculate straddle-carrier maneuvering times, and attend S/C movement so that no two S/Cs will operate over the same row or neighboring rows at the same time.

Routes and Delays. These blocks deal with all straddle-carrier movements outside the main blocks (stacking yards and truck pads). A database with distance information allows for time calculation of straddle-carrier movement from one truck pad to another or from truck pad to stacking yard and backwards, using the straddle-carrier's average speed as well as maneuvering, acceleration and braking times. Trucks also need an amount of time from the gate to the truck pad and back defined by average truck speed and route distance.

Export Area. The Import Area uses dedicated straddle-carriers, which are also used to transport containers to the Export Area's stacking yards. The time needed to perform this task depends on the relative distance of truck position and the Export Area and is calculated accordingly.

4.4 Simulation Parameters and Model Adjustment

An important part of the model implementation is the correct choice of the simulation parameter values. Typical values of parameters like truckload category percentages, straddle-carrier speed and times of loading - unloading maneuvers appear in Table 1. The maximum, most probable and minimum values of these parameters were estimated by on site observations and interviews.

Truck inter-arrival times were considered to follow an Erlang distribution (with m=2, k=2). Erlang distribution is proposed for the inter-arrival times in server-client traffic systems and was also proposed by Makris (1998). This hypothesis has been verified with actual arrival observations that helped establish the m and k Erlang parameters for the best fit to the specific case. The correlation is depicted graphically in Fig. 6.

Table 1: Typical Average Parameter Values

	Activity Type	Minutes		Activity Type	Minutes
Truck Pad Parameters	Loading/Unloading	0.6	Stacking Yard	Spreader Movement	0.3
	S/C Maneuvering	0.35		S/C Turning	0.15
	S/C Movement from one Place in a Pad to Another	0.35		Accelerating / Decelerating	0.02
General	Reaction Time of a Parked S/C	0.6		Container Spotting	1
	Truck Unloaded by Gantry	6	Export Area	Truck Pad to Stacking Yard Transfer Time	2
	Gate Passing	0.8		Return Time	1
S/C Speed	Outside the Stacking Yards	250 m/min	Truck Load Category	Empty	70%
	Inside the Stacking Yards	110 m/min		Loaded in – Empty Out	28%
				Loaded in – Loaded Out	2%

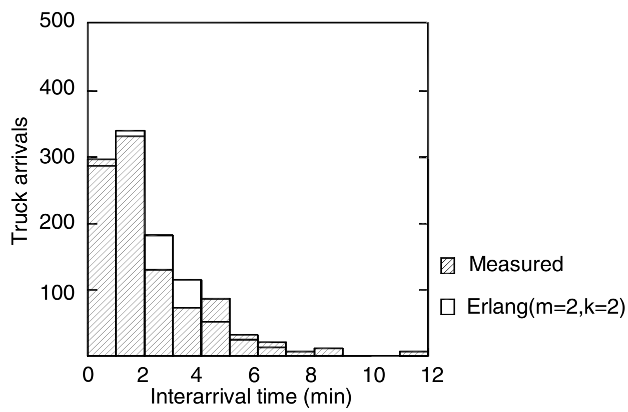

Figure 6: Comparison of Measured and Erlang Results

A previous study of Thessaloniki's container terminal (Makris, 1998) provided data of truck service time (average cycle time) based on measurements for the years 1995-97. That study does not provide information on truck service time according to load category. To update the service time database, observations were made during August 1999 and December 2001 to May 2002.

5 VERIFICATION, VALIDATION AND CREDIBILITY

After the completion of the simulation model and its computer implementation, a number of tests were conducted in order to validate the simulation model, verify the simulation computer program and establish credibility of the model and its results.

In order to compare several scenarios, experiments were conducted. Each experiment comprises simulation replications (runs) with altered input parameters. To ensure comparable results between experiments and reduce the number of runs that would otherwise be needed a variance reduction technique called "matched pairs" was used (Law and Kelton (1991) and Ioannou and Martinez (1996).

