

# **Evaluation of Container Terminals Using An Adaptable Container Terminal Simulator**

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## **Abstract**

Container terminals entail large amount of resources and their planning requires careful evaluation of various options. The conventional approach is often based on static, heuristic rules that are not sufficiently rationalized and quantified. To remedy this situation, Nanyang Technological University and Maritime and Port Authority of Singapore have jointly developed a system called Adaptable Container Terminal Simulator (ACTS) that allows users to specify the configurations and operational parameters. The model can be driven with realistic arrival patterns and detailed handling policies for evaluating the handling capacity of container terminals. To test-bed the ACTS tool, tri-party collaboration projects have been carried out to quantify the handling capacity of two container terminals. This paper will elaborate on the issues involved in container terminal simulation, the design and features of the simulator developed, and present the test bedding undertaken.

## **I. Introduction**

Since the introduction of containerization in the 1960s, container terminal operations around the world have come a long way. Millions of TEUs of containers are handled around the globe annually, connecting all major trade zones of the world. Increasing port connectivity and rapid growth in the shipping volumes has led to the construction of new ports and expansion and consolidation of existing facilities. In light of this, it has become increasingly important for operators to accurately assess the efficacy of their operations and to evaluate their sustainable capacities.

Several port operators that we have liaised with in the past three years have underlined the pressing need for a system that is able to simulate the port operations in details for the evaluation of their operations and the limits of their handling capacity as well as for planning of certain other aspects. There are many advantages to using simulation as a tool, one of which is the ability to compare various scenarios once the base model has been formed. This allows us to compare and evaluate the terminal performance using different resource types, settings and management policies.

Computer simulation has been an essential tool for planning and optimization of container terminals. A recent survey revealed that port operators have long applied computer simulations at various levels of sophistication to alleviate problems in various areas of operations. However, what is still lacking is a system-wide model to integrate models of the individual sub-systems. As a result, port operators are unable to simulate the full cycle of port operations. This deficiency becomes critical when optimizing operations of a container terminal, as ultimately what matters is the *overall* performance of the entire terminal, rather than the behavior of the individual subsystems. A generic tool that enables reconfiguration and integration of sub models will offer high value. Moreover, when specific handling policies are incorporated, the resulting simulation model will offer great assistance to, e. g. the evaluation of a proposed port terminal or planning/fine-tuning of current operations.

The simulation model developed replicates the chosen terminal in terms of layout and yard configuration, equipment setup details and policies. Simulation is then used to evaluate the efficiency of ongoing operations in the terminal and can highlight certain inefficiencies or bottlenecks. Solutions to overcome these inefficiencies can then be tested out in the simulation model and the effect observed. Based on such evaluations, certain promising operational changes can be made to the actual terminal operations to achieve better performance.

ACTS is an innovative tool because although currently the port operators have independent simulation models for different aspects of their operations, they do not possess one single system, which integrates all the activities of a terminal. The system is scalable, allowing users to plug in any equipment specification, change resource settings, modify policies etc. This powerful tool will enable the port operator to evaluate new technology and new policies easily, at hardly any extra cost.

In this paper, we discuss the need for an integrated, adaptable container terminal simulation system and review some existing work in this area in Section II. Section III presents the design and the features of the simulator we built. Section IV describes the utility of the adaptable container terminal simulation system while Section V talks about the test-bedding of the system. Lastly, Section VI concludes the paper.

## **II. Simulation of Container Terminal Operations**

Container terminal operations are typically very complex, involving coordination among several sub-systems. The quay-side (berth and quay cranes), which berths vessels and transfers containers between the vessel and ground, is the terminal's interface with the calling shipping lines. The yard facility (with accompanying yard cranes) serves as the terminal's store of containers, which are temporarily housed there before being transported inland (import) or onto other connecting vessels (transshipment or re-export). The ground transport system, typically prime movers or straddle carriers, convey containers between the quay and the yard. Local hauliers interact with the terminal gate and yard to haul export containers into and import containers out of the yard.

None of the terminal sub-systems performs in isolation - the performance of one closely depends on that of others. Conventionally, static analytical models have been used to gauge terminal capacities. However, the major drawback this approach suffers from is the lack of consideration of the dynamics between the various systems. The terminal capacity should be evaluated for the terminal as a whole, rather than as a measure of individual component capacities. Having said this, it should be mentioned that it is still useful to have an understanding of individual system capacities so as to ensure that no one resource is being overprovided and underutilized.

