HarborSym Deepening
Design Document

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U.S. Army Corps of Engineers
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HarborSym Deepening Design Document

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Contents

Figures v
Tables vii
Executive Summary 1
Section 1 Introduction 3
Section 2 Summary 5
2.1 Problem Statement 5
2.2 Prior Work 5
2.3 Overview of Approach 6
2.3.1 Existing Practice 6
2.3.2 HarborSym 6
2.3.3 Development of VCDBs for Future and With-Project Conditions 7
2.3.4 Statistical Analysis and Visualization 8
2.3.5 Status 8
2.3.6 Integration 9
2.3.7 Intended Operation 9
2.3.8 Next Steps 10
Section 3 Review of HarborSym 11
3.1 Overview 11
3.2 Data Requirements 12
3.3 Key Concepts 12
3.3.1 Vessel Call 12
3.3.2 Leg 13
3.3.3 Transit Rules 13
3.3.4 Processing Logic 13
Section 4 Database Architecture 15
4.1 Overall Structure 15
4.2 Vessel Call Database 16
4.3 Addition of Route Group Information 18
4.4 Additional Vessel Class Level Information 19
4.5 Unit of Measure Information 19
Section 5 Economic Analysis 21
5.1 Existing Practice 21
5.2 HarborSym Deepening Approach 21
Section 6 HarborSym Deepening Version 25
6.1 Deepening Version Enhancements 25
6.2 Cost Allocation Calculations 25
Section 7 Commodity-Driven Vessel Generator/Allocator 27
7.1 Background 27

7.2 Commodity-Driven Vessel Generator/Allocator Proof-of-Concept 28
7.2.1 Overall Process 28
7.2.2 Detailed Specification of Vessel Call Loading Assignment 30
7.2.3 Outputs from the CDVG/A 33
7.3 Next Steps/Issues 38
Section 8 Statistical Analysis and Visualization 41
8.1 Background 41
8.2 Example Outputs 42
8.2.1 Port Traffic Summaries 42
8.2.2 Data Checking 46
8.2.3 Vessel Physical Characteristics Statistics 47
8.2.4 Output Comparisons 48
8.3 Discussion 49
Section 9 Conclusions and Recommendations 52
9.1 Summary 52
9.2 Simplified Analysis 52
9.2.1 Default Simplified HarborSym 53
9.2.2 Simplified Analysis Using the CDVG/A 53
9.3 Recommendations 54
Section 10 References 56
Appendix A Spreadsheet Example 1

Figures

Figure 1 Relationship of Databases and Components 16
Figure 2 Vessel Hierarchy 17
Figure 3 Weekly Commodity Flow by Commodity (In This Case Liquid Bulk) at Individual Docks at the Port of Tampa 46
Figure 4 Cumulative Density Function of Capacity 48
Figure 5 Historic vs. Synthesized Results Comparison 49

Tables

Table 1 Deepening Proof-of-Concept Components ... 9
Table 2 Databases Used in Deepening Analysis ... 15
Table 3 Example of How Information is Described in the Route Group Table ... 18
Table 4 Class Level Summary Output From HSD Proof-of-Concept ... 23
Table 5 Iteration-Level Output by Vessel Class and Unit of Measure ... 24
Table 6 Vessel Class Commodity Category Loading Control Specification Table ... 32
Table 7 Allocation Results Satisfaction Output ... 34
Table 8 Fleet Usage by Allocation Process ... 35
Table 9 Unique Synthetic Vessels Generated By CDVG/A ... 36
Table 10a Vessel Call Loading Information Output (First Set of Columns) ... 36
Table 10b Vessel Call Loading Information Output (Second Set of Columns) ... 37
Table 10c Vessel Call Loading Information Output (Third Set of Columns) ... 37
Table 10d Vessel Call Loading Information Output (Fourth Set of Columns) ... 38
Table 10e Vessel Call Loading Information Output (Fifth Set of Columns) ... 38
Table 11 Port Traffic Summary – Rollup by Dock/Commodity/Vessel Class ... 43
Table 12 Port Traffic Summary – Rollup by Commodity/Vessel Class ... 44
Table 13 Port Traffic Summary – Rollup by Vessel Type ... 44
Table 14 Port Traffic Summary – Calls by Dock and Vessel Class ... 45
Table 15 Data Checking Output – Commodity Transfer Exceeding Capacity ... 46
Table 16 Data Checking – Unique Vessel Identification ... 47
Table 17 Vessel Class Level Statistics ... 47
Table 18 Estimated Regression Equations ... 48

Table A Transportation Cost Table-Ian Example of Transportation Cost Differentials on Per Ton Basis Transport of Containerized Cargo Via Containerships San Juan Harbor, Puerto Rico ... A-1

Executive Summary

Economic analysis of improvements to ports and harbors is acknowledged to be a difficult and complex task. The U.S. Army Corps of Engineers (Corps) guidance on the subject dates from 1991 and is currently being revised. The Corps recognizes a distinction between improvements that reduce congestion at a port through channel widening and provision of moorings/anchorages and those that allow larger/more fully laden vessels to transit the port through channel deepening. Economic analysis of "widening" projects is oriented towards determining time savings for vessels transiting the harbor, but does not, in general, involve assessing changes in vessel loading or shipping patterns. In contrast, the "deepening" analysis is much more complex—in the general case, it is a multi-port examination that considers fleet and loading changes and alternative routings of vessels through different ports.

The Corps has developed the HarborSym model, a Monte Carlo simulation model of vessel movement in harbors, to assist in studies involving widening analysis, but other than that, no standardized tools exist to support the data development and analysis associated with port improvement studies.

The Institute for Water Resources (IWR) has explored methods to extend HarborSym to assist Corps planners in deepening analysis studies. The basic approach relies upon a number of inter-related tools that are extensions of models and database structures developed for widening analyses with HarborSym. IWR has developed "proof-of-concept" models to demonstrate and test the methodology:

1. A database structure that describes vessel traffic at a port, including: date, time and draft at arrival; quantity of commodity transfer by dock and commodity type and ocean travel distances associated with each vessel call. Once port traffic information is placed in this standardized structure, a variety of modeling, analytical and display capabilities useful to Corps planners and analysts can be implemented.

