The Navigation Economic Technologies Program

July 2006

NETS

navigation · economics · technologies

DEVELOPMENT OF COMMODITY-DRIVEN VESSEL MOVEMENTS FOR ECONOMIC ANALYSIS OF PORT IMPROVEMENTS

US Army Corps
of Engineers®

IWR Report 06-NETS-P-02

Navigation Economic Technologies

The purpose of the Navigation Economic Technologies (NETS) research program is to develop a standardized and defensible suite of economic tools for navigation improvement evaluation. NETS addresses specific navigation economic evaluation and modeling issues that have been raised inside and outside the Corps and is responsive to our commitment to develop and use peer-reviewed tools, techniques and procedures as expressed in the Civil Works strategic plan. The new tools and techniques developed by the NETS research program are to be based on 1) reviews of economic theory, 2) current practices across the Corps (and elsewhere), 3) data needs and availability, and 4) peer recommendations.

The NETS research program has two focus points: expansion of the body of knowledge about the economics underlying uses of the waterways; and creation of a toolbox of practical planning models, methods and techniques that can be applied to a variety of situations.

Expanding the Body of Knowledge

NETS will strive to expand the available body of knowledge about core concepts underlying navigation economic models through the development of scientific papers and reports. For example, NETS will explore how the economic benefits of building new navigation projects are affected by market conditions and/or changes in shipper behaviors, particularly decisions to switch to non-water modes of transportation. The results of such studies will help Corps planners determine whether their economic models are based on realistic premises.

Creating a Planning Toolbox

The NETS research program will develop a series of practical tools and techniques that can be used by Corps navigation planners. The centerpiece of these efforts will be a suite of simulation models. The suite will include models for forecasting international and domestic traffic flows and how they may change with project improvements. It will also include a regional traffic routing model that identifies the annual quantities from each origin and the routes used to satisfy the forecasted demand at each destination. Finally, the suite will include a microscopic event model that generates and routes individual shipments through a system from commodity origin to destination to evaluate non-structural and reliability based measures.

This suite of economic models will enable Corps planners across the country to develop consistent, accurate, useful and comparable analyses regarding the likely impact of changes to navigation infrastructure or systems.

NETS research has been accomplished by a team of academicians, contractors and Corps employees in consultation with other Federal agencies, including the US DOT and USDA; and the Corps Planning Centers of Expertise for Inland and Deep Draft Navigation.

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www.corpsnets.us

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Abstract

Coastal ports operate through the interactions of shippers, carriers, dock owners, operators, pilots and the various governmental agencies responsible for maintaining and operating channels for safe and efficient movements. Monte Carlo simulation models of vessel movements in ports can be useful in determining the value of improvements such as channel widening or dredging. Such models require, among other things, input that describes the random arrival of vessels at the port. A method of generating synthetic fleet forecasts for Monte Carlo simulation models, consistent with historical and expected future fleets and commodity forecasts has been developed as part of a suite of navigation planning tools developed by the U.S. Army Corps of Engineers (Corps). The suite includes: the HarborSym Monte Carlo simulation model; the HSAM visualization/animation tool; a database structure for storing historical and synthetic vessel calls at a port; a set of statistical analysis tools that operate on data describing historic vessel port calls; and a commodity-driven forecast tool and synthetic fleet generator. The elements of the tool suite are described, with emphasis on the VCDB and the commodity-driven forecast tool. The tool suite development is a component of a major Corps research and development initiative on Navigation Economics Technologies (NETS) that is developing state-of-the-art research and tools for analysis of inland waterways and deep draft navigation.

Sommaire

Le bon fonctionnement des ports côtiers dépend des expéditeurs, porteurs, propriétaires de quais, opérateurs, pilotes, ainsi que des diverses agences gouvernementales responsables de la maintenance et de la mise en œuvre des canaux afin d’assurer que leur mouvements soient sûrs et efficaces. Les modèles de simulation de Monte Carlo des mouvements des navires dans les ports peuvent être utiles pour déterminer les bénéfices rendus possibles par l’élargissement de canaux ou le dragage. De tels modèles sont basés, entre autres, sur des données qui reflètent l'arrivée aléatoire des navires au port. Le Génie Civil Américain (US ARMY Corps of Engineers) a développé une méthode pour générer des prévisions synthétiques de flotte pour des modèles de simulation de Monte Carlo ; ces données synthétiques sont conformes aux données historiques et futures des flottes et charges transportées. Cette méthode fait partie d'un ensemble d‘outils de planification de navigation développés par le Génie Civil. Cet ensemble inclut : le modèle de simulation de HarborSym Monte Carlo ; l'outil de HSAM visualisation/animation ; une structure de base de données pour sauvegarder les données historiques et synthétiques des visites de navires au port ; un ensemble d'outils d'analyses statistiques basées sur des données historiques des visites de navires ; et un outil de prévision du volume des flottes basées sur le volume des charges transportées. Les éléments de cet ensemble d'outils sont décrits dans ce rapport. Sont détaillés, en particulier, l’élaboration de la base de données des visites des navires et l'outil de prévision basé sur les charges transportées. Le développement de cet ensemble d'outils fait partie d’un important travail de recherche du Génie Civil sur les NETS. Il s’agit de développer des technologies de pointe pour l’analyse des voies navigables et de la navigation a tirant profond.

Keywords: Ports, Planning, Simulation, Forecasting

1. BACKGROUND

The Corps is responsible for maintaining the navigable waterways of the United States, including ports and harbors. Any improvements to the ports that are under the jurisdiction of the Corps (channels and anchorages) must be cost-justified based on analysis of the relative benefits to navigation and the cost of the improvements. The planning horizon for such projects is typically 50 or more years, and uncertainty in variables must be taken into account. The complexities of the problem are such that the Corps has embarked upon a major research and development initiative, the NETS, to support fundamental research, data development and tools to assist Corps planners in the analysis of these problems.

The analysis of economic justification is done using a “without project” condition, i.e., the future configuration of the harbor if no improvement project is carried out, as compared to a “with project” condition, in which vessel traffic is projected based on the assumption of the new improvements being in place. Benefits resulting from such improvements are often dependent upon their effect in easing congestion due to interactions between vessels, for example by widening a channel to allow vessels to pass or by allowing deeper drafting vessels to service the port. The Corps has developed detailed economic techniques to model the impacts from changes to physical channel dimensions or in-channel vessel operating behaviors.

The Institute for Water Resources (IWR) developed the HarborSym Monte Carlo simulation model (Moser, 2004) to represent such vessel movements. This model takes as input a detailed set of historic or synthesized vessel calls at a port, including the vessel physical dimensions, arrival time at the harbor, destination dock and commodities carried onboard. This information is stored in a relational database constructed in Microsoft Access™, together with additional information on the harbor, including definition of the network, channel width and depth, and transit rules within the harbor. With this information, the model simulates vessel movements in the port, allowing for estimates of time savings and increased efficiency based on the proposed improvements. A set of existing or historical movements is used to populate the model and generate a set of initial conditions.

Examining the long run impacts of channel modifications requires consideration of any potential growth or decline in commodity movements and alterations to the fleet composition calling at the port. Because vessel calls in the future are not likely to be exactly the same as the historical pattern of vessel calls, projected vessel traffic at a port must be considered as sets of vessel calls, varying in terms of vessel size, time of arrival and commodity amounts carried. Developing a specific set of vessel calls that reflects the uncertain future conditions for use in either simulation or pencil-and-paper analyses has long been problematic for economists. A desirable approach is to start with forecasts of commodity movements at the port at 5 or 10 year intervals into the future and couple that with estimates of the fleet that can serve the port, both without the proposed improvements and with the proposed improvements. The basic concept is that a fleet resource attempts to service the shipping demands and this generates the traffic movements that can then be modeled through the HarborSym model.