At first the internal logical structure of the simulation model was established. Flow charts of program structure and major functions were created before writing the source code, so as to keep things as close to the actual phenomena as possible.

The text trace report file, along with the animation features, was used to verify that the simulation computer program worked precisely as planned. All parameters were assigned deterministic and not probabilistic values, and checks were performed with hand calculations.

The validation of the simulation model was based on comparing the simulation model results with real-world measurements. The actual (historical) data of truck arrivals, as recorded each day, was used as input for the simulation runs. Initially the model was run several times for calibration purposes, having as input a specific day's arrival data. After calibration, no other alterations were made and the model was run with the data of the rest of the days.

Final results of the above comparisons are shown in Fig. 7. These experiments indicate that the simulation model can represent the actual phenomenon and provides logical and acceptable results.

Interaction with the operating and management personnel of the case study terminal, in which the model developed in this investigation was applied, had been frequent during the development and especially validation phase. Presentation of the final product and its results to management personnel and specialists confirmed the credibility of the simulation model as being a valid aid for decision-making.

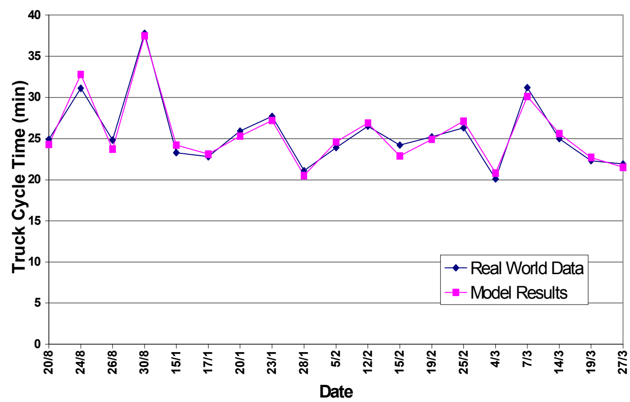

Figure 7: Comparison of Model Results and Real Data

6 EXPERIMENTS WITH SIMULATED SCENARIOS

6.1 Evaluating and Understanding Results

International experience and best practice indicate that a container terminal with this throughput should not exceed 30 minutes for the average turnaround time.

Another crucial parameter is the Straddle-Carrier utilization factor. A utilization factor less than 40% is considered poor whereas more than 60% is a good one. Straddle-carrier manufacturers recommend a factor around 70% utilization for cost effective exploitation of this equipment, but one should have in mind that straddle-carriers are also used for tasks not simulated here (irrelevant with Import Area operations).

The next section demonstrates part of the range of problems addressed by the model. The results are presented and discussed with focus on the case study terminal.

6.2 Results and Comparisons

6.2.1 Effect of Truck Arrival Distribution

A policy that promotes scattering of truck arrivals may in itself improve the terminal performance. While today approximately 50% of all trucks congest during peak hours this can be avoided by certain policy measures. Simulation testing shows that as much as a 15% improvement in Truck Cycle Time (22.7 min TCT against 26.9 min for 155 trucks per day) can be anticipated if truck arrivals are evenly scattered throughout the workday.

All experiments that follow were conducted using denser arrival rate during peak hours (50% of all traffic arrives during peak hours), as this is the current practice in the terminal under consideration.

6.2.2 Manually Managed Terminal Organization

Investigation of the current manually managed operational scheme under different traffic loads indicated the trends presented in Fig. 8. In a twelve-hour workday 4 S/C are needed for around 250 trucks (exp. A3&A4). If an increase of 100 trucks is expected then it is better to expand the workday to 16 hours (exp. A5). Improvement by adding another S/C further reduces the already low S/C utilization from 45% to 35% (exp A6). These results could be an indication of the inflexible downtimes due to lack of automation.

