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USING SIMULATION TO PREVIEW PLANS OF A CONTAINER PORT OPERATIONS

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ABSTRACT

The concept of using a simulation model to preview the integrated plan of a container port operation has been developed and tested. The results of the test has been encouraging as it gives the planner an opportunity to see the performance of the proposed plan and make changes to them before committing them to operations. This would result in less changes to the plans, fewer conflicts for resources and a better throughput for the whole port operation.

1. INTRODUCTION

The Port of Singapore Authority operates one of the busiest container terminal in the world, with an annual throughput of 9.05 million TEUs (twenty-foot equivalent unit) in 1993. The throughput is expected to increase over the next few years. Due to the strategic location of the port at the crossroads of the international shipping lanes, it has developed into a hub port in the sea freight network. All the containers relayed through Singapore are systematically sorted out for distribution to the second carriers. This has given rise to a very complex and challenging task of planning and managing the container handling resources so as to minimize conflicts in the use of these resources.

In the past few years, much efforts were focused on using information technology and expert systems to build a number of planning systems to manage the terminal activities in oder to achieve higher operational productivity. The various plans that are in place include the berthing plans for vessels, the loading and discharging plans for vessels, import delivery and export receiving schedules through the gates, and the yard plans for the stowage and rearrangement of the containers for more efficient handling onto the subsequent vessels. The key objective of all these is to achieve a shorter turn-around time for calling vessels which ultimately translates to a higher throughput.

All these plans are linked together into an integrated terminal operations system. While the individual planning systems were optimized within their own operating constraints, there is a general lack of a holistic view of the terminal. There may give rise to bottlenecks that will result in unnecessary delays.

A simulation model was proposed to be used to run the integrated plans prior to their actual execution. This provides the planners a preview of the overall performance of the pending operation. Potential problems can then be identified and changes made to the plans before committing them to operations. The simulation runs are expected to provide a more accurate projection of the vessel performance, and a higher level of resource utilization.

2. OVERVIEW OF THE PORT OPERATIONS

The activities in the container port begin with the arrival of the vessel, which is allotted a berth number. Based on the expected number of loading and unloading jobs, the planning system allocates the appropriate number of quay cranes to service the vessel. From the crane working plan, a scheduler assigns prime movers (PM) to the quay cranes to discharge and load containers. These prime movers ply between the wharf and the yard blocks. At the yard block, the yard cranes dismount/mount containers from/on the prime movers. After the initial stacking of the containers in the yard blocks, the yard operation rearranges or reassigns the containers to more suitable locations (yard shifting/inter-terminal haulage) so that the loading operations onto the second vessels may be executed with greater efficiency. The gate operation manages the import and export containers from the freight forwarders. Figure 1 gives an overview of the different activities in the container port operations.