2. A Monte Carlo simulation model of a single port (HarborSym Deepening) that calculates both "within harbor" costs and ocean costs of voyages, using the above database as input. This model, an extension of the HarborSym widening model, generates detailed and summary information that can be used to calculate cost savings associated with deepening projects. While the deepening model, like the widening model, is oriented towards analysis of a single port, the overall set of tools should be useful in supporting a multi-port analysis.

3. A model that uses fleet and commodity forecasts and channel depth limitations to generate synthetic vessel traffic data that is usable directly by the HarborSym Deepening simulation. This model should be useful in developing balanced fleet and commodity forecasts, in a structured and transparent fashion, even if detailed simulation modeling is not contemplated.

4. A set of statistical analysis, reporting and graphical display tools that support the overall process, that should be useful generally in standardizing many of the functions associated with port improvement studies.

Taken together, these tools/models constitute elements of a proposed "Navigation Analysis Tool Suite," that will provide a standard, certifiable framework for data collection and analysis for port improvement studies.

The major advantages of the proposed approach are:

- All elements of the analysis are explicit and data-driven. As such, the tools can be applied at different ports. The methodology provides a clear structure for data gathering and checking;
- Variability/uncertainty is included through the Monte Carlo simulation;
- The approach is commodity forecast-driven, but provides the user with information on the consistency of the forecast with the available fleet;
- The approach is scalable—it can be carried out with a detailed (i.e., dock level) or summary (i.e., entire port) representation of a port and the commodity import/export demands. Simplified approaches, with lesser data requirements, can be developed using the basic concepts and tools.

In terms of next steps, the proposed design should be explored within a larger community of those interested in deepening analyses within the Corps, to obtain additional insight and feedback on the approach. Careful examination of the specific algorithms, in particular those for generating synthetic vessel traffic, is needed. A test bed application is desired, that is, a deepening analysis project carried out in conjunction with a District, where the ideas and tools developed to date can be applied in a real-world situation to test their applicability and usability. Integration of the tools in a simple to use and understand framework and interface is required and is yet to be developed.

Section 1
Introduction

Economic analysis of improvements to ports and harbors is acknowledged to be a difficult and complex task. The U.S. Army Corps of Engineers (Corps) recognizes a distinction between improvements that reduce congestion at a port through channel widening and provision of moorings/anchorages and those that allow larger/more fully laden vessels to transit the port through channel deepening. Economic analysis of "widening" projects is oriented towards determining time savings for vessels transiting the harbor, but does not, in general, involve assessing changes in vessel loading. In contrast, the "deepening" analysis is much more complex—in the general case, it is a multi-port examination that considers fleet and loading changes and alternative routings of vessels through different ports.

The Corps has developed the HarborSym Model, a Monte Carlo simulation model of vessel movement in harbors, to assist in studies involving widening analysis. More recently, the Institute for Water Resources (IWR) has explored what would be needed to extend HarborSym to assist Corps planners in deepening analysis studies. This report describes design approaches that have been proposed to that end. In a number of cases, it has been necessary to build proof-of-concept extensions to HarborSym, and to construct associated support tools, to explore these ideas. Thus, this report describes both the basic design intentions, as well as the tools that have been built to date to explore and exemplify those ideas. This is somewhat different from the approach typically followed in design document development, in that preliminary tools have been built in parallel with the document development. These tools consist of:

1. An extended version of the HarborSym widening (HSW) vessel call database (VCDB), that incorporates information on vessel distances traveled to/from the port of analysis;

2. Data analysis and visualization tools for fleet arrival information;

3. A commodity demand-based vessel call generator, that can provide synthetic VCDBs under various alternative future scenarios of channel deepening and fleet assumptions;

4. A proof-of-concept implementation of HarborSym for deepening analyses, that provides cost savings per ton.

Because these tools must work together, the concept of a Navigation Analysis Tool Set has been developed as an umbrella concept. Tools in the set include simulation models, databases and data analysis and visualization tools.

Note that the work to date does not solve the multi-port problem explicitly. The focus is still on a single port, but extends the analysis to incorporate distance to prior and subsequent ports. The current work does, however, facilitate multi-port studies in that it proposes procedures that can reflect multi-port scenarios by development of datasets containing different assumptions about hinterlands and diverted traffic. These datasets can then be analyzed by the methods discussed herein.

It is recognized that the contents of this report may be difficult to digest easily—there are a large number of inter-related concepts and prior familiarity with HarborSym is particularly useful. A brief introduction and overview to the essential elements of Harborsym is presented in a later section, to assist those readers who are less familiar with the model.

This work was done under the technical direction of Ms. Shana Heisey of IWR, Project Manager and Technical Monitor for HarborSym, with additional guidance by Mr. Keith Hofseth, NETS Technical Director. Mr. Cory Rogers, CDM, Carbondale, Illinois and his staff developed the user interface capabilities for HarborSym and contributed significantly to the overall deepening design effort. The author relied on work done by Ms. Gloria Appell, Economist, SAG and Mr. Ian Mathis of IWR for examples of current Corps practice in analysis of deepening. This report was prepared by Mr. Richard Males, RMM Technical Services, Inc., Cincinnati, Ohio, in association with CDM, Carbondale, IL.

Section 2
Summary
2.1 Problem Statement

The current work addresses a portion of the economic analysis problem for deepening of channels in ports and harbors. Cost savings are presumed to accrue to shippers when a channel is deepened because they can: (a) increase the loading of existing vessels serving the port, which may currently be light-loaded due to depth constraints; (b) cause existing cargo to shift to deeper vessels that do not currently visit the port due to depth constraints; and (c) cause additional cargo to call at the port (induced traffic). Costs, expressed primarily as those derived from vessel time spent in port and at sea, are allocated to the tons transferred at the port (and in some cases to tons carried by the vessel, whether transferred or not). The difference in cost of moving a set quantity of commodity, under the without deepening and with deepening alternative, is a measure of the benefits that derive from the deepening. Detailed procedures for benefit estimation are set forth in the National Economic Development Procedures Manual for Deep Draft Navigation (IWR, 1991), currently under revision.