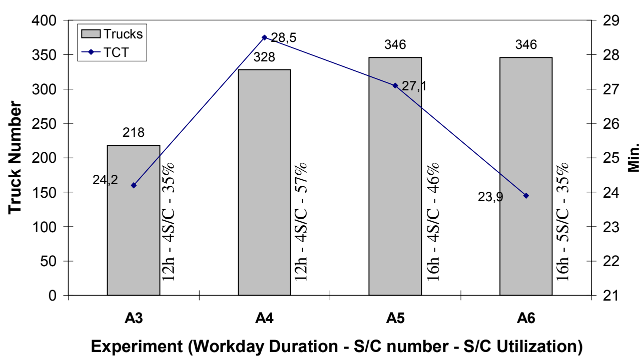

Figure 8: Manually Managed Terminal Organization

6.2.3 Computer Organized Yard Management System

The decision of the management of the case study terminal to develop and implement a computer organized yard management system was supported by the demonstration, through simulation, of effects and gains.

In this investigation, it is proposed to install a computer organized yard management system and operate two truck pads (10 places each) in front of the Import Area stacking yards. The results of the relevant experiments are presented in Table 2. The experiments in this table are grouped by names A and B, where experiments A refer to the manually managed system and B to the computerized one.

Table 2: Manual vs. Computer Organized Mgtm. System

Experiment	Input					Results	
	State Type	Workday Duration	Pad Places	Trucks Serviced	S/C	TCT	Carrier Utilization (%)
A7	Current	12	40	169	4	22.9	25
A8	Current	12	40	169	3	26.9	37
B1	Proposed	12	20	169	3	16.4	44
A5	Current	16	40	346	4	26.4	46
A6	Current	16	40	346	5	23.3	35
B2	Proposed	16	20	346	4	20.7	55

The benefits from the introduction of the proposed enhancement in the Import Area, compared to the current manually managed state, are obvious. For 169 serviced trucks, such a system costs less than investing on a new straddle-carrier, though it provides a 40% improvement on TCT (exp. A8 vs. exp. B1) versus 15% (exp. A8 vs. exp. A7) when putting one more straddle-carrier in operation. For heavier traffic, 346 trucks serviced, the comparison shows 24% improvement on TCT (exp. A5 vs. exp. B2) versus 14% (exp. A5 vs. exp. A6). The straddle-carrier utilization factor is increased (from 35% to 55% in experiments A6 and B2), indicating a more efficient use of the equipment. Therefore, this more efficient organizing scheme significantly increases the provided service level while reducing the required straddle-carriers.

6.2.4 Reshuffling

The reshuffling schemes, presented in the subsection c of the section “Typical Import Area Functions”, are examined here in terms of decreasing TCT and enhancing straddle-carrier utilization. A comparison of the reshuffling methods is based on the experiments of Fig. 9. These experiments were conducted using a maximum stacking yard coverage of 85% as compared to a normal value of 75% used in the previous experiments, in order to exaggerate the effect of reshuffling.

Simple reshuffling appears to have no measurable effect on TCT (exp. C2). On the other hand day-to-day planning results in a significant, 5.5 minutes, decrease of TCT (exp. C3 vs. exp. C1). The 2-2-1 arranging scheme im-

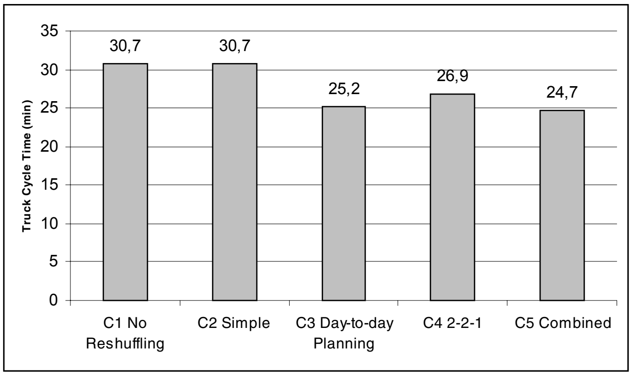

Figure 9: Reshuffling Schemes Comparison

proves TCT by 3.8 minutes (exp. C4 vs. C1). Although this improvement seems smaller than the previous one, it does not have as prerequisite any information and is based on random reshuffling. As it could be expected a combination of these methods results in a notable 6 minutes reduction of TCT (exp. C5 vs. exp. C1).

