PORTSIM 6.0: A PORT SIMULATION MODELING MULTIPLE MODES OF OPERATION

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ABSTRACT
The PORTSIM tool is used to analyze the movement of military cargo through seaports used by the Defense Transportation System (DTS). The current development version, PORTSIM v6.0, assists analysts within the Surface Deployment and Distribution Command – Transportation Engineering Agency (SDDC-TEA) to compare and select ports for military cargo movement based on their capabilities and develop deployment/redeployment strategies. It supports modeling both the Seaport of Debarkation (SPOD) and Seaport of Embarkation (SPOE) modes of operation within a single model. It can also model concurrent SPOD and SPOE flow through a single seaport. PORTSIM supports programmable processes, allowing analysts to input processes at simulation run-time without requiring a software modification or recompile. PORTSIM v6.0 is an important tool in the decision-making process, used to improve the efficiency and throughput of military deployment or redeployment operations. The capabilities of PORTSIM v6.0 are also flexible allowing the modeling of any cargo terminal (airport, rail yard, etc).

Keywords: Discrete-event simulation, Port simulation, Programmable processes, decision support system.

1. INTRODUCTION

PORTSIM (Port Simulation) is a discrete-event simulation used to analyze the movement of military cargo through worldwide seaports used by the Defense Transportation System (DTS). The PORTSIM tool supports analyses by the Surface Deployment and Distribution Command – Transportation Engineering Agency (SDDC-TEA), component of USTRANSCOM at Scott AFB, IL. PORTSIM assists SDDC-TEA analysts study cargo throughput and latency within a seaport, identifying bottlenecks in terms of resources and infrastructure allowing them to refine their strategies for movement of a set of materiel through a selected seaport.

The current development version, PORTSIM v6.0, developed by MYMIC LLC, integrates the various components of the PORTSIM tool, some developed by other organizations, into a single integrated model, while providing major enhancements in capabilities over previous versions. PORTSIM v6.0 models the resources and infrastructure within a seaport (including terminals and operational areas), and supports the configuration of an individual seaport according to its characteristics. PORTSIM models the competition for resources (cranes, drivers, etc.) and infrastructure (berth space, staging space, etc.) by cargo and transports within a seaport. PORTSIM supports programmable processes. Processes are provided as a run-time input to the simulation. Previous PORTSIM versions captured processes within the simulation software code, requiring a rewrite and recompile whenever modifications were required. PORTSIM supports modeling different modes of operation, such as Seaport of Debarkation (SPOD) and Seaport of Embarkation (SPOE) within a single model. It also supports concurrent SPOD and SPOE flow through the same seaport.

Section 2 identifies the problem under study, Section 3 provides a complete description of the PORTSIM system architecture, Section 4 identifies other application areas for PORTSIM and Section 5 briefly describes related work in this field.

2. PROBLEM STATEMENT

Transportation logistics planning is used extensively to prepare for the movement of military cargo, i.e., troops, equipment, and supplies, from a military installation to a theater of operations. The initial input of troops into a theater of operations is usually by air. After this initial input, the movement of military cargo, both to support military operations and to sustain the existing force, is by sea, usually through a commercial seaport. For a variety of reasons, both political and economic, only a portion of an entire seaport is available for military operations. Planning for these operations involve modeling the Seaport of Embarkation (SPOE) mode, which includes ships being loaded at a seaport with cargo arriving via convoys, trucks and trains as shown in Figure 1. These ships are then transported to a distant seaport where cargo is offloaded using the Seaport of Debarkation (SPOD) mode of operation, shown in Figure 2. Previously, separate tools were used by SDDC-TEA to study these 2 modes of operation and were inhibited by the lack of inter-operability between the tools, the disparate requirements for the input data, the level of fidelity within the tools and the output data produced after a simulation run. PORTSIM v6.0 provides SDDC-TEA with the ability to concurrently study the SPOD and SPOE modes of operation, using the same level of fidelity and identical input and output data formats.