In order to implement this approach in a consistent and verifiable manner, IWR has developed the Navigation Planning Tool Suite, an evolving set of statistical, forecasting and simulation tools for analysis of vessel movement in harbors. The tools, consisting of inter-related simulation modeling, database, statistical analysis and forecast capabilities, are oriented towards planning analysis for an individual deep-draft harbor, with focus on water-side considerations (channels, anchorages) as opposed to the land-side terminal operations. The tool suite is designed to allow for simulation of the impacts of alternative harbor improvements, to determine potential reductions in vessel delays and potential increases in loading and vessel capacity.

2. ARCHITECTURE

The navigation planning tool suite uses a “data-driven” approach to tool design and use. Rather than developing software that represents only a single port, with internal code that is tightly bound to the specifics of that port, the problem is generalized, such that the port structure (channels, docks, anchorages) and vessel movements can be specified in user-provided data. The information is stored within a set of structured relational databases, implemented using Microsoft Access™ and the various programs of the tool suite read from and write to the databases.

This general data-driven architecture, as applied to the Monte Carlo simulation and animation aspects of the tool suite, is shown schematically in Figure 1.

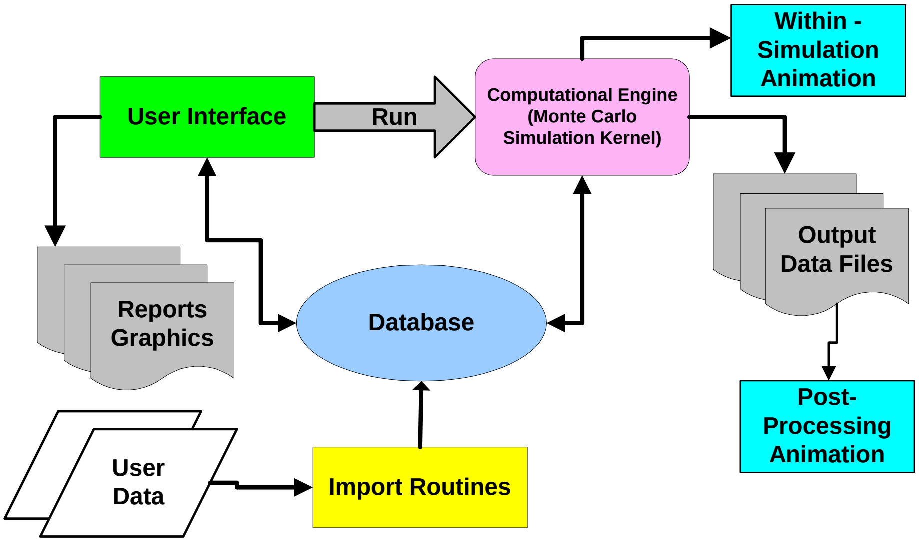


FIGURE 1
DATA-DRIVEN ARCHITECTURE

Under this structure, the needed information is stored in the central database. User data, often in the form of spreadsheets, is passed through import routines into the database. A graphical user interface allows direct data entry, editing, generation of reports and graphics, and launching of other modules such as the simulation engine or visualizations. This allows the tools to be applied at many locations. This is particularly valuable because the Corps is responsible for maintaining a large number of ports and harbors, and using a single model, where applicable, that can be easily parameterized and adapted to multiple locations is preferable to developing and maintaining separate individual models. It is recognized that not all ports share the same characteristics that need to be modeled – however, by enhancing and expanding model capabilities as new problems and opportunities present themselves, rather than developing distinct models for each new situation, the resulting general model becomes more capable and of broader applicability, and is thus more suitable for future applications at other sites.

An important feature of the architecture is the database that is dedicated to storing information on vessel movements in the port. This is referred to as the Vessel Call Database (VCDB). Each VCDB typically represents a year of vessel movements, and may contain historic or synthetic data.

Within this framework, the basic entities of the navigation planning tool suite interact as shown schematically in Figure 2. Historic data is entered into the VCDB, where it can be used to run the HarborSym model for existing conditions, for purposes of calibration and determination of delays in the "without-project" condition. The vessel call analyzer module is a suite of statistical tools, using Microsoft Access queries and the R Package for Statistical Computing, a freely-available graphical and statistics software program (R, 2005), that develops various types of reports and statistics that are useful in data checking and summarization, and in the forecasting process, including regression analyses of vessel physical characteristics and capacity of the fleet that is represented in the VCDB. These statistics are then used, in conjunction with commodity and fleet forecasts, in the forecast tool.