6.2.5 Future Expansion Plans

The container terminal studied in this paper covers a part of the 6th pier of the port. The expansion of the pier for another 500m into the sea is already in the final study phase. Since no official layout plans were available at this point, a hypothetical layout consisting of seven separate stacking yards was used as basis. Truck arrivals, within a decade, are expected to surpass five hundred or even six hundred trucks per workday.

Several simulation experiments were conducted to investigate the above configurations and the results are presented in Table 3. These experiments were designed to investigate and optimize the number and capacity of truck pads, the number of operating straddle-carriers, workday duration, truck queues and the effect these issues have on the service level provided.

Three truck pads evenly distributed in front of the Import Area should allow efficient truck loading and unloading. The pad closer to the mainland, pad III, though, may create several problems in the overall straddle-carrier circulation, by its proximity to a transtainer crane Area and railroad tracks. The necessity of pad III was assessed with the experiments D1-D4 of Table 3. In case all three proposed truck pads function, there is an improvement in TCT that ranges from 1.6 minutes or 8% for 339 serviced trucks to 3.7 minutes or 15% for 471 trucks/day. Obviously, for a highly stressed system, the additional pad offers greater relief. This relief though does not dictate a full time use of the pad. It may be more productive to use the third pad in situations with heavy workload (more than 450 trucks/day for 4 operating straddle-carriers and 600 trucks/day for 5 S/Cs) or not adopt it altogether.

In extreme situations (exp. D5, D7), the outside queue reached about 30 trucks, compared to about 10 trucks in more normal conditions. A proper placing of the gate allows the linear development of much greater queues.

It appears from experiment D3 that 4 straddle-carriers may service as many as 471 trucks over a 16-hour workday with an acceptable service level (TCT 24.9 minutes) and high straddle-carrier utilization (79%). For 551 trucks serviced, 5 straddle-carriers must operate providing a TCT of 20.6 minutes (exp. D6). A truck arrival rate of over 600 trucks/day creates a heavy workload even for 6 S/Cs, since the TCT reaches an unacceptably high value of 37.8 minutes for 650 trucks (exp. D7). Such an arrival rate dictates either the transition to a trailer system to compensate for the great operational distances or the expansion of the workday to three 8-hour shifts, i.e., a 24-hour workday. If the latter measure is put in practice, 4 straddle-carriers can manage the workload with a TCT of 23 minutes and a high straddle-carrier utilization factor (>70%) (Exp. D8).

Table 3: Experimenting with Future Expansion Scenarios

Experiment	Input				Results		
	Pad Status	Workday Duration	Trucks Serviced	S/C	TCT (min.)	Outside Queue	Carrier Utilization (%)
D1	I, II, III	16	339	4	20.7	11	55
D2	I, II,	16	339	4	22.3	12	50
D3	I, II, III	16	471	4	24.9	10	79
D4	I, II	16	471	4	28.6	10	67
D5	I, II, III	16	647	5	46.6	32	80
D6	I, II, III	16	551	5	20.6	10	71
D7	I, II, III	16	650	6	37.8	29	79
D8	I, II, III	24	652	4	23.5	13	74

7 CONCLUSIONS

A container terminal's Import Area can be successfully modeled through the software developed for this project. The simulation environment used proved to be an ideal base, which allows one to focus on the simulated problem and not on programming complexities.

The model was demonstrated by its use to study extensively the current state of a container terminal and possible future scenarios. The model has helped to visualize deficiencies of the system. It was used as a medium term planning tool. Namely, it was used to optimize S/C number for different traffic loads, investigate different layout solutions regarding truck pad placing, investigate the benefits of reshuffling techniques and estimate queue lengths for adequate available space.

The simulation model can evaluate the effectiveness of several proposed plans, in terms of service level improvement. Layout changes, equipment investments, working shift policies can be investigated. These features were successfully employed in the case study terminal.

The flexibility of the model allows the consideration of many alternative possible scenarios, thus making it an excellent tool for decision-making.

The model can be adapted to various features and layouts of terminals that use All-Straddle-Carrier systems.

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