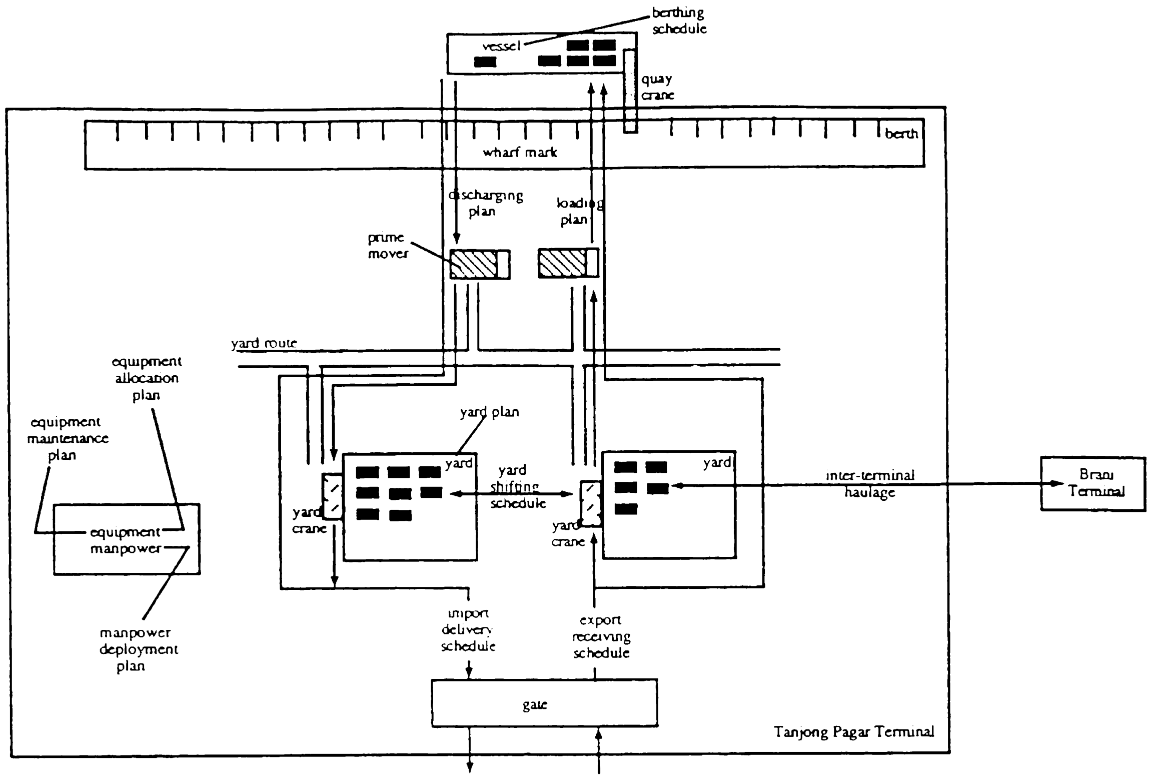


Figure 1: Overview of the Physical System

The main activities that make up the whole container port operation can be broken up into the following:

a. **Berth operation:** The berth operation concerns the schedules of arriving vessels and the allocation of wharf space and quay crane resources to service the vessels. The port is fully equipped to handle almost all types of vessels, ranging from 80-TEU coastal barges to third generation vessels of 4000-TEU capacity. The key concern of the berthing operation is the turn-around time of vessels.

b. **Ship operation:** The ship operation involves the discharging and loading of containers onboard the vessel. This is handled by up to 4 quay cranes (QC) working in synchronization so as to maintain safe separation from each other. To achieve high crane rates (number of containers moved per hour), the planner has to optimize the crane working sequence (a detailed list of crane moves), so that there would not be any clash involving neighboring cranes and at the same time ensure a smooth feed rate of prime movers to cart away (discharge) and send (load) containers to the quay cranes.

c. **Yard operation:** The yard operation is perhaps the busiest of all the activities in the terminal. The operation involves discharging of containers from the vessels, loading of containers onto vessels, shuffling of containers that are out of sequence, in the yard block, redistribution of containers to other blocks (yard shifting) for more efficient loading onto the second vessels and inter-terminal haulage where containers are moved to other yards in another terminal.

d. **Gate operation:** The gate operation deals with external freight forwarders. Two activities are involved, namely export delivery where the freight forwarders bring in export containers to the yard or wharf to be loaded onto the vessels, and import receiving, where the freight forwarders receive containers from the yard or wharf to bring into the country.

e. **Scheduling:** This is the function that ensures the various resource pools, such as the prime mover (PM), yard crane (YC) and other container handling equipment pools, are utilized efficiently given the constraints and other conflicting demands on them.

3. OBJECTIVES OF THE PORT SIMULATION MODEL

The simulation model that was developed was a prototype to mimic the main operations of the container port. This model, called the BASIC model, must be able to be integrated with the current integrated planning and operational systems so that it is able to extract the plan and status information from these systems. Results generated from the simulation run should highlight any contentions for key resources, bottlenecks and deficiencies in the plans and be presented in a manner that will aid experienced planners zoom in on problem areas and make changes to the relevant plans to alleviate the problems.