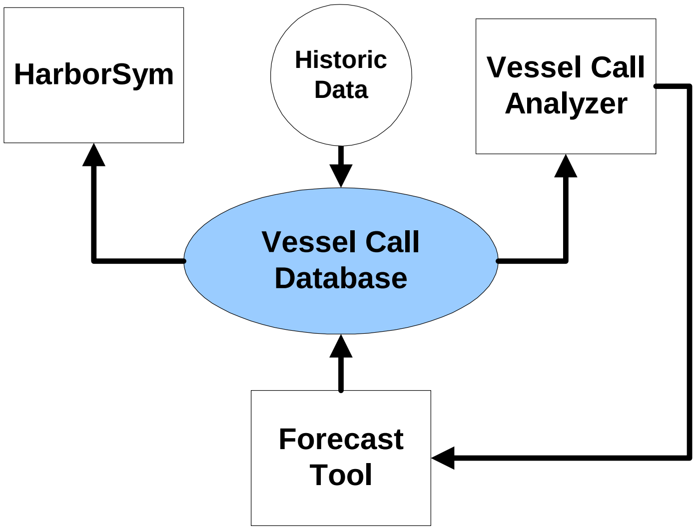


FIGURE 2
NAVIGATION TOOL SUITE INTERACTION

3. HARBORSYM

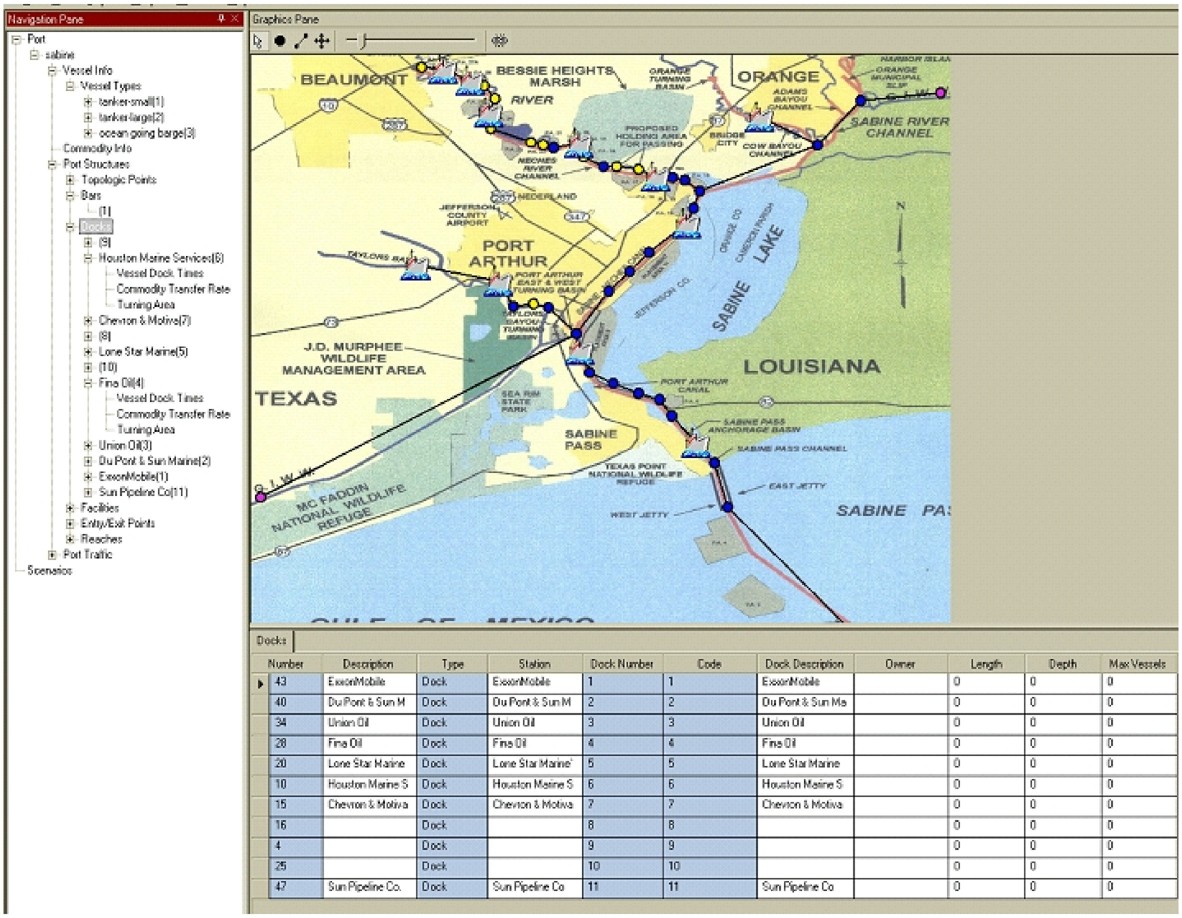
Harborsym is the simulation model component of the navigation planning tool suite. It allows the user to specify the configuration of a harbor as a tree-structured network of reaches connecting the bar, docks and anchorages. The user then selects and parameterizes rules for transit in each of the reaches from a menu of pre-programmed rules designed to cover common situations. A typical transit rule states that two vessels cannot pass each other if their combined beam width exceeds a user-entered amount. Another rule states that vessels of a user-set size are not allowed to transit a particular reach if the current in the reach exceeds a user-defined amount at the projected time of vessel transit. Rules can be applied to the port as a whole, or set for individual reaches. The user can specify if a rule is to be applied at night, during the day or at any time. A large number of rules that can be selected and parameterized by the user are embedded in HarborSym. Certain applications may require the development of new rules, which involves additional programming, but the object-oriented programming techniques and data-driven structure used within HarborSym make the addition of new rules relatively straightforward.

Once the harbor is defined, and the rules specified, the major additional piece of information required is the vessel call database. This database, described in more detail below, contains information on the physical characteristics of each vessel that services the port, each port visit, and the dock visits and commodity transfers associated with the port visit. This represents a complete description of the vessel and commodity movements that are the driving force for the simulation.

HarborSym uses the concept of a transit leg to determine when a vessel can move and when it must wait. A leg is a set of contiguous reaches from a vessel starting point (bar, dock, anchorage) to a stopping point (dock, anchorage, bar). A vessel is not allowed to stop during transit of a leg, other than to enter a turning basin. Thus, a vessel must have clear passage (no rule violations) before it is allowed to start movement within a leg.

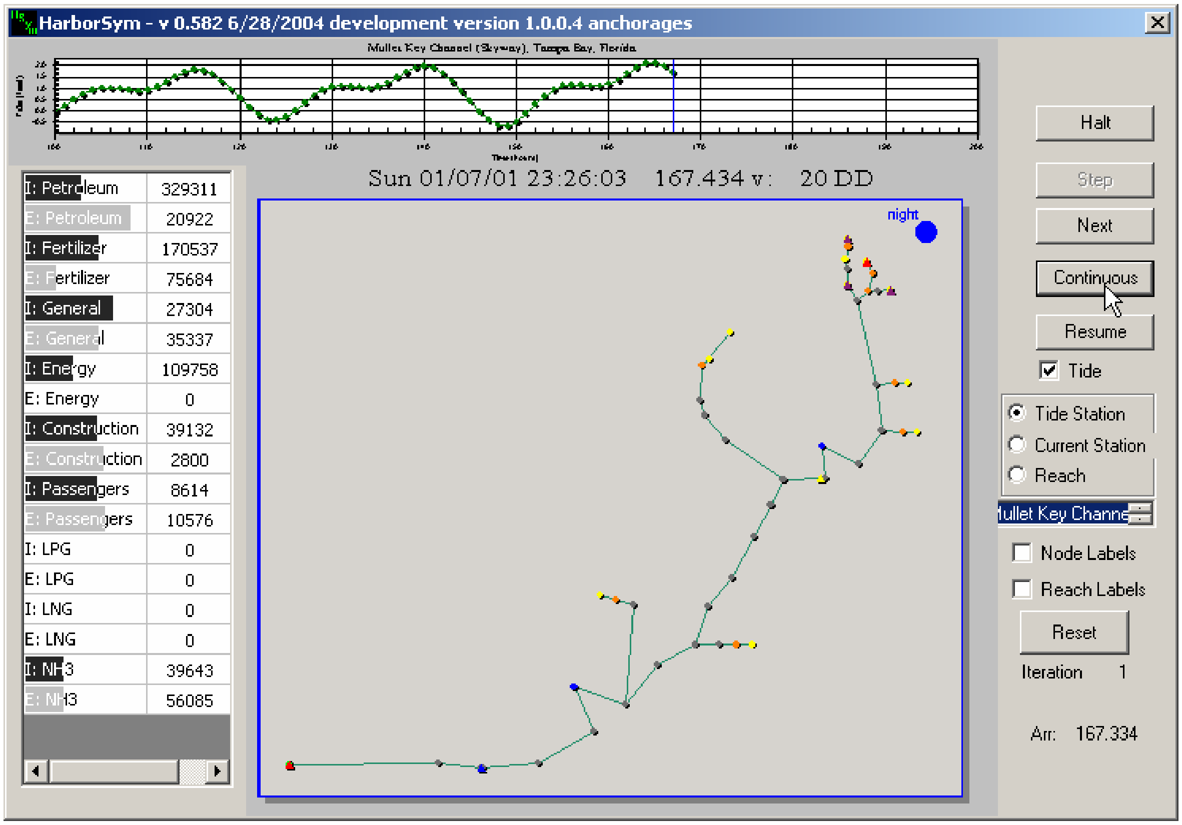
When a vessel arrives at the bar, the route through the network to the docks that are to be visited is determined and the estimated arrival time at each reach is determined. HarborSym keeps track of the scheduled times of arrival and departure of all vessels that are moving in the system, for each reach. Vessels already moving in the system have priority of movement over vessels entering at the bar, leaving a dock or leaving an anchorage. Special provisions are made for certain classes of vessels, such as cruise ships and LNG tankers, such that all other vessels must defer to these vessels. These so-called “priority” vessels are scheduled into the system before other vessels are processed. Potential conflicts are determined by calculating the time when the vessel that desires to move will arrive in each reach, and testing the transit rules for conflicts with other vessels that will be in the reach at the same time, or limitations imposed by vessel size, tide, current or time of passage. If a vessel cannot transit a leg, it waits a user-specified amount of time for the conflicts to clear, and then tries again. The more congested the system, the longer the time a vessel must wait before moving. As each vessel transits the system, the time that it spends waiting, transiting each reach, loading and unloading at the dock, and in anchorages and turning basins, is recorded for the individual vessel, and accumulated for the system as a whole.