A port simulation model is a facility used by port managers for determining the effects of changes in throughput, and various operational, technological and investment options and, thus, to assist in decision making process (Wadhwa, 1990). In recent years, simulation has been used to good effect for container terminals. It has the following advantages

- Evaluate proposals within a short period of time and at a low cost
- Compare alternate plans on an objective basis and without committing resources
- Quantify the impact of change without disrupting operations
- Identify constraints and diagnose problems in design / operations
- Visualize the operations
- Reduce uncertainty in decision making

In general the modeling detail of a simulation system should be based upon the required level of accuracy that is in turn closely associated with the particular purpose and utility of the system. Two types of simulation are normally found in the existing literature, namely, strategic simulation and operational simulation.

Strategic simulation is to study and compare alternative layout plans, leasing policies, or handling equipments, and identify the best solution in terms of efficiency and cost-effectiveness. It is mainly used in the design and master-planning phase of a new port or extension of an existing port. For strategic planning purpose, a high level of abstraction is allowed (Carpenter 1990; Yun 1999; Kia 2002). Operational simulation focuses on the issues raised in allocating and planning resource for actual operations. It implements and evaluates, with pre-defined layout and equipment setting, different operating concepts, such as yard allocation (Bielli 2005), berth planning (Legato 2001), or overall resource sharing and planning (Gambardella 2001). Operational simulation is most valuable in the terminals with high demand on throughput and operation efficiency, where the alternative optimization methods for planning can be tested before implementation (Koh 1994; Veeke 2002). An operational simulation system can be further developed to integrate with container terminal management system for real time data exchange. It can assist in pre-alerting "hot spots" where congestion of traffic is identified and proposing possible solutions for the planner to work on. This typical type of simulation for real time planning is referred to as tactical simulation by D. Steenken, S. Vob, and R. Stahlbock (2004).

However, a review of published materials reveals that despite the substantial amount of attempts at developing a container terminal simulation model, most of them used a simplified approach with several abstractions to the key parameters, for example, yard allocation logic that is the most complicated part of the system and determines the port efficiency to a great extent. The flexibility in allowing different simulation resolutions for different purposes is missing.

Moreover, most of the models developed, instead of encompassing the complete range of terminal operations, focus only on certain specific areas. For example, the models may be used to simulate berthing operations or yard operations separately,

for the purpose of optimization or evaluation of new policies and operations concepts. Typically, small-scale operations are modeled and successful solutions are then extrapolated into larger terminals assuming that the complexity in operations does not increase with the size or scale of a terminal. The approach is inadequate nowadays when terminal operators encounter limited availability of land, intense competition, and high operating cost, and a single mistake could be ruinous.

### **III. Adaptable Container Terminal Simulator (ACTS)**

ACTS incorporates and models all major aspects of container terminal operations. It contains the following major components:

- (A) Terminal Layout
- (B) Ship Arrival Generator and Stowage Plan Generator
- (C) Berth Allocation
- (D) QC System
- (E) Transport System
- (F) Yard Planning
- (G) Yard Operations

Each component in turn models operations down to the box level, with all stages in the container handling cycle being taken care of, to make the model realistic. The model architecture and relationship between modules are shown in Figure 1 below.