The BASIC model will enable the planner to experiment with various environments in the terminal in order to better define the specifications for an elaborate decision support system to complement the planning of the container port operations. A typical scenario on how the BASIC model may be used is shown in Figure 2.

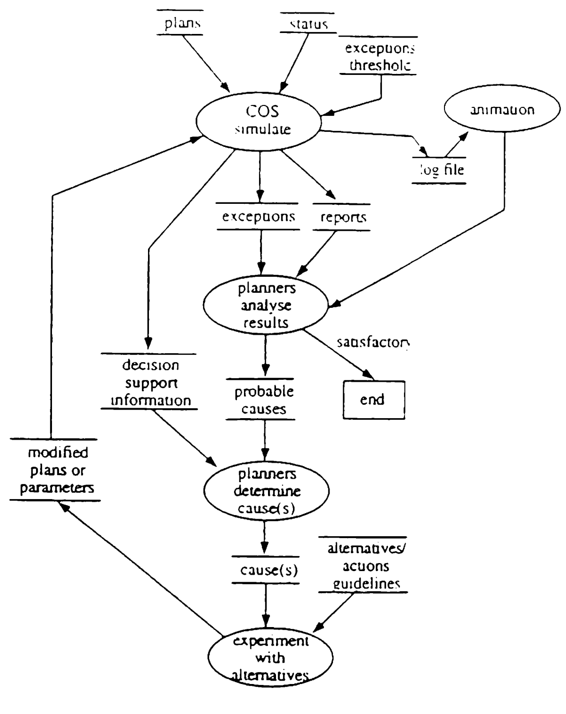


Figure 2: Scenario in which the System will be used

This is a decision support information system that the BASIC model produces. The results manager organises these information and present them to the planners to assist them in trouble shooting problems that may arise when the integrated plan is implemented. In this particular example, we are interested in determining the possible causes of a vessel overstaying its allotted berthing duration.

The immediate interests of the planners and the operations managers that the BASIC model can satisfy are the followings:

a. activities monitoring in the terminal,
b. progress monitoring in terms of tasks completed by each resource,
c. better estimates for the vessel turn-around times,
d. better understanding of the factors contributing to yard block congestion
e. experimentation with different scheduling concepts for terminal resources,
f. a decision support information system to assist the planner to analyse the causes of some of the problems highlighted by the simulation.

The longer term user requirement are:

a. a decision support system with embedded intelligence to analyse the voluminous output data and advise the planner on the alternatives to improve performance,
b. a intelligent system to produce pseudo plans for incomplete and fuzzy input in order to extend the planning horizon.
c. an expert system to analyse the 'goodness ' of the plans and to suggest improvements to the plans based on defined goals, constraints and planning rules.

4. SYSTEMS DESIGN AND ARCHITECTURE

The architecture of the BASIC model is shown in Figure 3. This which consists of:

a. the database subsystem,
b. the graphical user interface subsystem,
c. the scheduling subsystem,
d. the simulation subsystem and
e. the animation subsystem