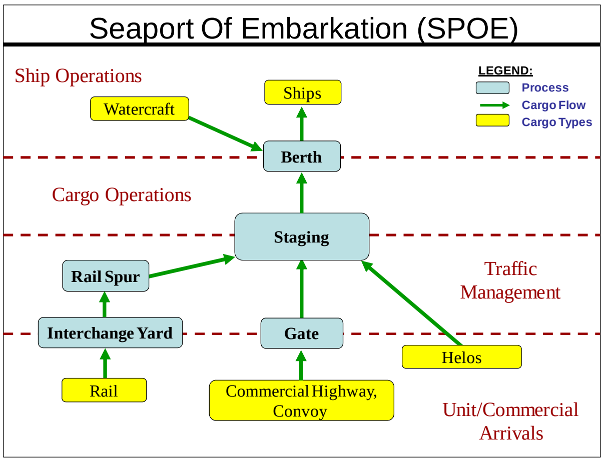

Figure 1. Seaport of Embarkation (SPOE) Operation

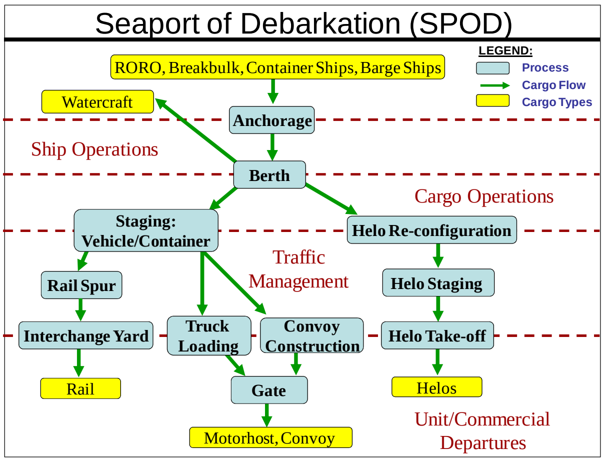

Figure 2. Seaport of Debarkation (SPOD) Operation

Moreover, for extended military operations, it is possible that the flow of cargo from the theater of operations back to an installation will begin before the flow into the theater of operations has ended, with some military units starting returning to the U.S., while other units are still being deployed. Additionally, following the initial surge of military equipment and personnel into a theater, cargo supplies needed to sustain the existing force often constitute a major portion of the continuing cargo flow. This results in a bi-directional flow of cargo and resources, with cargo moving in both directions competing for limited resources and infrastructure within a given seaport. Proper resource and infrastructure allocation is important in any transportation logistics operation. It is critical to ensure that the flow of cargo in one direction does not unnecessarily delay, or worse, block the flow of cargo in the opposite direction (Mathew 2002). Therefore, resource and infrastructure allocation between the concurrent flows of cargo, as well as the resolution of any contention that might arise, is vital. PORTSIM v6.0 facilitates this type of study condition through its ability to model concurrent SPOD and SPOE operations within a single port. This allows analysts to study the operational requirements for both modes and the impact of simultaneous execution of one mode on another.

3. MODEL DESCRIPTION

This section provides a complete description of the PORTSIM model. The model was developed to satisfy the following requirements identified by SDDC-TEA:

- ***Nodal Cargo Terminal Architecture:*** An individual cargo terminal should have the ability to be initialized independent of other cargo terminals. The cargo terminals should also be reconfigurable, that is, the infrastructure and the resources in the cargo terminal as well as the sequence of cargo flow through the areas in a single terminal should be changeable. The model should also support the initialization of multiple cargo terminals simultaneously as well as the flow of cargo between them, enabling the simulation of an end-to-end cargo flow from point of origin to destination.
- ***Programmable Processes:*** The processes within the model should be programmable by an analyst.
- ***Concurrent SPOD and SPOE operations:*** The model should support concurrent POD and POE operations through a single cargo terminal.
- ***Non-proprietary simulation executive:*** The model should utilize a non-proprietary simulation language as its underlying executive.
- ***Simulation of 1,000,000 pieces of cargo:*** The model should support the simulation of over 1,000,000 pieces of cargo within a reasonable execution time.