The proposed approach deals with two of the three elements of cost savings noted above: increased loading of existing vessels and changes in fleet composition. It does not explicitly deal with the induced traffic component, but the effects of induced traffic can be expressed by increased commodity transfer demand at the port, as will be described later.

2.2 Prior Work

The path to the deepening design has been an evolutionary one, starting with the development of the HarborSym model and associated databases. Work on HarborSym was initiated in late 2001, with a draft design document issued in February of 2002. The basic architecture consisted of an underlying relational database describing the port and the vessel calls, and a computational kernel that performed the Monte Carlo simulation. An initial version of the model, without a sophisticated user interface, was developed in March through October of 2002, in conjunction with the Galveston District (SAG) for work on improvements in the Sabine-Neches waterway. A design for a subsequent round of improvements to support application to a study of the Port of Tampa by the Jacksonville District (SAJ) was developed. The major proposed enhancements included the incorporation of a user interface that allowed for graphical development of a port database, addition of tidal influence and the ability to handle vessel right of way (for example so that other vessels must keep clear of cruise ships). A model with the new capabilities was prototyped starting in February of 2004 and a design document summarizing the enhancements was issued in April of 2004. Iterative prototyping, bug fixing and enhanced output and user interface capability has led to many subsequent revised versions, but the basic architecture and approach remains that established in July of 2004. HarborSym training classes have been conducted in the Jacksonville (November 2005) and Mobile (March 2006) Districts.

The design approach to HarborSym relies upon the existence of a VCDB, that describes the vessels arriving at a port, the dates of the calls that they make to the port and the associated commodity transfers at individual docks for each call. This is typically developed based on a year's worth of historic information and is used to examine the existing condition at the port.

Once historic information is placed in the VCDB format, it is available for statistical analysis. Early exploratory work (starting in January 2004), using datasets containing Tampa vessel call information, was carried out using the R Statistical Package (www.r-project.org). This work has continually been enhanced and expanded to display information related to vessel calls graphically and to obtain statistical information.

For out-years and estimation of calls under various future assumptions about fleet composition, project attributes and commodity forecasts, it is necessary to create VCDBs that are reflective of those assumptions. Initial efforts at developing a "commodity-driven" fleet generation capability were undertaken, starting in February of 2004, with a first-cut proof-of-concept model in March of 2004. This work was continually extended for the widening model and has subsequently been developed as a proof-of-concept generator of synthetic vessel calls for deepening.

In summary, four components of the deepening approach have been evolving in the context of the widening application and have been modified to support the deepening design:

1. Widening VCDB → Deepening VCDB
2. Commodity-Driven Vessel Generator/Allocator (Widening) → Deepening Version
3. Widening computational kernel → Deepening kernel
4. Statistical Analyzer/Visualizer → enhanced capabilities

2.3 Overview of Approach

2.3.1 Existing Practice

The typical spreadsheet-based deepening economic analysis carried out within the Corps estimates cost savings per ton for a representative vessel of a given class. The user provides information for the without-project condition and with-project alternatives on:

- Tonnage Carried
- Time in Port
- Time at Sea
- Operating Cost at Sea
- Operating Cost in Port

This information is used to calculate "at sea" and "in port" costs, leading to a total cost per ton for the with- and without-project conditions and thus the net cost savings per ton. This analysis is done separately for representative vessels of different classes and the information is aggregated to provide a net cost reduction associated with the improvement.

2.3.2 HarborSym

The HSW analysis takes as input port information (stored in the input database [IDB]) and vessel call information (stored in the VCDB database). It then simulates vessel movement to docks at the port, subject to congestion, tide and transit rules. HSW calculates individual times for each vessel (in reaches, waiting, at docks, etc.), determines cost based on operating cost per hour and provides aggregate totals by vessel class and overall. This is the "in harbor" component of costs used in the deepening analysis. The widening version of the VCDB does not contain any information on prior or subsequent port calls, thus there is no calculation of "ocean" costs. [Note that, within HarborSym, a distinction is made between time spent sailing in reaches and time spent waiting/docked at port facilities. The total "in harbor" costs are calculated with different operating costs for the sailing in reaches and waiting at dock elements of time that a vessel spends while visiting the port.]

The HarborSym deepening (HSD) analysis adds calculation of the "at sea" or ocean costs to the existing "in harbor" cost calculation of HSW. This is accomplished by adding information to the VCDB for each vessel call, giving the "at sea" distance associated with that call. This is implemented in an indirect method, where vessel calls are associated with "route groups" and actual distance for the call is determined from separate description of the route group. HSD can then carry this information along, calculating times and costs in port as before and adding the ocean costs for each vessel call. In essence, HSD is simply doing additional accounting, at the vessel call level, to obtain the needed ocean cost information for the deepening economic analysis, while still maintaining the more detailed congestion, tide and transit rule based analysis for the in port portion of the calculations.

2.3.3 Development of VCDBs for Future and With-Project Conditions

HarborSym deepening does an analysis of an individual VCDB, developing detailed cost data for that situation. The existing condition is based on historical vessel call data, but projections must be developed for future and with-project situations. Separate HSD runs are made for the without- and with-project conditions, for existing conditions and projected futures.

The real issue is thus the generation of VCDBs that represent fleet arrivals and loadings under future without- and with-project conditions. That is, a with-project VCDB must represent the future fleet and commodity demands for import and export at the port and the associated commodity transfers and vessel loadings must be reflective of the possibilities offered by the deepened channels. Generation of these VCDBs is the role of the Commodity-Driven Vessel Generator/Allocator (CDVG/A), an essential element of the deepening design approach. The CDVG/A is designed to generate a VCDB that can be run through HSD, from input describing the fleet, channel constraints and commodity demands.

The user provides specification of:

1. Commodity forecasts (import/export) at each dock.

2. Dock depth limitations at each dock, for the project alternative being considered.

3. Description of the available fleet, by vessel class.

4. Logical constraints describing commodities that can be carried by each vessel class and vessel classes that can be serviced at each dock.