Harborsym provides a graphical user interface, as shown in Figure 3, schematic within-simulation animation, as shown in Figure 4 and post-processing animation based on data files created during the simulation using the HSAM program (Rogers et al, 2005), as shown in figure 5.



Number	Description	Type	Station	Dock Number	Code	Dock Description	Owner	Length	Depth	Max Vessels
43	ExxonMobile	Dock	ExxonMobile	1	1	ExxonMobile		0	0	0
40	Du Pont & Sun M	Dock	Du Pont & Sun M	2	2	Du Pont & Sun Ma		0	0	0
34	Union Oil	Dock	Union Oil	3	3	Union Oil		0	0	0
28	Fina Oil	Dock	Fina Oil	4	4	Fina Oil		0	0	0
20	Lone Star Marine	Dock	Lone Star Marine'	5	5	Lone Star Marine		0	0	0
10	Houston Marine S	Dock	Houston Marine S	6	6	Houston Marine S		0	0	0
15	Chevron & Motiva	Dock	Chevron & Motiva	7	7	Chevron & Motiva		0	0	0
16		Dock		8	8			0	0	0
4		Dock		9	9			0	0	0
25		Dock		10	10			0	0	0
47	Sun Pipeline Co.	Dock	Sun Pipeline Co	11	11	Sun Pipeline Co		0	0	0

FIGURE 3
HARBORSYM GRAPHICAL USER INTERFACE



HarborSym - v 0.582 6/28/2004 development version 1.0.0.4 anchorages

Sun 01/07/01 23:26:03 167.434 v: 20 DD

I: Petroleum	329311
E: Petroleum	20922
I: Fertilizer	170537
E: Fertilizer	75684
I: General	27304
E: General	35337
I: Energy	109758
E: Energy	0
I: Construction	39132
E: Construction	2800
I: Passengers	8614
E: Passengers	10576
I: LPG	0
E: LPG	0
I: LNG	0
E: LNG	0
I: NH3	39643
E: NH3	56085

☑ Tide

● Tide Station
○ Current Station
○ Reach

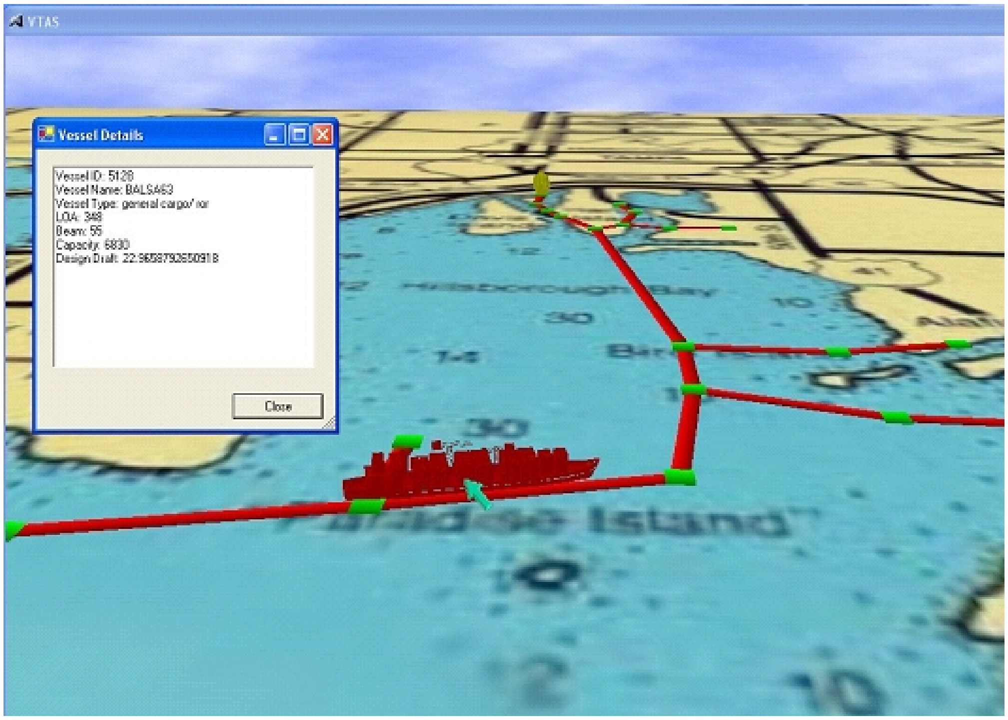
Mullet Key Channel

☐ Node Labels
☐ Reach Labels

Iteration 1

Arr: 167.334

FIGURE 4
HARBORSYM WITHIN SIMULATION VISUALIZATION



Vessel ID: 5128
Vessel Name: BALSA63
Vessel Type: general cargo/ ror
LOA: 348
Beam: 55
Capacity: 6830
Design Draft: 22.9658792650918

FIGURE 5
HARBORSYM POST-PROCESSING ANIMATION

4. VESSEL CALL DATABASE

A central feature of the overall tool suite and the analysis methodology is the VCDB, a relational database that stores information about vessels, vessel arrivals (calls) and commodity transfers at a harbor over a period of time. Vessels are categorized by type (tanker, RORO, etc.) and class (size within type). The VCDB stores information about:

- Individual vessels in the fleet and their physical characteristics:
  - Name
  - Capacity
  - Beam
  - Length overall
  - TPI
- Vessel calls
  - Date and time of individual vessel arrival
  - Arrival draft
- Dock visits
  - Dock visited by a vessel on a particular call
  - Order of dock visitation (which dock is visited 1st, which dock is visited 2nd, etc. for an individual vessel call)
- Commodity transfers at each dock visit
  - Commodity type
  - Quantity imported (transferred to the port)
  - Quantity exported (transferred from the port)

This information exists in a hierarchy whereby the vessels can make multiple vessel calls and each vessel call can have multiple dock visits (intra-harbor movements), as shown in Figure 6, where CT stands for commodity transfer. At each dock visit, multiple commodity transfers can take place, with simultaneous import and export possible. This structure allows for storage of historical vessel movements at a port, where the information is obtained from port authorities, harbor pilots, Coast Guard and other record-keeping sources. Within the HarborSym model, a capability is provided to build the hierarchical database structure from an input spreadsheet that is simpler for users to develop.