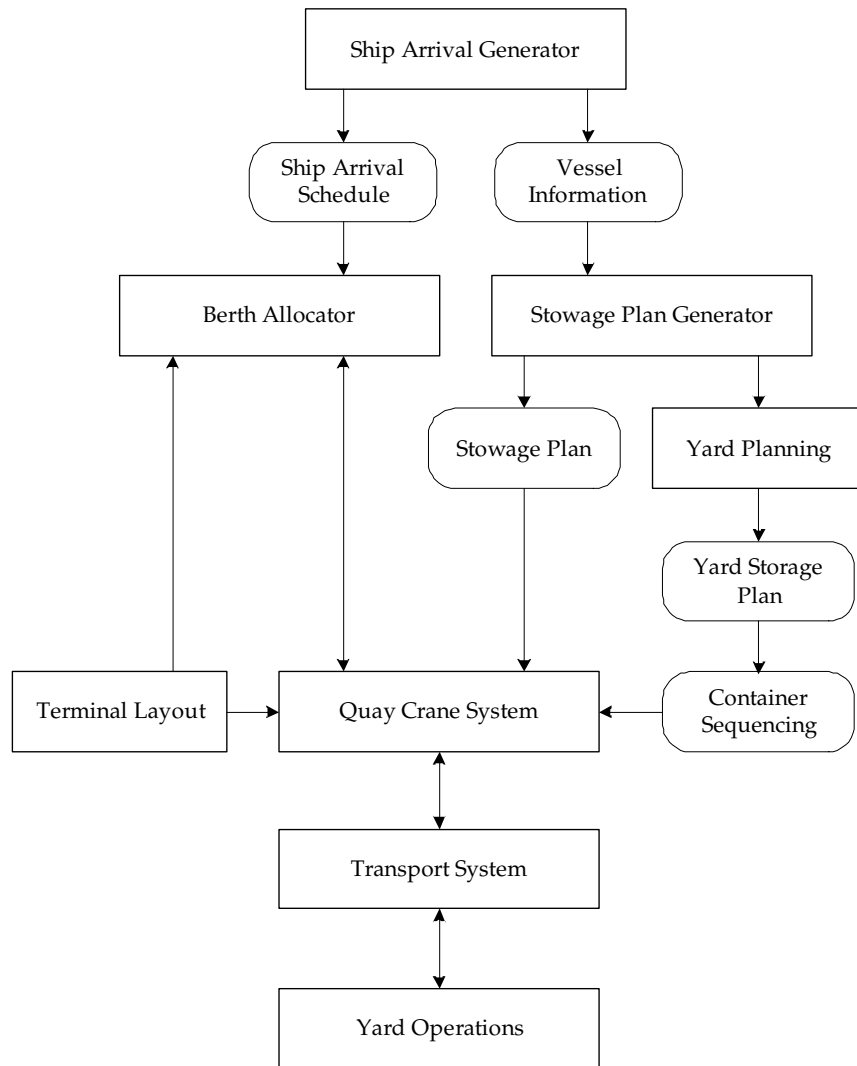


Figure 1. Relationship between modules

The model is designed and developed in a framework that supports modularity, generality and a multi-resolution level of detail. All the major container terminal activities are modeled and are separated into sub-models that can be swapped out and replaced by newer versions. In addition, decision logic is modularized into “control” sub-models so that current logic can be replaced by new logic to facilitate the evaluation of different handling policies at the desired level of details.

### **Modularity**

For example, the decision logic for assignment of Prime Movers and Cranes to work will be localized in one or a short list of functions. With this framework, the user may easily change the decision logic in the future, for purposes of experimentation and analysis, without changing the remainder of the model, and indeed, without having to understand the remainder of the model at the code level. All decision logic, for job assignment, deployment, routing and other key aspects of port operation, will be modularized and documented. The concept of sub-models is to allow for the ease of replacing sub-models with newer sub-models providing the means to modularize code and functions for ease of maintainability and updating.

### **Generality and flexibility**

The model's logic will support modified or new layouts for the yard and vehicle paths. In addition, all numerical data will be in external data files that can be manipulated in Excel, Access, or any other software. In addition, the simulation model can be driven with realistic arrival patterns for evaluating the handling capacity of container terminals. The input data that drives the model includes

- 1) Equipment Type. For example, type of Quay cranes ("QC") based on different types in terminal
- 2) Equipment Number. For example, Number of QCs or Number of RTGs.
- 3) Equipment Settings. For example, timing parameters like crane trolley speed, aiming time of crane.
- 4) Number of Ground Slots in Yard. This is the Number and position of ground slots in the yard that can be used for container storage.
- 5) Maximum yard stack height. How high containers can be stacked in the yard.
- 6) Incoming Vessel Traffic. Based on user pre-specified vessel mix and throughput requirements, corresponding sets of vessel traffic are accordingly generated for the simulation runs. The relevant traffic can then be chosen by the user for each simulation run.

By varying the input parameter values, different scenarios may be created for capacity estimation.

To evaluate whether a terminal is able to handle a certain capacity, there are two ways to increase the vessel traffic to test out the Terminal Capacity:

- i. Increasing Services' TEUs/Call
- ii. Introducing new Services

A combination of options (i) and (ii) is chosen as the method for increasing container traffic as it is the most realistic case.

### **Multi-resolution**

With ACTS, the entire sub-models may be "swapped out" and replaced by other "plug-ins", that is, by a newer sub-model based on new and improved logic. The different components of the terminal simulation can be run at different levels of detail. For example, if a particular analysis focuses on yard operations, a high-resolution component for yard module is plugged in while lower resolution versions are used for the quay and transport modules. This feature allows the user to easily zoom in to the required areas of interest.