Moreover, SDDC-TEA identified the following performance requirements:

- Operate on a PC, minimally 2 GHz with 2 GB of RAM.
- Handle at least 30 multiple runs on the same scenario for statistically meaningful results.
- Capable of executing experiments involving on the order of 150 variations.
- No significant performance degradation compared to legacy versions.

The performance requirements mandated that a single PORTSIM run, with a standard cargo load of about 25000 pieces of cargo take no more than 19.2 seconds.

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The PORTSIM v6.0 tool is shown in Figure 3. The tool accepts scenario data from different databases. The *Transports* database provides information about trucks, trains and ships, while the *GIS* database provides information about the seaport under study. Process flows, developed using the PPFN language (described in Section 3.2), are provided as input during simulation run-time.

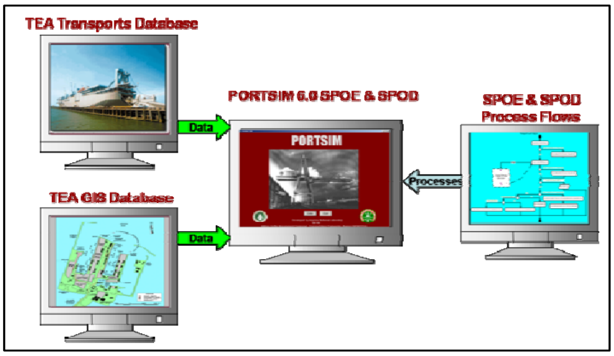

Figure 3. PORTSIM v6.0

The PORTSIM system architecture is shown in Figure 4. The characteristics of the seaport, including operational areas, infrastructure, and resources are provided as input to the simulation along with routing information to support simulating the movement of cargo through the seaport via XML files. Process flows are also passed to the simulation kernel via text files.

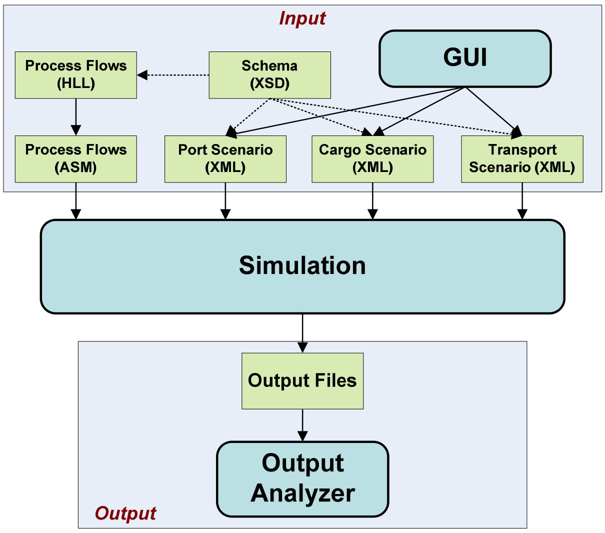

Figure 4. PORTSIM System Architecture

3.1. Nodal Cargo Terminal Architecture

The architecture is defined as a network of nodes, each node defined by processes. A node could also potentially represent a whole other network of nodes. This allows a hierarchical structure where individual nodes are defined either by a new network (network nodes) or by the internal processes performed on the cargo and transports. The capacities and capabilities of individual nodes are programmable, and so are the processes within them. The architecture is configurable to support different port types, different individual ports, different cargo types, and different transport types. A network node may define a seaport, a terminal within a seaport, or an operational area within either the seaport or a terminal. Sets of terminals in a seaport could handle ports that are made up of individual terminals, for example the Port of Hampton Roads which itself includes multiple terminals, such as Norfolk International Terminal, Portsmouth Marine Terminal, Lambert's Point Docks, etc. Each terminal itself is defined in terms of port areas: the berths, staging, and loading areas within a seaport. Multiple network nodes, each modeling a complete seaport in itself, can be connected together to model an end-to-end cargo flow from a point of origin to a destination.