5. Parameters, defined at the vessel class/commodity level, for determination of how individual calls and commodity transfers are generated. This includes statistical information relating to physical characteristics of a vessel class and user specification to control the loading process (i.e., how much of vessel capacity is loaded, whether the loading is export-only, import-only or both import/export, etc.).

The CDVG/A then generates a synthetic fleet (based on statistics on the physical characteristics of each vessel class) and attempts to load vessels to satisfy the user input commodity forecasts at the dock, creating a vessel call (a movement, at a specific time of an individual vessel to a specific dock, with associated commodity transfers). All of this information is stored in a generated VCDB, which can then be run through the HSD.

The CDVG/A requires explicit statements of fleet characteristics and commodity forecasts. The process followed reveals any inconsistencies in these two separate inputs, such as insufficient fleet to carry the forecasted quantity or excess fleet assumptions. The approach and methodology are described in detail in a later section and an overview is provided by Hofseth (2006).

2.3.4 Statistical Analysis and Visualization

The widening analysis and the deepening analysis are both "data-driven," relying on user input data to specify the particular situation that is being analyzed. This information is typically stored in Microsoft Access™ databases. Similarly, output information from the individual modules can be quite extensive. The CDVG/A requires statistical information on vessel characteristics in order to generate synthetic vessels. Taken together, this situation dictated the need for development of a number of data-checking, summarization, visualization and statistical analysis tools that allow a user to examine inputs and outputs in tabular and graphical displays and to develop needed statistical information for the CDVG/A. Many of these tools have been developed in a proof-of-concept framework and are not at present well-integrated into a concise and consistent user interface.

2.3.5 Status

In order to work out many of the ideas that are embodied in this design, it has proven necessary to actually build initial/proof-of-concept versions of the inter-related components that work together to do a deepening analysis, as listed in Table 1. The inputs and outputs of these components serve to illustrate how the intended deepening approach works, but additional work remains to be done to insure that the overall process functions as desired.

TABLE 1
DEEPENING PROOF-OF-CONCEPT COMPONENTS

Element	Status	User Interface	Issues
Vessel Call Database	Extended to support deepening	Not applicable	Review of methodology for developing and assigning ocean distances through route groups
HarborSym Deepening	Extension of widening version	Initial UI developed to support testing	Outputs need close examination to assure that they support required economic analysis
Commodity-Driven Vessel Generator/ Allocator	Proof-of-Concept version	Rough, MS Access-based	Requires detailed review of approach, outputs. User interface required
Statistical Analysis and Visualization	A variety of individual elements exist, using MS Access and the R Statistical Package	MS Access, R and exploratory efforts (using C# and Visual Studio .NET environment) at a more integrated interface	A good deal of organizational and development effort is required to take the various elements that have been constructed as proofs-of-concept, generalize them and place them in an appropriate user interface that is integrated with the other components

2.3.6 Integration

The deepening approach requires the interaction of a number of components:

- Development of a "deepening" version of the HarborSym simulation, adding additional "accounting" calculations for ocean costs of the voyage and calculation of cost per unit of commodity transferred.

- Creation of the capability to generate synthetic sets of vessel calls that can be used with the deep draft version of HarborSym, under different sets of assumptions about commodity forecasts, fleet resources and channel deepening (referred to as the Commodity-Driven Vessel Generator/Allocator, CDVG/A).

- Development of a set of analysis procedures that calculate needed statistics for use by the CDVG/A and provides various kinds of graphical displays as well as allowing for various forms of statistical summarization and data checking on HarborSym databases.

At present, each of these capabilities has been developed in proof-of-concept form, but are not tightly integrated, that is, there is no single user interface (or even a single user interface technology) that allows for a simple interaction with these capabilities. The capabilities are, however, highly intertwined and interdependent and a clear knowledge of these interdependencies is essential to understanding the process and will be necessary in developing an integrated user interface.

2.3.7 Intended Operation

Given the availability of the above elements, the intended operation is roughly as follows:

1. Develop a HarborSym structure for the port area in question (reaches, nodes, transit rules, etc.).

2. Develop existing condition data from historical data, much as is currently done for the widening analysis. Additional information will need to be gathered relating to prior and next ports of call.

3. Run HSD to obtain without-project base year conditions.

4. Use statistical analysis tools to develop basic information needed for the CDVG/A (statistics on vessel physical parameters, etc.).

5. Prepare commodity and fleet forecasts consistent with the project alternative for outyears and future project alternatives, stored in the appropriate format for use by the CDVG/A.

6. Prepare alternative VCDBs, under different assumptions about channel deepening, commodity forecasts and fleet availability.

7. Run HSD with the alternative VCDBs, to develop transportation cost and commodity tonnage data for each alternative.

8. Compare the with- and without-project runs for cost savings.

2.3.8 Next Steps

Taken together, the existing capabilities should provide a framework that will be of use in performing economic analyses of deepening projects, consistent with the Corps approach to those studies. However, this remains to be demonstrated by creation of a sample analysis using these tools. It is expected that developing such a sample analysis will clarify the needs for additional steps, in terms of model outputs, computational capability, displays and user interface.

Due to the complexity of the problem, the considerable amount of data required to support the analysis and the inter-relationship of the various components, a substantial level of understanding of the design approach is needed. In particular, examination of the outputs of HSD and the internal processes used within the CDVG/A are necessary. Integration of the various elements, via a user interface that clearly delineates the underlying interactions, is also important.

In addition, the possibility of developing a more simplified analysis procedure for deepening, that does not require using the Monte Carlo simulation of HSD, is suggested and described in a later section.

Section 3
Review of HarborSym

A number of papers and presentations describing HarborSym are available at the NETS website: http://www.nets.iwr.usace.army.mil/coastalnav.cfm. The latest version of the model, together with supporting documentation, is available at: http://www.pmcl.com/harborsym/default.htm

The following information is extracted from one of the reports describing the HSW model (Moser, 2004).