### **Other features**

ACTS also enables collection and visualization of a wide range of statistics for gauging the effect of changing particular input parameters on the terminal performance e. g. terminal performance figures like throughput, BOA, vessel rates; and equipment performance and utilization figures. Using the model, the operator was able to run simulations with varied input parameters and observe the collected statistics, so as to assess the performance and capacity of the terminal and to obtain useful insights into the bottlenecks and inefficiencies of their operations.

In summary, the model will be a "template" model that is general, adaptable and as easily modifiable by the user as possible.

## **IV. Utility of ACTS**

A simulation tool of such magnitude for container terminal, which integrates the entire set of operations in a container terminal, does not currently exist. The tool is not for a one-time design of terminal. Port operators can use ACTS at any stage of their business cycle to assist in critical decision making processes.

### **Initial Port Design and Setup:**

Container terminals cost hundreds of millions of dollars to build, taking into account the cost of land space, cranes, vehicles, berthing area, storage structures and other infrastructure. Clearly, there should be a strong basis for such new investment. Simulation helps in choosing the best terminal design and setup, thus potentially leading to huge savings. ACTS can be used to evaluate new layouts, designs and equipment on the drawing board, before undergoing a field test. Millions of dollars of investment could be saved if, for instance, the number of cranes required is reduced by 1.

### **Long Term Planning:**

To improve efficiency of operations and to cater to the ever-increasing throughput requirements, port operators constantly need to innovate, plan for the future and cut costs. The tool can help in:

- Terminal Capacity Estimation: it helps to answer questions like *"what is the maximum throughput the current terminal resources can provide?"* or *"if we were to try and achieve such and such throughput with the given resources, what would be the impact on vessel waiting time and other performance indicators?"* The goal of the capacity analysis is to determine the highest annual throughput a container terminal can sustain without decrease of service level, based upon the detailed vessel and gate arrival information and operating parameters. The capacity analysis predicts average and peak demand for various resources in the terminal, including berths, yard space, quay cranes, yard cranes, and container carriers such as prime movers. The quantitative analyses suggest guidelines for adequate allocation of resources for port design and identify the bottleneck for port planning evaluation.
- Terminal Upgrade or Expansion, new types of container handling equipment might need to be evaluated. The tool can provide accurate estimates of the expected performance improvements using the new equipment, suggest the appropriate number of equipment to purchase to achieve a desired level of performance and also provide the impact on related statistical figures like Cost/TEU.

- Performance Analysis: The goals of the performance analysis are to assess the productivity of the terminal from an integrated view and to identify and diagnose problems, if any, caused by the operations planning. The performance analysis simulates the detailed operations of individual containers at both quayside and yard-side to test the terminal's response to predefined operating scenarios, such as forecast vessel and container volume, or estimated gate arrival patterns. Issues addressed in the analysis can include:
  - Terminal layout
  - Traffic flow design and congestion detection
  - Equipment type and performance
  - Equipment deployment logic
  - Space (including berths and yard) allocation efficiency
  - Other work rules and schedules
  
- Resource Analysis: Resource analysis zooms into the usage of a particular type of resource, such as berth, yard, or cranes, and aims to assess the assignment logic and/or to compare alternative assignment patterns so as to help improve efficiency. Typically the assignment of the following resources can be evaluated:
  - Berth
  - Quay crane
  - Yard
  - Yard crane
  - Container carriers
  
- Incorporating New Operational Policies: you may evaluate new ideas for improvement in operational policies such as yard stacking / clustering, vehicle deployment, crane deployment and scheduling.

Operations Planning for Short Term:

ACTS assists in short term planning and enables the operator to evaluate how different options would affect the productivity and which would be the most suitable option to undertake. This could potentially save the port operators millions of dollars in recurring operating costs.

- Resource deployment: The tool can look ahead a few shifts and based on expected terminal activity, estimate what would be the number of equipment (quay/yard cranes, prime movers) to be deployed for those shifts. This will help in cutting down excessive resource usage costs (fuel, wear and tear and manpower).
- Bottleneck detection: Simulated scenarios can indicate bottlenecks in operations. For example, the system can predict possible crane clashes and feedback to the operator so that changes in the crane split can be made.
- Live Simulation: It is also possible to connect live data to the simulation tool by interfacing with current planning systems. In that case the simulation will perform runs using actual live terminal input like yard status, vessel stowage etc. and can give useful predictions about where bottlenecks may arise e. g. it can predict potential crane clashes or vehicle congestion in the yard or need for heavy yard shifting.
- Simulation-based training: Novice planners can be trained using ACTS, whether it be yard, ship or resource planning. Planning done by trainee planners can be fed into the simulation system where the planner can then observe the efficacy of his plans.