The architecture also supports routes through the network. A route is defined by a starting node, a destination node, and a sequence of nodes traversed en route. An important approach to avoid infinite queuing in the interconnection segments is that a node must request the next node in the route before advancing. This provides a level of flow control to aid in the avoidance of deadlock.

3.2. Programmable Processes

Processes within PORTSIM are programmable, unlike many applications where processes are hard coded within the simulation. The Programmable Process Flow Network (PPFN) supports defining processes that are input into PORTSIM during simulation run-time (Mathew and Leathrum 2008). PPFN is a process flow programming language that describes the process activities at a cargo terminal. Previous versions of PORTSIM were implemented in the MODSIM simulation language and processes were an integral part of the simulation code. Once the processes were programmed and the code compiled, the processes were static in nature and any change in processes required modification to the simulation code; this could not be done by an analyst. PPFN provides an analyst the ability to modify processes independent of the simulation and provide it as an input to the simulation in the same way other data is input; this makes the tool more responsive to changes in requirements. Moreover, port Subject Matter Experts (SMEs) view operations within a cargo terminal in terms of processes that must be performed in a given situation. PPFN provides an intuitive approach to capturing these processes for PORTSIM. PPFN provides a process-oriented interface (in terms of flowcharts) for a discrete-event simulation, with processes being defined as sequences of activities and decisions.

PPFN is partitioned into a high level language and an assembly language. Processes are developed using the high level language, which contains programming control structures commonly found in standard programming languages. There is usually a one-to-one relation between the activities in the flowchart and the structures within the high-level process flows. The high-level language is translated into assembly language instructions by a *Translator*; these correspond to data structures internal to the simulation. During run-time, the assembly-level instructions are provided as input to the simulation; they are interpreted by a *Virtual Machine* within the simulation kernel. The *Virtual Machine* interacts with the cargo terminal architecture within the underlying simulation through a static declaration file defined in the XML Schema Definition (XSD) format; it contains definitions for types, modes, resources, and infrastructure. This structure is shown in Figure 5. The programmable processes provide analysts complete control of the simulation processes, enabling PORTSIM execution given an appropriate set of process instructions. This approach also allows PORTSIM to model military or commercial logistics, at any cargo terminal.

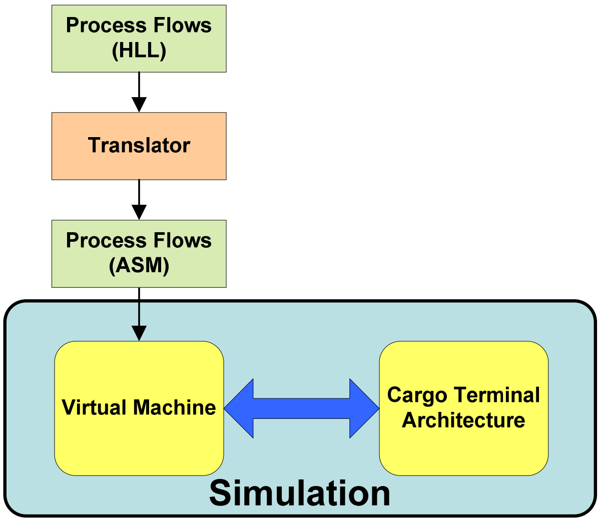

Figure 5. PPFN Structure

3.3. Programmatic Events

Programmatic events allow an analyst or an external disruption model to program unusual events to occur at specific simulation times. These events can change the available resources, capabilities of infrastructure and processing and transit times (specified as simulation input) within a seaport during simulation run-time. For example, an analyst can program a new berth to become available on day 20, instead of day 0. This allows PORTSIM to interface with other disruption models, to portray the effects of disruptive events on seaport operations, i.e., allowing the capability of the seaport to be degraded as a result of a disruptive event and then be gradually restored over time (Leathrum, Mathew, and Mastaglio 2009).