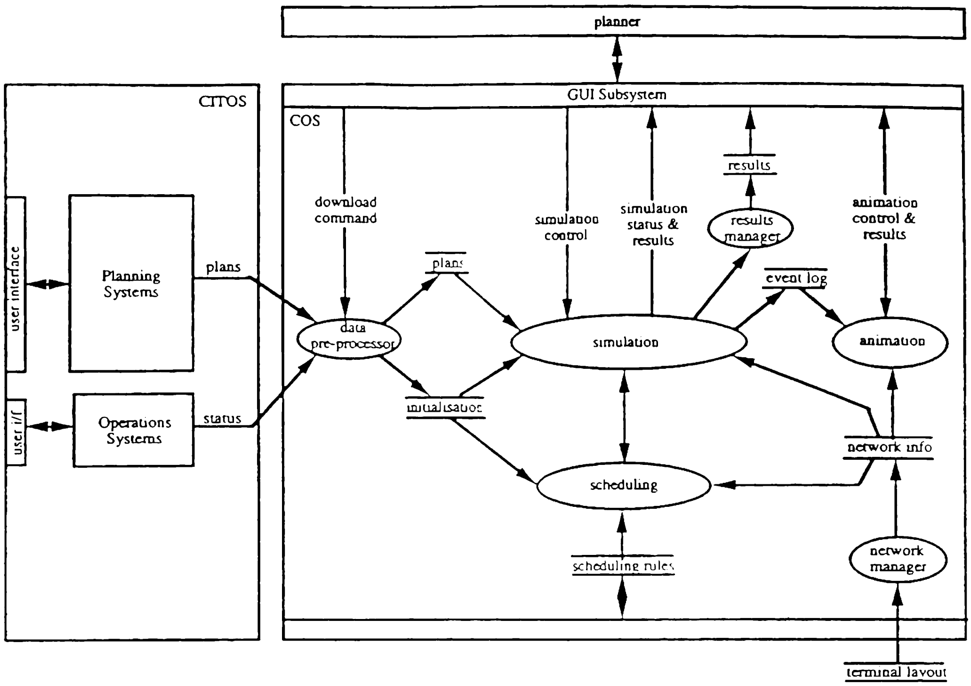


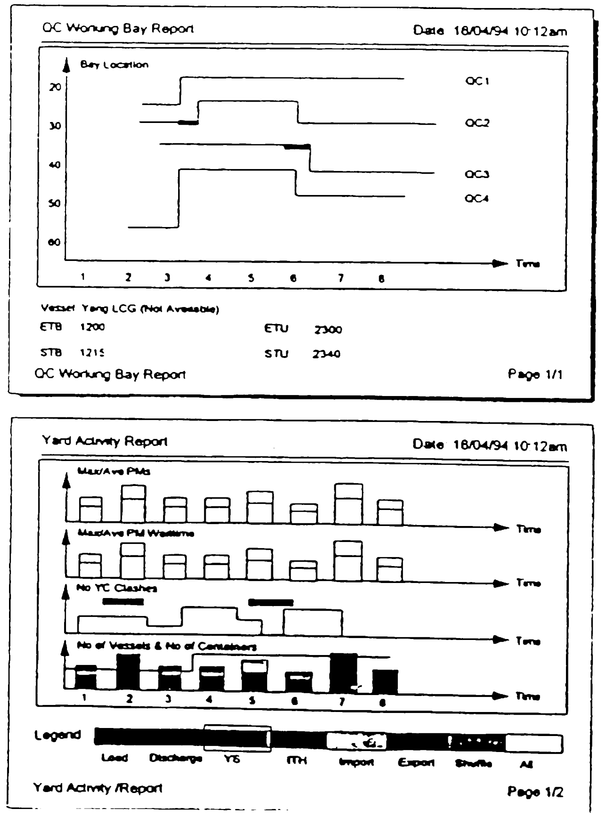
Figure 3: Basic Model System Architecture

The whole BASIC model was designed and implemented in MODSIM II.5, an object oriented simulation software from CACI. The choice of the object oriented simulation software was driven by the complexity of the requirements of the model and the demand by the user for a system that not only allow for ease of integration and customization but also high level of reusability of the modules in the simulation model.

The database subsystem accesses the planning and operational systems and extracts the relevant data from these systems. It then preprocesses these data into formats that can be used by the other subsystems.

The scheduling subsystem is an important part of the Basic model that handles the dynamic scheduling of the resources in the terminal. It maximizes the utilizations of each of the resource pools by using a look ahead concept. All routine activities, such as preventive maintenance, change of shifts, etc., are handled by the schedulers.

The user interacts with the system through the graphic user interface (GUI). It enables the user to setup the simulation parameters and the environment, the initiation of the system data extraction and the control of the simulation from the GUI screen display. Post simulation reporting and animation of the simulation runs are also handled through the GUI. Figure 4 is an example of the layout of the GUI screen.