Except for ACTS, no tools seem to exist in the market today to assist the port operator in the spectrum as described above. Tools existing are used by port consultants in the design and analysis of ports but are not available for the port operator to use in later stages of their planning and operations.

It will help port operators answer the following oft-asked questions:

- What is the best operation for us on this site?
- What is the maximum throughput our terminal can sustain?
- Should we expand into a larger area or increase the density of our operation?
- As volume increases, what part of our facility will become a constraint first?
- How can we take advantage of new technology, and how can we know what the operation will look like if we incorporate it?

n How do we remodel this facility to make it more efficient?

Since ACTS runs an integrated simulation model, it can model each stage in the container handling chain. In addition to using the tool as a complete simulation model, individual parts of the chain can be used independently for planning purposes. For example, the berth allocation module can be used to allocate berths to actual incoming vessels. Similarly, standalone modules for stowage planning, crane allocation and yard allocation can also be made available.

ACTS can assist in improving operational efficiency and will help to reduce costs by cutting down on excessive equipments and improving handling policies.

## **V. Test-bedding of ACTS**

The ACTS team has applied its simulator to two independent container terminals in South-East Asia to showcase the capability of the ACTS tool, through a real-life example. The purpose was to illustrate how a port operator can potentially use ACTS to construct a dedicated model for the purpose of conducting capacity estimations and planning exercises.

The customized simulation model was based on the existing container terminal in terms of layout, traffic lanes, yard setup and quayside setup. In addition, the operational policies incorporated into the model were those used in the day-to-day planning activities by the operators. The simulation model was made as reflective of the terminal's current operations as possible. Thus the same terminal resource settings and the same operational policies were used.

The vastness and complexity of container terminal operations at times led to unavailability of accurate data and hence certain simplifying assumptions were made during the modeling process, without loss of modeling accuracy. Additionally, numerous operations at terminals need human intervention under critical situations, and modeling this abstract human intelligence was a challenge. Nevertheless, the key performance results when compared to the actual terminal results were found to be matching within acceptable limits (the difference is 5%-10%) and hence the model was affirmatively validated by terminal operators (users).

The validated model was then used to conduct the capacity estimation study. The objective was to determine the maximum throughput the terminal's current terminal resources could handle. The terminal was determined to be unable to handle a certain throughput when the storage yard ran out of space, or the service level downgraded to an unacceptable level. To find the terminal capacity, the vessel traffic is increased in a recursive-doubling and recursive refining fashion. For example, assume the current total throughput from the vessel traffic is  $a$ . The simulation model will try  $a + b$ ,  $a + 2b$ ,  $a + 2^2b$ , with  $b$  as the first increment step. If the model finds that  $a + 2^2b$  is not sustainable but  $a + 2b$  is, then the mid point between  $a + 2b$  and  $a + 2^2b$  will be evaluated, etc. Having identified the terminal's current capacity, it was also evaluated how much additional resources of different types would be required to achieve target throughputs forecast for the future.

Based on the results of the study, ACTS helped to identify the operational efficiency of the terminal and to evaluate the terminal capacity. Recommendations and guidelines were provided to the terminal to help them enhance their capacity. The increase performance and service levels were also verified through simulation.

## **VI. Conclusion**

ACTS (or Adaptable Container Terminal Simulator), as the name suggests, can be used to simulate the complex container terminal operations for the purpose of terminal design, capacity planning and operations planning. It can simulate the entire multitude of terminal operations down to the box level and being modular and flexible, also provides a multi-resolution level of detail for its various components. ACTS can be used to model and simulate terminals of any reasonable magnitude. ACTS provides several standard ready-made design templates of the component modules for users to configure into a running system. The system comes with a comprehensive easy- to-use graphical user interface enabling even the casual user to conveniently use the system. ACTS was applied to two container terminals and was found to be effective in replicating real-world operations and in conducting capacity evaluations to enhance terminal capacity and operational efficiency. ACTS, the tool customized for simulating container terminal operations, is now available for wide applications.

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