3.4. Output Analysis

PORTSIM models cargo and transports at the individual entity level and the data collected during a simulation run (or iteration) can be used for extensive after-action reporting and visualization. Data capture within PORTSIM is completely programmable and is part of the processes input at simulation run-time. Data can be captured at the entity-level as well as at an aggregate level. This data is captured during a simulation run using text, .csv and .xml files and passed to the PORTSIM Output Analyzer. The Output Analyzer generates various charts and graphs used by analysts to study the results of an iteration. The Output Analyzer currently captures information about the following:

- Throughput for the seaport, terminal and individual operational areas.
- Average processing times for cargo and transports in individual operational areas.

Since data capture is programmable, any relevant data can be captured during PORTSIM execution and the Output Analyzer can be modified to process and display the new data.

For any simulation, sufficient independent and identically distributed (IID) iterations of a particular scenario needs to be performed (30–60 runs are normal) to ensure the precision and reliability of the statistics being calculated. PORTSIM is a terminating simulation and inherently supports a multiple iteration capability so that a single scenario can be executed any number of times. PORTSIM captures pertinent information about each individual iteration and the total number of iterations as a whole. For every new iteration, PORTSIM calls a new instance of itself before terminating and passes on the last random number drawn from the predefined random number stream thereby continuing the random stream.

3.5. Simulation

PORTSIM is capable of simulating over a million pieces of cargo at an entity level of detail. The PORTSIM simulation kernel is a high-performance simulation model capable of simulating the flow of over 25,000 pieces of cargo through a seaport in under 6 seconds and a million pieces of cargo in under 50 minutes, comfortably meeting its performance requirements. PORTSIM execution times for different cargo loads are shown in Figure 6. The execution times are nearly linear, which implies that these times are a directly related to the number of pieces of cargo being processed. The PORTSIM simulation kernel was developed as an ANSI Standard C++ implementation. The underlying simulation engine used is a C++ implementation of the Distributed, Independent-platform, Event-driven, Simulation Engine Library (DIESEL) (Mathew 2007), a non-proprietary simulation executive model.

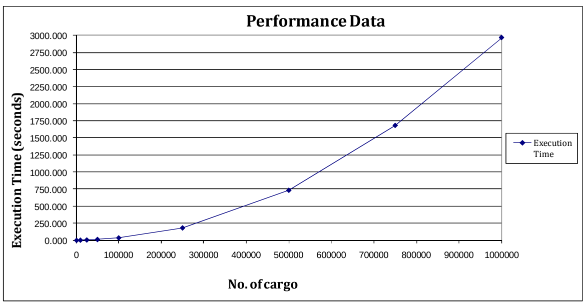

Figure 6. PORTSIM Execution Times

The PORTSIM system is designed for portability across alternative computing systems. The simulation kernel is separate from the I/O user interfaces. Simple text files and industry-standard XML and XSD files are used to handle data-passing between the kernel and the different interfaces. The user interfaces (the GUI and the Output Analyzer) are easier to develop with code specific to a computer platform. The simulation kernel can be ported to any platform using an appropriate C++ compiler.

4. OTHER APPLICATION AREAS

The capabilities of the PORTSIM system have applicability beyond modeling military cargo flow through a seaport. These capabilities can be utilized for a variety of studies as described below.

4.1. Modeling Commercial Operations

The programmatic process capability described in Section 3.4 can model commercial operations with a seaport. Commercial shipping activity differs from military operations in terms of types of cargo being moved and the methods for processing each cargo type. The programmable process capability allows different processes to be defined for different seaports. Additionally, concurrent SPOD and SPOE operations are a vital component of commercial operations, where ship loading activity has a direct impact on ship offloading capability.