Fgiure 4: Typical GUI Screen Output

The two charts shown in Figure 4 are samples of some of the outputs from the simulation that are available to the user through the GUI. The first chart reports the activities of all the quay cranes working on a particualr vessel. The second chart is a report of the activities in the yard.

5. SIMULATION MODEL DESIGN AND DEVELOPMENT

Figure 5 illustrates the main objects in the simulation model. At the top level is the SimControl object, which is responsible for the initialization, the terminal setup and starting the simulation through the SimulationObj. The terminal setup is responsible for the setup of the static objects in the terminal which includes the wharf, yard blocks, road network and the gates. The initialization object provides the status and location of all the active objects in the terminal.

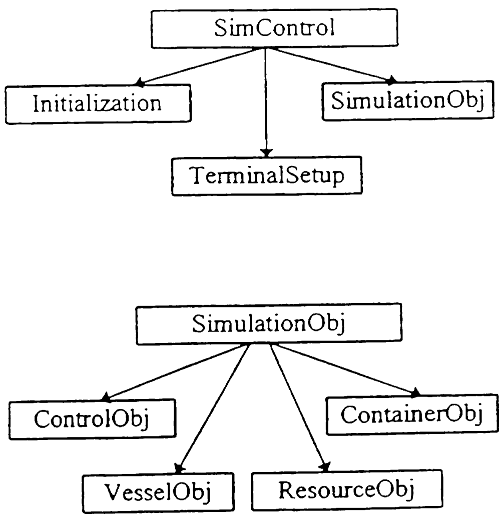


Figure 5: The Main Object Classes in the BASIC Model

Under the Simulation Object are the Control, Resource, Vessel and Container Object Classes. The Control Objects include Network Manager and the Schedule Manager. These are objects that provide the macro level schedules, rules and sequencing of activities for the simulation and dynamic scheduling.

The resource class in the simulation model includes the Crane Object Class, the RoadVehicle Object Class and the Gate Object Class.

As a large portion of the simulation is concerned with the movements of the PMs in the road network and within the yard blocks, we spent a considerable amount of effort in designing an efficient Network system that defines accurately the traffic flow and the relationship between nodes. The Network Manager accepts drawing files in the DXF format such as those from most commercial CAD software. A network algorithm is then used to determine the shortest available route between two points in the network during simulation.

6. ISSUES ADDRESSED IN THE DESIGN

An important requirement of the user is that all the plans and status information that are needed by the Basic model have to be extracted, processed and stored in a manner that will not adversely affect the performance of the existing network users. This places a very heavy demand on the design of the database sub-system, which has to work with all the existing planning systems and the operations control system.

A common problem encountered in trying to execute real plans in simulation is the presence of voids in the extracted plans. As the planning horizon lengthens, some planning information become less accurate. One example is that some of the actual stowage plans for vessels cannot be confirmed early enough for the next planning cycle. Without the stowage plan, the detailed crane working sequence for each quay crane assigned to the vessel cannot be finalized. Despite the voids in the plan, the Basic model is required to provide a patch module to ensure that the terminal traffic activity level is maintained and also to provide good estimates of the ship turn-around times.

A possible future investigation is to use a knowledge based system to provide provisional data for the voids in the plans. If this is possible, then the planning horizon can be extended, leading to more time for the analysis of the simulated results.

7. DATA COLLECTION AND ANALYSIS

Extensive efforts were spent studying the data collection requirements for the simulation model.
The collection efforts were focused on :

Crane cycle times - the time taken for a complete mounting/dismounting of a container by a yard crane or quay crane. Statistical analysis of the collected data indicated that the variations in the cycle time for the different types of yard cranes were insignificant. However the cycle time of the quay cranes were found to be dependent on the type of vessel and the presence of cell guides. For this particular groups of cranes, the Weibull distribution seems to fit the cycle times very well.