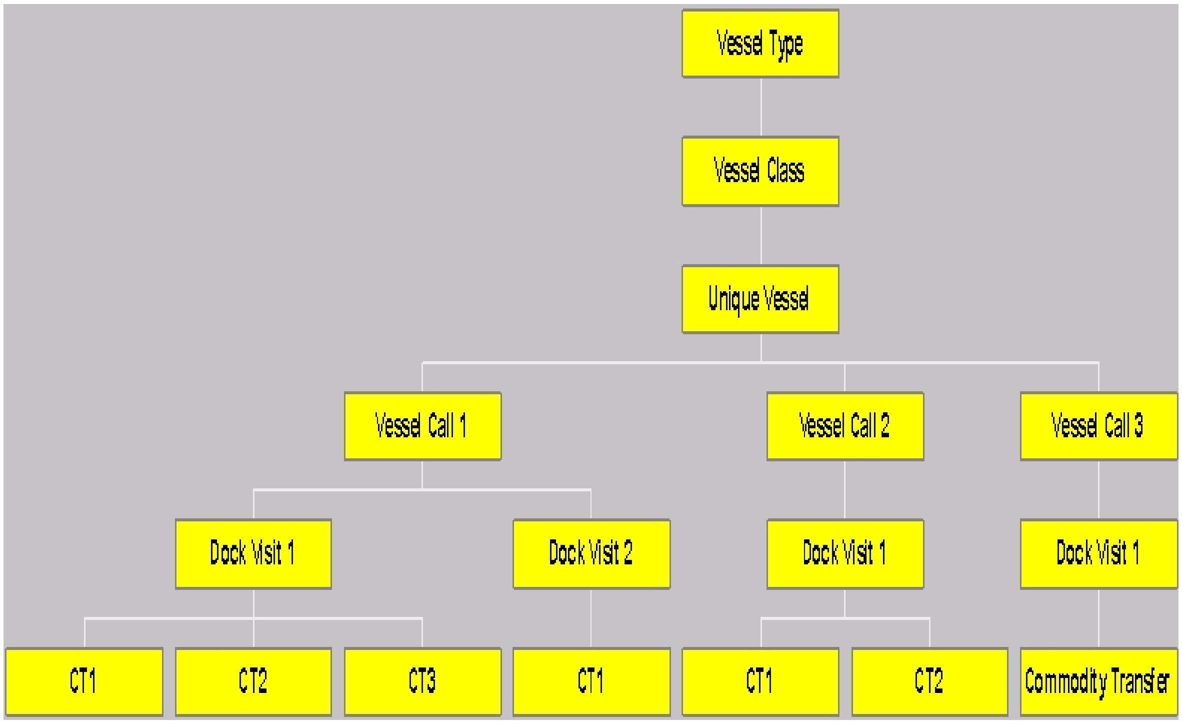


FIGURE 6
VESSEL CALL DATABASE HIERARCHY

The VCDB allows for a number of different views of the traffic at a port:

- Individual vessel call – tracing the movements of a vessel from the time of arrival at the port to the different docks visited, with the associated commodity transfers
- Individual vessel – examining all the calls made by a vessel to the port, with the capability to look at the interval between vessel calls
- Fleet – composition of the fleet
- Vessel class and type – aggregated statistics of vessel traffic and commodity movements
- Dock – time-based stream of commodity flows over time to each dock; aggregated measures of commodities imported/exported at each dock
- Port-level – time-series and aggregate analysis of commodity imports and exports and summary information on port traffic by vessel type, class, and commodity type

Once the historical VCDB is created, it can be used for two purposes: 1) as the driving data for the Monte Carlo simulation; and 2) as a source for statistical analysis of the port calls, vessel characteristics, and commodity movements. Once the statistical analysis has been carried out, the information can be used to assist in generation of synthetic vessel movements under a variety of assumptions, as described below.

5. VESSEL CALL ANALYZER

Information stored in the VCDB represents a complete description of the vessel and commodity movements into and out of the port. A reporting and analysis system, the Vessel Call Analyzer, has been developed that combines the use of queries on the relational database and calculations of regressions and other measures, to extract statistics useful for simulation, forecasting and generation of synthetic vessel calls. By directing the Vessel Call Analyzer to examine a particular VCDB, a number of numerical and graphical outputs can be obtained. Many of the numerical outputs are themselves stored in a database, for use by the commodity-driven forecast tool. Typical graphical outputs available include regression plots of vessel characteristics by class (Figure 7), time history of commodity movements to the port by commodity type (Figure 8) and plots and distribution fitting of inter-arrival days for a particular vessel (Figure 9).

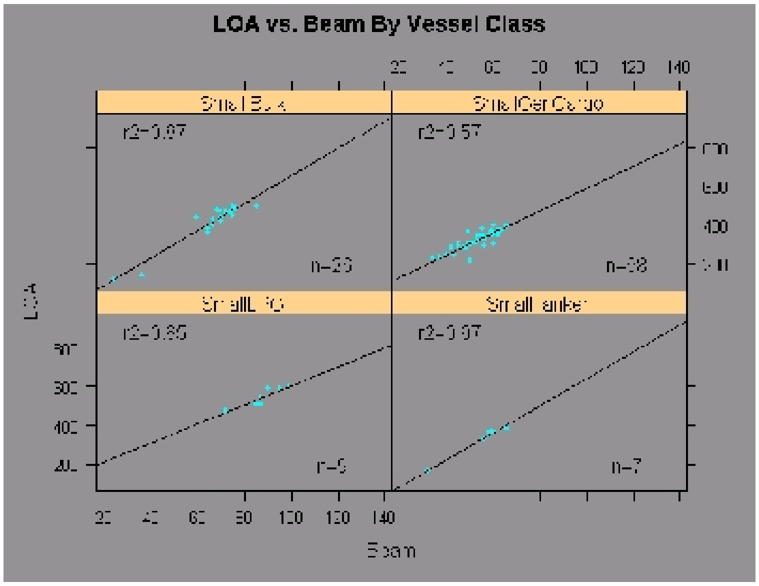


FIGURE 7
REGRESSION ANALYSIS – LOA VS. BEAM BY VESSEL CLASS

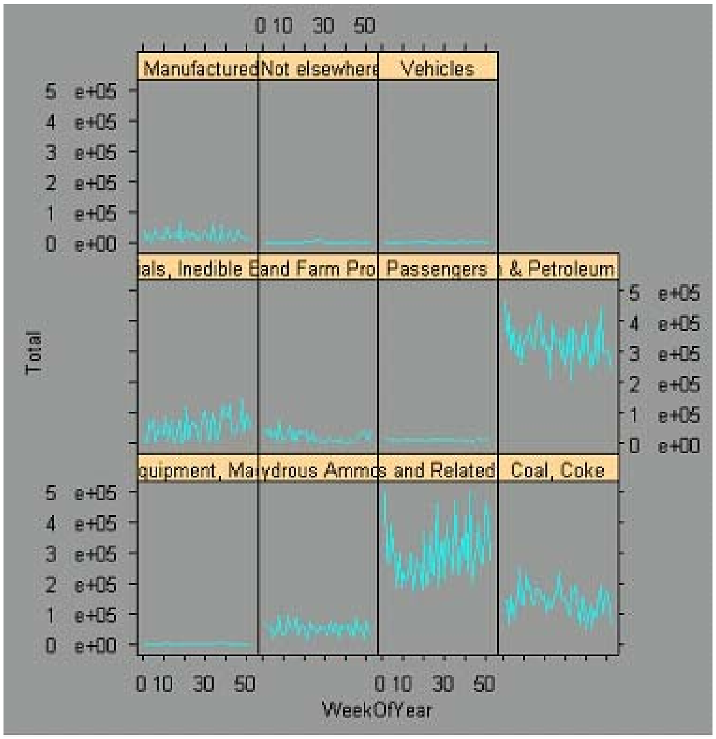


FIGURE 8
COMMODITY FLOW TO PORT

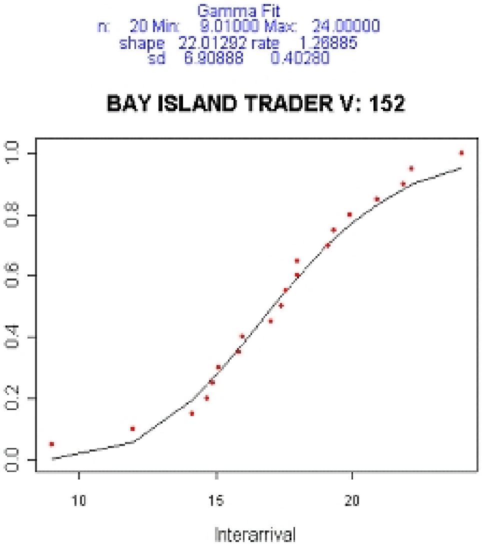


FIGURE 9
FITTED INTERARRIVAL TIME

Numerical outputs include regression coefficients for vessel beam, length overall and design draft vs. capacity, using regression models of the form: X=a*Capacity b , where X is either beam, length or design draft, and the parameters a and b are estimated from the existing fleet, within each class of vessel. The TPI is estimated by a regression model of the form: TPI=a + b1*Capacity + b2*Beam + b3*LOA + b4*Draft, again with the a and b parameters estimated from data stored in the VCDB, by vessel class.