4.2. Modeling Disruptive Events

PORTSIM can be used to study the effects of disruptive events -- natural ones, such as earthquakes, hurricanes, or man-made events such as terrorist attacks or chemical/biological accidents -- on normal operations within a seaport. The programmatic event capability described within Section 3.3 introduces events into the simulation that alter the capabilities of different resources and infrastructure within a seaport and/or change behavior of entities. Analysts can program these events to occur at specific times during a simulation run. The scenario defined can then be used to study different strategies, both proactive and reactive, to deal with such disruptive events in order minimize the effect of these types of events on seaport operations. An initial study using this capability is described in (Leathrum, Mathew, and Mastaglio 2009).

4.3. Evaluation of New Technologies

PORTSIM can be used to study the potential impact of new technologies that have not been developed as yet. The user-programmable and generic nature of the architecture makes it easy to define new technologies, such as new resources in terms of their capabilities. This capability will support the refinement of requirements for future technologies able to support a deployment or redeployment operation. A study using this capability to analyze the potential impact of a new Theater Support Vessel on a Joint Logistics Over the Shore (JLOTS) operations is described in (Leathrum, Mielke, Frith, and Mathew 2002).

4.4. Networks of cargo terminals

PORTSIM can model the end-to-end flow of cargo at an entity level, from multiple US-based installations to a set of destinations within a theater of operations located anywhere in the world in the form of a nodal network. PORTSIM models the resource and infrastructure allocations and competition within each node in the network, as well as between the nodes, to identify conflicts that may arise. Since the underlying PORTSIM architecture is hierarchical in nature and is completely configurable and programmable, the same architecture that is used to describe a seaport can be used to link together different cargo terminals, even those with different transportation modes, into a single integrated scenario. Used in this fashion, PORTSIM can model any type of cargo terminal (airport, rail yard, inland port, or distribution center), whether military or commercial. For an airport, the terminals could be partitioned into the cargo terminal and the passenger terminal, with multiple possible passenger terminals. The runways would then be defined as another port area at the port level. An initial prototype for modeling end-to-end logistics is described in (Mathew, Leathrum, Mazumdar, Frith, and Joines 2005).

5. RELATED WORK

Transportation logistics planning for military operations has been captured in a variety of simulation tools. These tools model the cargo terminals (points of origin and destination, intermediate transfer points for transportation mode changes and/or points of intermediate storage) within the DTS, as well as the transportation infrastructure connecting these terminals. Examples of cargo terminal models include *TRANSCAP* (Burke, Love, Macal, Howard, and Jackson 2000), which models offloading at installations, *TLoads* (Hamber 2001) which attempts to assess the capability of tactical and sea-based distribution systems and *POPS* (Snyder and Henry 1987) that estimates the capability of a seaport to handle military cargo at an aggregate level. Past work at modeling the actual transportation segments of the DTS, include *ELIST* (Braun, Lurie, Simunich, Van Groningen, Vander Zee, and Widing 2000) which models theater rail and highway infrastructure, and *MIDAS* and *JFAST* (Mckinzie and Barnes 2004) which model the strategic lift segments. However, none are stochastic models. These models study the restrictions of the transportation infrastructure rather than the flow of cargo through the cargo terminals. They also aggregate the cargo, often dealing with it as quantities in terms of weight, bulk size, or number of pieces, rather than individual items. The *AMP* model (Stevens, Tustin, and Key 2004) acts as a shell to interconnect these models into an end-to-end logistics model, but at a low level of fidelity, again focusing more on the links than the nodes within the network.

PORTSIM models the different cargo terminals represented by the models mentioned before at a very high level of fidelity. PORTSIM however, models the transportation infrastructure between terminals at a low level of fidelity, by representing the transit between terminals as a transit time. Outputs from the MIDAS, JFAST and ELIST models can be used to derive accurate values for these transit times.

6. CONCLUSION

The PORTSIM development has implemented a programmable process input, entity based model of cargo approach to satisfy the requirements of analysts planning a military deployment or redeployment. Its architecture, design, and implementation approach provide a scalable and reusable capability to model any type of port operations, irrespective of end user and type of port facility. PORTSIM is a flexible approach to modeling nodal logistics operations that can be used not just for individual ports but also to capture networks of ports while still providing detailed results down to the individual cargo items level.

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