PM transit speeds - there were much discussions on the best way to model the speed of the PM. As the PM are manually operated, we were of the opinion that a detailed model which incorporates acceleration and deceleration of the vehicles would not necessarily give better results. A time study on the speeds of the laden and unladen PMs at the various transit road segments was eventually conducted. These included travels on the main trunk roads or the yard cluster roads. The results suggested that we could use constant average speeds to model those transits. Similar field studies were conducted to obtain the crane gantry speeds and gate inspection times.

8. VERIFICATION AND VALIDATION

The model has been subjected to a series of verifications to ensure that the standard distributions used in the software are producing the right cycle time distributions, and that the speed of the PMs in the terminal are reasonable. Specially designed data sets were used to check the logic concerning the resolution of crane clashes and the collision avoidance rules at the road intersections. The scheduling subsystem was probably the most difficult to verify in the integrated Model. On its own, the designed verification tests seem to indicate that it was working well but when integrated with the other subsystems, we have to resort to the laborious tasks of tracing the logic flows of a number misbehaving loops which were not detected before. The final results were generally satisfactory.

For validation purposes, we used the quay crane working rates (the total number of containers handled by the quay crane divided by the number of hours the quay crane worked on the vessel), and the ship turn around time. These two parameters were chosen because their values are very much influenced by the performances of the resources and the scheduling systems in the terminal. On face value validation, the model seems to produce reasonable results. Detailed analysis however revealed that our model was consistently producing crane rates that were about 5% to 26% higher. This is also consistent with the fact that the vessels turn-around time were also faster by about that order. Tables 1 and 2 show the comparison between the actual and simulated results for five vessels. On further analysis to try and account for the discrepancies, we were able to trace the possible causes to three sources:

Table 1 : Simulated vs Actual Port Stay (in hours)

Vessel Name	A	B	C	D	E
Actual Port Stay	7.50	8.33	6.00	8.75	3.75
Simulated Port Stay	6.53	7.43	4.55	6.92	2.90
% difference	13.9	10.8	24.2	20.2	22.7

Table 2 : Simulated vs Actual Quay Crane Rates

Vessel Name	A	B	C	D	E
% diff in their respective Crane Rates	13.0	5.2	20.5	20.6	4.6

a. **PM scheduling system:** while our model uses a dynamic scheduling system for the PMs which is to be implemented by the end of this year, the current scheduling system assigns a group of PMs to work specifically for a quay crane (fixed QC assignment). The Scheduler in the Basic model provides a look ahead scheduling for the PMs as a common pool. This ensures that each PM will have a new job whenever it completes an assignment. In the case of the fixed QC assignment, at the end of each job, the PM will travel empty to the start point. Therefore, the Scheduling system, as designed in the BASIC model will always produce higher PM utilization than the current fixed QC assignment concept, thus resulting in higher feed rates for the QC.

b. **Yard shifting activities:** Although we have deliberately left out the yard shifting activities from the validation run, and also remove proportionately the percentage of PMs from the available PM pool and YC pool during simulation, we are concerned that we are not simulating the right level of traffic in the terminal. By removing PMs from the PM pool we are actually reducing the activity level in the terminal, and unwittingly creating a faster PM feed rate for the quay cranes.

c. **Yard Crane Scheduling system:** the present terminal operations system does not have a yard crane scheduling system in operation, and as discussed in point (a), the operation with an efficient YC scheduler would definitely give a much higher throughput.

We have discussed the discrepancies between the simulation model and the current terminal operations with the user. We are confident that when the full scheduling system is implemented, the model can be fully calibrated and validated.

9. CONCLUSION

An interesting concept of using a simulation model to exercise the integrated plans of a port operations has been tested. The model that was developed has demonstrated great potential to be able to improve the plans and prediction of the port performance. In order for the potential to be realized, there is a need to develop an intelligent DSS system to be able to analyze and advise the planners on the 'goodness' of the plans to meet the desired objectives of the port. Another important capability that needs to be build up is the capability to be able to extend the planning horizon so as to allow more time for the planner to preview and analyze their plans.

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