As new statistical analyses or graphic outputs are developed, the Vessel Call Analyzer provides a place where they can be added, so that the analytical capabilities grow over time.

6. COMMODITY-DRIVEN FORECAST TOOL

In economic planning for port development, the transport capacity of the port must be balanced with the demand for commodity movements and the nature of the fleet that is expected to call at the port. Channel improvements can result in the ability for larger vessels to call, and/or for increased loading of existing vessels. Simulation models are helpful in analyzing the interactions among vessels, and the commodity movements that occur in a port. In prior work in this field, Pachakis and Kiremidjian (2003) make a valuable contribution with a clear discussion of the general issue of simulation modeling and present a statistical methodology for developing simulation input for a container port. The current work differs from theirs in that it emphasizes developing simulation input from fleet and commodity forecasts, as opposed to statistical analysis of vessel inter-arrivals and in developing a data-driven, non-proprietary planning tool suite.

The commodity-driven forecast tool was developed for two primary purposes:

1. To allow a user to develop balanced forecasts that are based on commodity demand at the port, with vessel calls being developed as a function of transport demand, rather than as direct projections of calls, and;
2. To prepare a set of synthetic forecasted vessel calls, under different port improvement and future projection scenarios, that can be used with the HarborSym model to estimate congestion in the port. Pachakis and Kiremidjian (2003) note that “Simulation models have been used extensively in the planning and analysis of port operations...The algorithm that generates the ship traffic that goes through the simulation model is a very important part of the simulation process.”

The commodity-driven forecast tool takes as input:

- A definition of the fleet resource that is available to the port to transport commodities;
- Commodity quantities to be imported/exported at each dock;
- Constraints on the transport.

6.1 Fleet Resource

The fleet available is defined by the number of potential vessel calls that can be made, during the period of analysis (typical 1 year), by each vessel class. For example, the availability of the small tanker fleet might be 400 vessel calls per year, while the large tanker fleet might have a resource capacity of 150 calls per year.

Each vessel class is characterized by size ranges (maximum and minimum for beam, length overall, draft and capacity). Alternatively, cumulative probability distributions of capacity by class can be entered as piece-wise linear functions, as shown in Figure 10, showing the cumulative distribution function for capacity for large oil tankers, as developed by the Vessel Call Analyzer for a particular existing fleet. Two lines are shown – the red line is the cumulative distribution based solely on the vessels in the class, while the dotted blue line weights the vessel capacity by the number of calls that vessel makes

Class-based regression information for displacement TPI, beam, LOA, and design draft as a function of capacity, are also provided, using the equations and coefficients from the Vessel Call Analyzer. Each vessel class is also assigned a user-defined “allocation priority,” indicating which vessels are to be preferred in assigning cargo. This allows the allocation algorithm, as described later, to preferentially favor more efficient vessel classes.

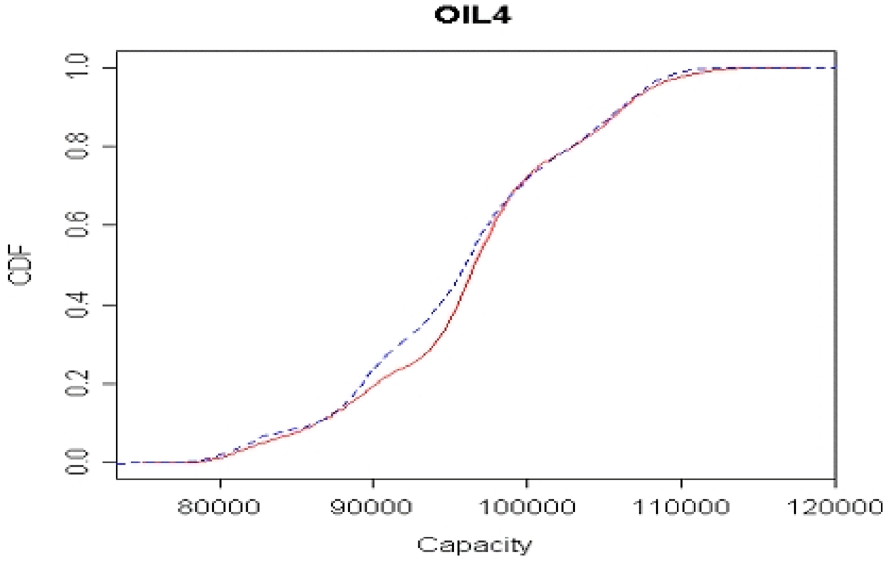


FIGURE 10
CUMULATIVE DISTRIBUTION FUNCTION - CAPACITY

6.2 Commodity Quantities Imported/Exported at the Dock

An historical VCDB will provide complete information about the quantity of each commodity that is imported or exported at each dock. This is the form of input required by the forecast tool. Dock level forecasts are essential for developing synthetic vessel calls for use with HarborSym, as each call must visit at least one dock. However, in common forecast situations, only port level forecasts are likely to be available for future years, and these must then be externally disaggregated to the dock level. The Vessel Call Analyzer can provide statistics on the percentage of each commodity that it is imported/exported from each dock in the port, to assist in the port-to-dock disaggregation.

6.3 Constraints

Vessel classes can carry only certain commodities – an oil tanker does not carry containers. Docks at a port can service only certain vessel classes – a container terminal is required to service container ships. Constraint input to the forecast tool takes the form of two tables:

1. Vessel class-commodity relationships: a listing of the commodities that can be carried by each vessel class, as shown in the example table 1:

TABLE 1
VESSEL CLASS COMMODITIY RELATIONSHIPS

VesselClass	Commodity
GCRR2	Petroleum Products
GCRR2	Grain
GCRR2	Chemicals
GCRR2	Wood

2. Dock constraints, listing the vessel classes that can be serviced by individual docks, as shown in Table 2 below:

TABLE 2 DOCK CLASS CONSTRAINTS	
Dock ID	**Vessel Class**
Dock 1	GCRR2
Dock 1	TUG2
Dock 1	TNKB1
Dock 1	OIL4
Dock 1	OIL3
Dock 1	OIL2
Dock 1	BLKC3
Dock 1	BLKC2
Dock 1	BLKC1
Dock 1	OIL1
Dock 2	TNKB1
Dock 2	OIL4
Dock 2	OIL2
Dock 2	OIL3

In addition, the user specifies draft constraints at each dock, indicating the maximum draft that a vessel importing or exporting from the dock can have. Note that this is not necessarily the draft at the dock, the channel depth to the dock may be constraining. The draft constraints may be changed with different harbor improvements.