3.1 Overview

HarborSym is a Monte Carlo simulation model of vessels moving within the channels of a port. It represents a port as a tree-structured network of reaches and nodes. Reaches represent channels, while nodes are used to represent docks, anchorages and turning areas. Each vessel visit to the port is termed a vessel call. Vessel movements within a vessel call are subject to transit restrictions based on channel width, depth, tide and rules on passing other vessels for each reach, resulting in delays until the restriction is no longer present. As vessel calls are processed, statistics are accumulated relating to transit and waiting times and commodity throughput. Alternative channel dimensions and/or sets of rules can be tested to determine the impact on port traffic. As rule restrictions are relaxed due to proposed harbor improvements (such as channel widening), simulated delays are reduced. Using the model, analysts can estimate transportation cost savings, in the form of reduced delays that result from each project alternative, allowing for a comparison of various proposed plans. Sufficient detailed output is available from the model to verify behavior and trace each vessel and its interaction with other vessels.

Four interacting modules make up the system. A set of Microsoft Access™ databases store descriptive data including definition of the reaches, nodes, vessel classes and transit rules. A graphical user interface module, written in Microsoft Visual Basic™ reads and writes the database, allowing for easy construction of port networks, specification and modification of data and viewing of results. A computational simulation kernel written in C++ using object-oriented techniques reads information from the database, carries out the Monte Carlo simulation, writes results back into the database and generates additional detailed output that is used for the post-simulation visualization module, which also reads from the database. This modular structure allows for the choice of an appropriate programming language/tool to address different parts of the problem. The system is designed to run on computers using Microsoft Windows 2000 and above.

The key features of the model are:

- User defined network describing the port;
- Historical vessel calls, with multiple commodities and docks;
- User definition of vessel classes and commodity types;
- Tidal influence and internal calculation of tide height and current by reach;
- Transit analysis based on user-parameterized rules;

- Intra-harbor vessel movements;
- Use of turning areas and anchorages;
- Within-Simulation and post-processing visualization and animation.

3.2 Data Requirements

As a data-driven model, HarborSym requires the user to define almost all of the information that specifies the simulation conditions, with as little as possible "hard-coded" in the programming languages. Six general categories of information are required to be available in the database:

1. Parameters of the simulation run: start date, duration; number of iterations; wait time before rechecking rules; level of output;

2. Physical and descriptive characteristics of the port network: node location and type (dock, turning area, anchorage, port entry and exit points, intermediate nodes); definition of reaches (as node origin-destination pairs, with length, width and depth); identification of tide and current stations used for predictions;

3. General Information on vessel and commodity classes (user-defined), commodity transfer rates at each dock as triangular distributions and specification of turning area usage associated with each dock;

4. Loaded and light vessel speeds in each reach by vessel class;

5. Transit rules for each reach, to govern allowable vessel movements based on vessel size, tide, current, draft and rules on meeting, passing and overtaking, including the conditions under which the rules apply;

6. Specification of vessel calls, either through historical data or through parameters of a "vessel generator." This requires definition of the physical characteristics of the fleet calling at the port during the period of simulation.

3.3 Key Concepts

3.3.1 Vessel Call

The driving parameter for the Monte Carlo simulation is a vessel call at the port. A fleet of distinct vessels services a port, with any one vessel in the fleet calling one or more times during the period of simulation. Each such vessel call takes place at a known or generated date and time, is identified with a specific real or synthetically generated vessel and includes one or more dock visits (intra-harbor movements are represented by multiple dock visits within a vessel call). Each dock visit consists of one or more commodity transfers. A commodity transfer is an import and/or export of a known quantity of a given commodity. Vessel calls are obtained either from historical data available at the port that is stored in the database or are generated synthetically, as described later. Historical vessel calls are stored in the Access database as a set of related tables (see the description of the VCDB, later in this report).

3.3.2 Leg

Each complete vessel call (voyage from entry to destination dock(s) through to exit) is considered to be composed of a set of "legs." A leg is a contiguous set of reaches between stopping points. It is assumed that a deep-draft vessel cannot stop except at docks or anchorages. The legs of the vessel call are thus the sets of reaches from the entrance to the first dock (Leg 1), from the first dock to the second dock (Leg 2), etc. and from the final dock to the exit (Leg *n*). A vessel can only start moving within a leg when no transit rule restrictions are activated for any of the reaches in the leg. A key assumption of the simulation is that once a vessel is moving within a leg, it has priority over all other vessels that enter the leg subsequently. If there are activated rule restrictions (as described below), the vessel must wait at the entry, dock or anchorage, until the rule restriction situation no longer exists, at which time the vessel can enter the leg.

3.3.3 Transit Rules

The user assigns transit rules to reaches of the network, from a menu of pre-defined rules that are available within HarborSym. Rules are defined in terms of the type of rule (e.g., no vessel movement, no passing), applicable condition (day, night, any time) and vessel-specific parameters that characterize the rule's application, e.g., beam, draft, length overall. For example, a rule may state that two vessels may not pass at night in a given reach if their combined beam width exceeds 250 feet (76.2 meters). Other rules within the model relate to vessel movement under maximum current conditions or specific draft limitations. Capacity limits can also be specified for docks, turning basins and anchorages/moorings.

The rules currently implemented are based on procedures of pilots on the Sabine-Neches Waterway (Texas and Louisiana) and the Port of Tampa, (Florida), USA and were developed by interviews with pilots in those ports. It is recognized that other ports may require additional rules if specific transit behavior cannot be expressed by parameterization of the pre-defined rules. In such cases, recoding the model will be necessary to incorporate the additional behavior, but once the new rules have been added they will be available for subsequent model applications.

3.3.4 Processing Logic

HarborSym is an event-driven Monte Carlo simulation model. Each vessel call is modeled individually and its interactions with other vessels are taken into account. For each iteration, the vessel calls for that iteration are accumulated and placed in a priority queue based on arrival time. When a vessel arrives at the port, the route to all of the docks in the vessel call is determined algorithmically. (Recall that the network is tree-structured, thus there is only one path between any two given points). This involves determining which turning areas are used by the arriving vessel class at the dock (as stored in the database), so that the traversal of reaches in the leg properly includes the turning area. Thus, the path a vessel will traverse is determined at the time of vessel entry.