6.4 Allocation Algorithm

Given the above inputs, the forecast tool operates by using the specified fleet resource to attempt to satisfy the commodity demands (import and export) at different docks within the port. First, the constraints are checked to make sure that the fleet resource can carry the forecasted commodities (i.e., is there an oil tanker available if there is a dock export of oil?), and that a vessel class that carries the designated commodity can actually service the dock. This is done without respect to the size of the fleet or the quantity of commodity that is exported or imported – it is only a logical consistency check to insure that no infeasible commodity transports have been requested. In the second step, the actual allocation of commodity to vessels takes place:

a) Generate Vessels: The user input describing the fleet is first used to generate a set of specific vessels of distinct size and capacity. A single vessel is created for each vessel call, but not all vessels generated may actually be needed to satisfy the forecast. Conversely, there may be an undersupply of vessels, leading to an unsatisfied forecast. Each vessel is assigned a set of physical characteristics by first choosing a capacity from the user input range or probability distribution of capacities for that class, and then using the regression equations to determine beam, design draft, length overall, and tpi value. Thus, the available vessels within a class will have distinct physical characteristics.

b) Assign Commodity to Vessels: The input data is converted into a set of individual dock-commodity-quantity forecasts. The algorithm then proceeds to loop through all of the forecasts:

```
Loop through the commodity demands.

    Find a vessel that can carry the commodity at the dock (subject to constraints);
    Load it to maximum capacity, subject to loading factor and depth limitation at dock;
    Reduce the remaining commodity transport demand at the dock by the amount loaded;
    Remove the vessel from the available fleet;

Process the next demand.
```

This looping proceeds until all commodity forecasts have been satisfied, or until it is no longer possible to assign a vessel to satisfy any remaining forecast (because no vessels that satisfy the constraints are available).

Determination of loading is based on the vessel capacity, TPI, design draft, a minimum draft for the vessel that is back-calculated from the maximum capacity, design draft and TPI and the dock constraint. First, the vessel is loaded to maximum capacity, which allows for the maximum draft to be determined. This is then compared with the draft constraint for the dock. If the loading exceeds the dock maximum draft, then commodity is removed from the vessel until the vessel draft is no larger than the dock maximum draft. This sets the maximum quantity that can be loaded on the vessel.

c) Assign Vessel Trip Times: After all forecasts have been assigned and the number of vessels of each class that have been utilized is known, vessel trip times are assigned. At present, the model operates on an annual basis. The total number of vessels used within a class is known and the algorithm simply sets a uniform inter-arrival time for all vessels in the class, such that vessels of that class will arrive at the port with a constant time interval, for example every 3.2 days. When all classes are combined, however, the vessel inter-arrival is more random. More complex time assignment algorithms are anticipated in the next generation of the forecast tool, in particular the use of seasonal forecasts and time assignments.

d) Generate Outputs: The result is a complete set of vessel calls as required by the simulation models, as well as statistical information on the movements and commodity totals. The output can be used to test the rationality of forecasts to determine whether or not there is consistency between the fleet forecasts, the commodity demands, and the proposed port configuration. The detailed output of the model shows any occurrence of commodities that were forecasted but not moved into the port due to insufficient vessel calls or predictions of ship movements that were not required to move the anticipated cargo. Outputs of the process are of various kinds:

1. Summary report and spreadsheet information that gives the satisfied and unsatisfied forecast quantity and percentages that have been achieved, i.e., the amount of the forecast quantity that was allocated to vessels (Table 3);

TABLE 3
COMMODITY-DOCK FORECAST SATISFACTION

Commodity Category	Dock	Demand Type	Forecast Quantity	Allocated	Number of Calls	Deficit	Percent Deficit
Crude	Dock 1	Import	26249881.6	7397000	122	18852881.6	71.8%
Crude	Dock 2I	Import	20146287.3	7344750	122	12801536.8	63.5%
Crude	Dock 3	Import	9072806.6	6332826	109	2739980.7	30.2%

2. Report and spreadsheet information that indicates the fleet utilization, i.e., when excess fleet capacity has been provided that has not been needed (by vessel class), shown in Figure 11;

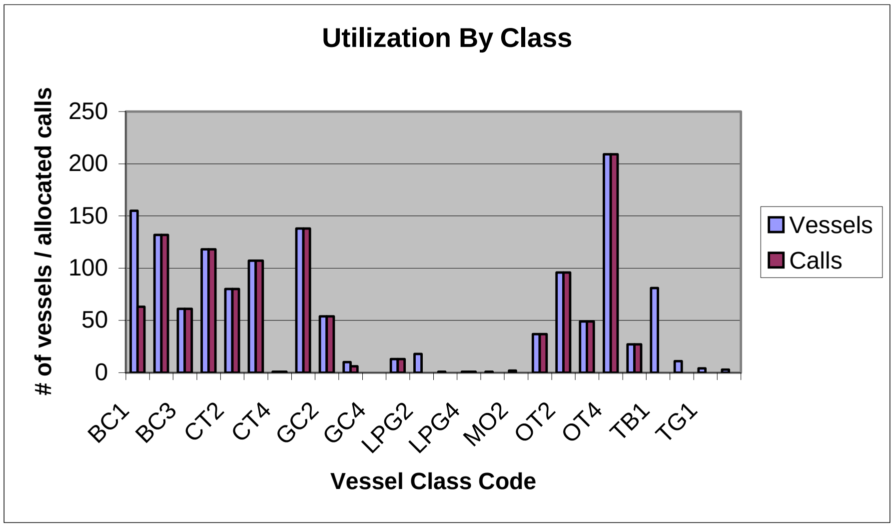


FIGURE 11
FLEET UTILIZATION BY CLASS

3. Detailed information on the vessel classes used to satisfy each individual forecast;
4. Detailed information on the physical characteristics, loading, and destination of each vessel;
5. Optionally, a complete vessel call database can be written out, for use with additional analysis and the HarborSym model. This option is enabled once the fleet and forecasts have been balanced through prior model runs.

6.5 Current Simplifying Assumptions

The commodity-driven forecast tool, as it currently stands, contains a number of simplifying assumptions that are expected to be relaxed in later development:

1. Each vessel call carries a single commodity to or from a single dock;
2. Each vessel call is purely an import or export (this assumption needs to be relaxed for better modeling of container ports);
3. The model operates on a yearly basis, with no seasonality;
4. Tidal influence is not considered;
5. The statistical methods of generating vessel characteristics based on the existing fleet, rather than the world fleet, can be improved;
6. Vessels exporting from the port are assumed to arrive at minimum draft;
7. A constant inter-arrival time for a vessels within a class is assumed; and
8. Each vessel call is a unique vessel (rather than having the same vessel make multiple calls).

7. Usage

The intended approach for the commodity-driven forecast tool involves the following steps:

1. Develop a VCDB of historical data for a port, typically for a recent year for which reasonable data are available (the base year); this represents the existing condition.
2. Run the base year data through HarborSym, for the with- and without-project conditions, developing the baseline delays and delays under improvement alternatives.
3. Use the Vessel Call Analyzer to develop starting point statistics, constraints and existing condition commodity demands. Adjust these as necessary to create future fleets and commodity forecasts, typically at 5 or 10-year increments. The future fleet definition may be dependent upon the proposed port improvements.
4. Run the commodity-driven forecast tool for the future fleet and commodity forecasts, under different sets of dock draft constraints that reflect various with-project improvement alternatives. This will result in a set of VCDBs for out-years in the planning process, under different improvement alternatives.
5. Run these with-project/projected VCDBs through HarborSym, determining the delays under these scenarios.
6. Compare the delay cost differentials under the with- and without-project alternatives over the planning horizon (typically 50 years), at the 5- or 10-year forecast intervals and determine the average annual benefits of the improvements over the planning horizon under the alternatives. This information is then factored into the decision-making process relative to the desirability of making the particular improvement.

8. Discussion

Illustrative results of the nature of the process are provided below. In preliminary testing of this process, using data for a Gulf Coast port in the United States, the types of results are illustrated, as shown in Table 12, where HarborSym runs have been made for a historic VCDB under existing conditions and with all proposed improvements, together with the same alternatives run against a synthetic VCDB that attempts to mimic the historic condition, that is, one that is generated directly from the commodity and fleet statistics that are derived from the historic condition. (This comparison of historic and "synthetic historic" is considered the first step in calibration of the forecast tool). Given that only minimal calibration was done to "tune" the synthetic historical VCDB, the results appear generally reasonable. Fewer vessel calls are generated in the synthetic historic condition to carry the same commodity quantity, most likely due to assumptions about loading vessels to the maximum.

TABLE 3
COMPARISON OF HARBORSYM SIMULATIONS – HISTORIC AND GENERATED VCDB

	Historic		**Synthetic Historic**	
HarborSym Output Metric	**Existing Condition**	**All Improvements**	**Existing Condition**	**All Improvements**
Number of Exiting Vessels	1,847.8	1,847.8	1,601	1,601
Total Commodity (tons) transferred	85,524,372	85,556,592	85,518,773	85,518,773
Average Cost ($)	48,740	47,470	50,010	48,550
Total Cost ($)	90,070,090	87,726,090	80,061,770	77,732,210
Average Vessel Time Waiting (hours)	7.68	5.86	8.74	6.66

Graphical comparisons of historical and generated VCDBs can easily be made. The example shown in Figure 12 takes a single parameter that is generated from HarborSym, the average vessel time waiting, that is calculated by vessel class and compares the synthetic data (upper bar) with the historic data (lower bar). As can be seen by the absence of upper bars for some vessel classes, the forecast tool, in this particular run, did not generate a synthetic fleet that utilizes all of the vessel classes that are present in the historic data. Such comparisons can easily be made for other statistical outputs of the simulation, such as time at docks, time in reaches, overall time in system, etc.

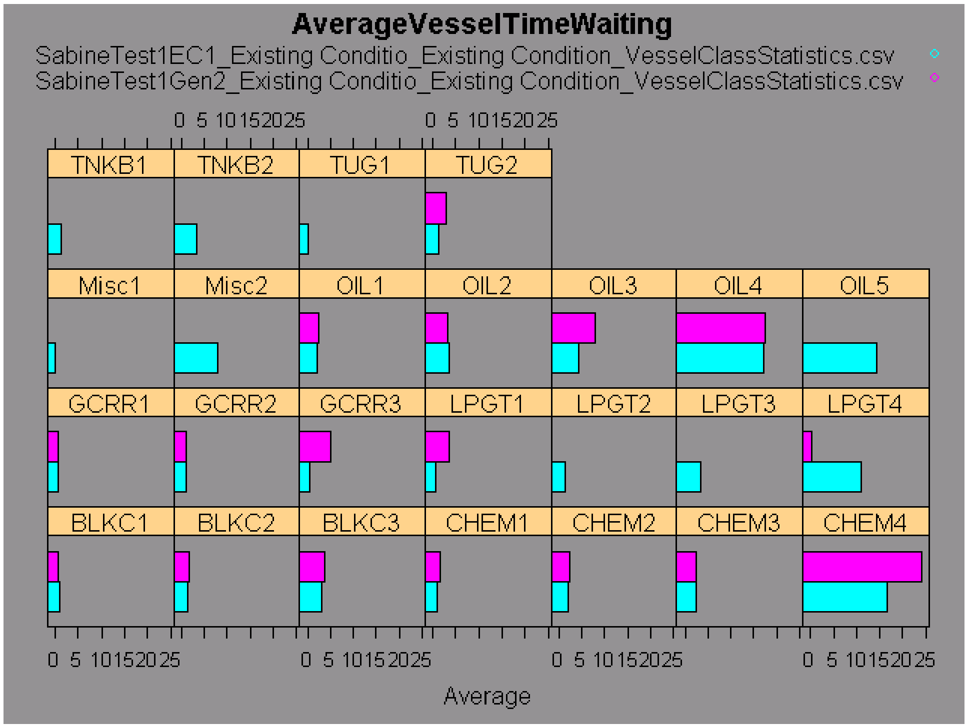


FIGURE 13
COMPARISON OF HISTORICAL AND SYNTHETIC SIMULATION OUTPUT –
AVERAGE VESSEL WAITING TIME

Obviously, data checking, calibration and validation needs to be performed both for HarborSym and for the Commodity-Driven forecast tool, with reasonableness checks throughout the process. A variety of improvements are planned for the VCDB, Vessel Call Analyzer and Forecast Tool, including:

- Adding additional information to the VCDB, to allow for storage of distance and location of prior and subsequent ports of call, needed for a more comprehensive economic analysis.
- Enhancements to the user interface for the Vessel Call Analyzer, for improved ease of use.
- Addition of seasonality, combined import/export, better methods of entering statistical descriptions of vessel physical characteristics and better calibration tools for the commodity forecast tool, as well as better packaging of the tool with an improved user interface.

9 Summary

The Corps has developed an evolving suite of tools to assist planners in the economic analysis of harbor improvements. The tools are designed to be portable, such that they can readily be applied to a number of sites without requiring extensive specialized development. The tools are designed to be transparent, that is, easy to understand in terms of behavior, such that the inputs, outputs and internal processes are made apparent, through detailed outputs, graphical displays, visualizations and animations. This is particularly important with complex simulation models. The tools are also non-proprietary, so that users can obtain and use them without having to purchase expensive specialized software.

As of this writing (July 2006), the HarborSym model and post-processing animation tool HSAM are available as beta test versions (available for distribution, but still in testing), with associated documentation. Training classes have been provided to Corps personnel. HarborSym is being used by Corps Districts in studies of ports in Florida and Texas/Louisiana, and improvements to the model are continuing, based on experience in those studies. The Vessel

Analysis tool is in late stage development, with improvements being made to the user interface and the commodity-driven forecast tool is in alpha testing and will be placed in beta test in the near future.

10 Acknowledgements

This work was carried out as a portion of the NETS program of the Institute for Water Resources of the U.S. Army Corps of Engineers, under the direction of Mr. Keith Hofseth of IWR. Ms. Shana Heisey of IWR was responsible for much of the design, testing and data development. Model development was carried out by Mr. Cory Rogers of CDM, Carbondale, Illinois and Dr. Richard Males, RMM Technical Services, Inc., Cincinnati, Ohio. Mr. Joseph Berlin of CDM Carbondale, Illinois conducted extensive testing of HarborSym, the Vessel Call Analyzer and the Commodity-Driven Forecast Tool.

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The NETS research program is developing a series of practical tools and techniques that can be used by Corps navigation planners across the country to develop consistent, accurate, useful and comparable information regarding the likely impact of proposed changes to navigation infrastructure or systems.

The centerpiece of these efforts will be a suite of simulation models. This suite will include:

- A model for forecasting **international and domestic traffic flows** and how they may be affected by project improvements.
- A **regional traffic routing model** that will identify the annual quantities of commodities coming from various origin points and the routes used to satisfy forecasted demand at each destination.
- A **microscopic event model** that will generate routes for individual shipments from commodity origin to destination in order to evaluate non-structural and reliability measures.

As these models and other tools are finalized they will be available on the NETS web site:

http://www.corpsnets.us/toolbox.cfm

The NETS bookshelf contains the NETS body of knowledge in the form of final reports, models, and policy guidance. Documents are posted as they become available and can be accessed here:

http://www.corpsnets.us/bookshelf.cfm

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