The vessel then attempts to move along the initial leg of the route. Vessel speeds are determined based on input data; in each reach the user provides two speeds, one for vessels loaded with commodities, the other for vessels light with commodities, for each vessel class. Upon arrival, the condition of the vessel as either loaded or light with commodities is known, so the projected arrival time of the vessel in each reach of the leg is estimated based on the reach distances and the appropriate vessel transit speed stored in the database. Potential conflicts with other vessels that have previously entered the system are evaluated according to the user-defined set of rules for each reach, based on information maintained by the simulation as to the current and projected future state of each reach.

If a rule activation occurs, then the arriving vessel cannot proceed directly to its destination. It must instead either delay entry or proceed as far as possible to an available anchorage, waiting there until it can attempt to continue the journey. If the vessel can proceed, then a reach entry event is generated for the first reach of the leg and the projected arrival and departure times of the vessel in all reaches of the leg are stored for each reach. In this fashion, at any given time, each reach is aware of the vessels that are currently in the reach and those that are projected to be in the reach at times into the future. Also, during processing of the reach entry event, the reach exit time is determined, based on the vessel speed in the reach and a reach exit event is generated.

If the vessel cannot enter the system due to rule restrictions in the leg, another vessel entry event is generated at some user-specified time increment into the future, when the entry is attempted again. This process is repeated until the vessel can enter the leg. The accumulated waiting time is stored, as well as statistics on the particular transit rules that create rule activations.

As each event is added to the event queue and processed in turn, vessels move from reach to reach, eventually arriving at the dock that is the terminus of the leg. A dock entry event is then created. The time required for the vessel to exchange its cargo is calculated based upon the commodity type and quantity carried and the dock-commodity specific transfer rates. The commodity exchange rates are determined based upon a user specified distribution and are specific to each commodity type and dock pair. It is recognized that this is a simplification of the actual landside transfer process, but the emphasis of the model is not on the landside operations but on the channel improvements. After the cargo exchange calculations are completed, a dock exit event is generated. A dock exit event represents the start of a new leg of the vessel call; a set of rule testing in reaches, analogous to that which occurs with the arrival event, is carried out before it is determined that the vessel can proceed on the leg. As with the entry into the system, the vessel may need to delay departure and re-try at a later time to avoid rule violations and similarly, the waiting time at the dock is recorded.

A vessel that encounters rule conflicts that would prevent it from completely traversing a leg may be able to move partially along the leg, to an anchorage or mooring. If so, and if the vessel can use the anchorage (which may be impossible due to size constraints or the fact that the anchorage is filled by other vessels), then the vessel can proceed along the leg to the anchorage, where it will stay and attempt to depart periodically, until it can do so without causing rule conflicts in the remainder of the leg.

The determination of the total time a vessel spends within the system is the summation of time waiting at the dock, time transiting the reaches, time turning, time transferring cargo and time delayed at docks or anchorages. An input requirement is the time the vessel arrives at the system but all other times result from simulation calculations.

Section 4
Database Architecture
4.1 Overall Structure

Understanding of the HarborSym database architecture is key to understanding many aspects of the methodologies used. As noted, HarborSym is a data-driven model, with information stored in multiple databases. At present, five databases are used with HSW and HSD (3 for input, 2 for output) and two other databases are used in conjunction with the CDVG/A. All the databases are Microsoft Access™ databases. Each database contains tables (where the data is actually stored), queries (particular views of the data), forms and reports. One of the features of Access is the ability to link information that is actually stored in separate databases, so that, to the user, all of the information appears to be in a single database, but the tables are actually spread over multiple databases. HarborSym uses this architecture to separate and organize the required information. Each database type is identified by its file extension. The individual databases are not completely independent, for example vessel call information (in the VCDB) references information about individual docks (stored in the IDB), as shown in Table 2.

TABLE 2
DATABASES USED IN DEEPENING ANALYSIS

Database	File Extension	Contents/Usage
Master Database	MDB	Links together all relevant information needed for runs of HSW/HSD. Linked databases are the IDB, VCDB and ODB. This database in and of itself does not contain any study-specific content. The study-specific content is contained in the linked IDB and VCDB.
Input Database	IDB	Description of the port, channels, docks and transit rules, as well as vessel types, vessel classes and commodity categories.
Vessel Call Database	VCDB	Description of vessels, vessel calls and commodity transfers. Must be associated with an IDB.
Output Database	ODB	Stores output results from multiple runs of HSW or HSD.
Scenario Output Database	SODA	Stores detailed output associated with a single run of HSW/HSD.
Analyzer Generator Database	MDB	Serves as an interim user interface for functionality associated with data checking and the CDVG/A, links to a MDB, IDB, VCDB and FCDB.
Forecast Database	FCDB	Stores information about commodity forecasts at docks, constraints on vessel class capability to carry commodities and serve individual docks and statistical information (cumulative density functions and regression equations) needed for synthetic vessel generation. Requires an association with an IDB.

This structure is somewhat complex, as illustrated in Figure 1, and undoubtedly could bear a re-examination in light of the needs of the deepening analysis.

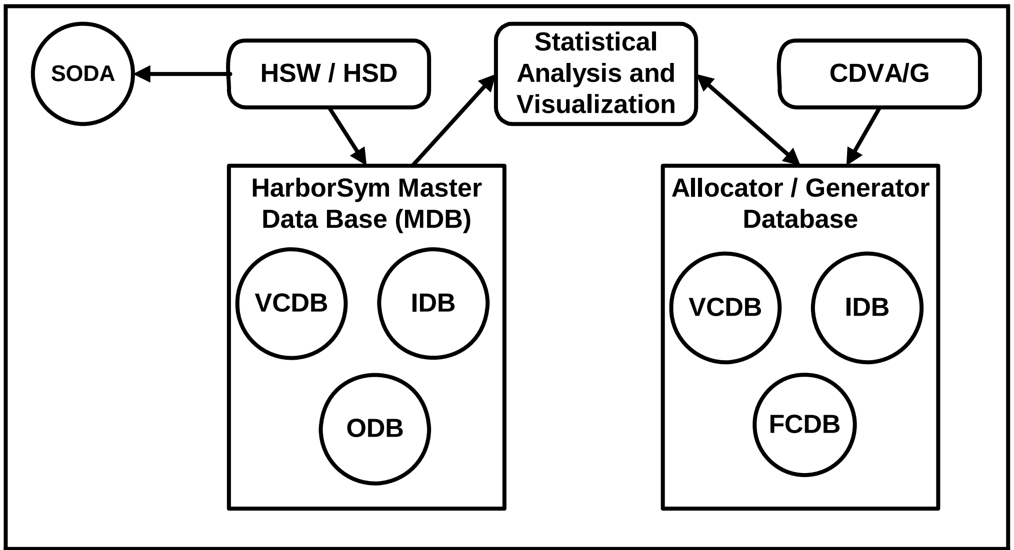

FIGURE 1
RELATIONSHIP OF DATABASES AND COMPONENTS

4.2 Vessel Call Database

For purposes of this report, a basic understanding of the structure of the VCDB is required. A number of hierarchies exist that are important:

1. Vessel Class Hierarchy

   Each individual vessel is a member of a vessel class, which itself is within a vessel type. For example, vessel types may include Passenger Vessels, Container Ships, Tankers, Vehicle Carriers, etc. This is primarily a definition of the function of the vessel. Within a type, individual vessel classes exist, typically organized by some measures of size/capacity: large, medium and small tankers. Individual vessels are then assigned to one of the existing classes. This vessel type and class information are stored in two related tables in the IDB, while individual vessels and their calls are stored as a separate hierarchy in the VCDB, described below.

2. Vessel Call Hierarchy

   Each unique vessel can make one or more vessel calls (arrival at the port at a given date/time). At each vessel call, the vessel can make one or more dock visits, and, at each dock visit, one or more commodity transfers. Four tables within the VCDB implement this structure:

   a. A table of unique vessels, with physical descriptions of beam, length overall, design draft, capacity (DWT) and tons per inch displacement (TPI). This table is stored in the VCDB and references vessel class information stored in the IDB.

b. A table of vessel calls, giving the unique vessel making the call, the arrival date and time, and the entry draft. The deepening version adds information on the route group, which provides information on the ocean distances. This table is stored in the VCDB and references route group information stored in the IDB.

c. A table of dock visits associated with each vessel call, identifying the specific dock that is visited (and for the case of multiple dock visits, the order of the visit within the vessel call). This table is stored in the VCDB and references dock information stored in the IDB.

d. A table of commodity transfers, giving the import and export amounts of a given commodity type associated with the dock visit. This table is stored in the VCDB and references commodity category information stored in the IDB.

This structure is shown schematically in Figure 2, where CT1, CT2 and CT3 represent different commodity transfers associated with each vessel call.

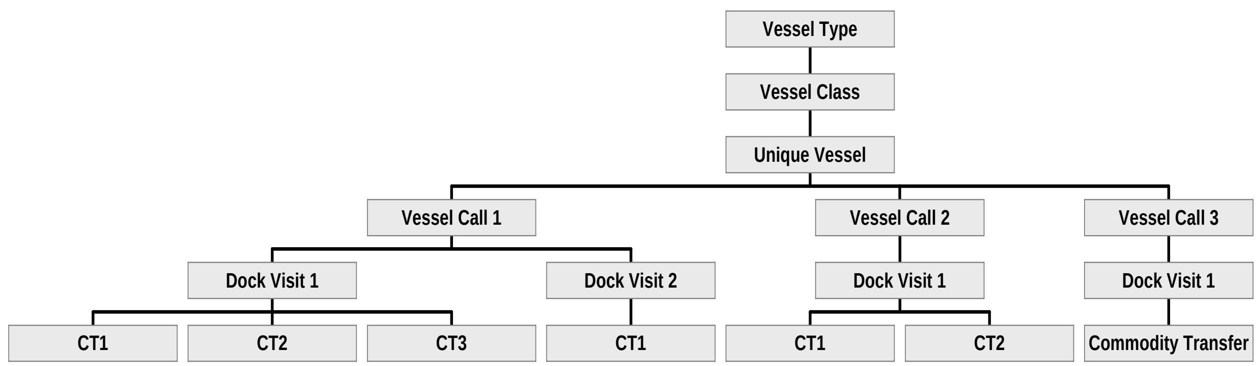

FIGURE 2
VESSEL HIERARCHY

This structure allows a number of alternate views of this information:

- Vessel Call—Knows which vessel it is, the time of arrival at port, where it needs to go (which docks) and the commodities it needs to transfer;
- Dock—Sees a stream of commodity transfers, from different vessels, satisfying demand at the dock;
- Commodity—Time-based flow of commodities to the port as a whole and to individual docks;
- Fleet—the set of vessels servicing port, organized by class, inter-arrival time, etc.

Storing historical vessel calls in this hierarchical structure supports the simulation modeling and can also be used for a variety of database queries, statistical summaries and graphical visualizations of the data. Synthetically generated vessel calls are also stored in the same structure, allowing use of the same tools.

4.3 Addition of Route Group Information

The deepening analysis requires additional information for each vessel call, specifying the ocean distance to be assigned to the call. The proposed implementation uses the concept of "route groups" as an alternative to directly specifying this distance for each vessel call. A route group is a named itinerary or portion thereof that a vessel may travel before and after visiting the port under study, for example Western Europe – New York – Brazil. Itineraries can be defined generally by larger geographic areas or more specifically where individual ports are known. If exact port-to-port itineraries are known, then the distance can be fixed, otherwise, a distribution of distances can be specified, for example if the exact port in Western Europe is not known. This is an indirect method of obtaining the ocean distance and is expected to make data development and incorporation of variability in distance, simpler for the user.

Route Groups are defined in a table located in the IDB. This table describes three triangular distributions for each route group (prior port, next port and additional distance). Note that these are kept separate in the table, so that a route group might refer to a more reality-based route (e.g., prior port Halifax – port under study Savannah – subsequent port Rotterdam – Additional distance return to Halifax). The distributions are then used to separately generate the three distances for each vessel call. Internal to HSD, only the total distance (sum of prior port, next port and additional distance) is used. Consequently, it should be possible, as a simplification, to set PriorPort and NextPort to zero, and just use the AdditionalSeaDistance (or any of the three) to represent the total distance distribution. In addition, if each of the three parameters of the triangular distribution for a distance (e.g., prior port distance) is set to the same value, then the route group will return a fixed value, for example, 1,107 nautical miles between Halifax and Savannah. An example of how this information is described in the route group table is shown in Table 3 (bogus information).

TABLE 3
EXAMPLE OF HOW INFORMATION IS DESCRIBED IN THE ROUTE GROUP TABLE

Route Group Short Description	Prior Port Distance P1	Prior Port Distance P2	Prior Port Distance P3	Next Port Distance P1	Next Port Distance P2	Next Port Distance P3	Additional Sea Distance P1	Additional Sea Distance P2	Additional Sea Distance P3
RG1	100	200	300	300	400	500	250	350	450
RG2	200	400	600	600	800	1000	500	700	900
RG3	300	500	700	200	300	400	100	149	234

Each vessel call must be associated with a Route Group, by assigning one of the stored route groups to each individual call. This can be done manually for historic vessel calls or assigned based on statistical percentages using the typical distances that groups of vessels within a vessel class travel, by providing the percentage of calls within a class that are associated with each route group. Because costs (in port and at sea) are associated with a vessel class and due to the nature of the calculations within HSD, the exact assignment of sea distance to individual calls is not strictly necessary, as long as the overall assignments to the class are reflective of the distribution of distances traveled by vessels of that class. This process has been implemented directly in the CDVG/A for future/synthetic VCDBs and as a separate process after the import step within the HSD UI for existing/historic vessel calls.

4.4 Additional Vessel Class Level Information

In order to support the required calculations of ocean cost, it is necessary to translate sea distance into time and apply the cost per hour at sea. Cost per hour is defined at the vessel class level (in the IDB), so it is reasonable to put sailing speed at this same level. Accordingly, the user must provide information on vessel speed at sea for the ocean legs of the voyage. This is defined as the usual triangular distribution, with three parameters (minimum, most likely and maximum speed at sea). Given this information for the class, the vessel call can be associated with a sailing speed, allowing for the needed translation of sea distance to time and time to cost. For the future, the possibility of associating speed with other physical characteristics of the vessel should be considered, to provide a better estimate of ocean travel times. If such correlations are known, there should be sufficient information available to the HSD to develop improved speed estimates beyond those developed from a distribution at the vessel class level.

Additional information, specified at the vessel class level, that supports the behavior of the HSD, is the inclusion of minimum and maximum allowable sailing draft. This information is used to constrain draft changes at docks, allowing the model to better represent draft changes associated with transfers such as fuel bunkering and ballasting that are not specifically modeled.

4.5 Unit of Measure Information

Cost per commodity unit transferred is the basic metric for deepening analysis. This has generally been taken to be tons. However, other units may be employed (passengers, containers, vehicles, etc.) and HSW associates commodities with units of measure. This is made more explicit in HSD where a separate listing of possible units of measure is maintained in the master database (MDB) and each commodity is then assigned to a unit of measure (in the commodity category table in the IDB). The number of tons per unit and the value (dollars per unit) are also specified for each commodity category. This allows HSD to keep commodity transfers separate by unit and also to provide information on value transferred (for cases where low tonnage cargo might be of high value). Existing Corps practice seems to be oriented towards using tons exclusively, but the inclusion of units of measure and value allows HSD to provide other outputs that may be worthwhile in the economic analysis. Existing units of measure currently specified are:

- Tons
- Passengers
- Containers
- Automobiles

This information is not currently designed to be user-editable but additional units of measure can readily be added to the master list.

Section 5
Economic Analysis

5.1 Existing Practice

The basic economic analysis for deepening is designed as an extrapolation of the existing methodologies for vessel cost calculations under with- and without-project conditions, as shown in spreadsheets based on work of Gloria Appell of SAG and Ian Mathis of IWR. These spreadsheets assume a single vessel, with a known at sea distance, with different draft-dependent loadings under with- and without-project conditions. Costs are calculated separately for the time spent within the harbor and the time spent at sea and unit costs in $/ton for the round-trip are calculated. An example of the sheet provided by Ian Mathis is shown in the attached appendix. It is not clear whether/if these calculations, in actual application, take into account the variability in fleet, capacity and ocean distances that are present in a port.

The essential elements of the calculation are:

1. Assign vessel loading under without-project and deepened project conditions.

2. Assign vessel distance traveled at sea.

3. Assign ancillary costs associated with the port visit (pilotage, costs associated with docking, cargo loading/unloading).

4. Calculate the total costs of the voyage under the with- and without-project condition as the sum of three elements—at sea cost, in port cost and ancillary costs:

   a. At sea costs are taken as identical. [Note that, under some situations, deepening a channel can result in different vessel routings in a voyage, such that the order of ports of call might switch so that the newly deepened port is called first, resulting in a change in at sea costs that would need to be taken into account.]

   b. The primary difference is calculated within-port costs is the additional cost associated with transferring a greater amount of commodity, in the with-project case (greater time to load/unload). The assumption appears to be that all of the incremental tonnage carried under the with-project condition is transferred at the port under study.

   c. Ancillary costs may vary slightly, but are largely the same.

5. Determine the unit costs (total $cost/total ton carried).

5.2 HarborSym Deepening Approach

The HSD approach, at present, essentially follows these calculations for each individual vessel call. Ocean distances for the call are determined using the route group approach described above and translated to time by using the vessel speed at sea (defined as a triangular distribution at the vessel class level) and then to cost using class level values of cost/hour (note cost per hour is not currently defined as a distribution, rather it is a point estimate).

HarborSym calculates, as usual, the "in harbor" costs. Costs associated with increased cargo show up as increases in loading/unloading time. Note that not all ancillary costs are directly included in HarborSym, but are presumed to be subsumed in time costs associated with docking/undocking. It may be advisable to develop better procedures for explicit incorporation of ancillary costs associated with a call and commodity transfers within HarborSym, consistent with the overall approach of transparency in data. Pilotage costs could be associated with an individual call or all calls of vessels of a given class and unloading time might be better represented by a functional representation rather than a simple commodity quantity times loading/unloading rate. The possibility of doing exploratory data analysis on historical commodity transfer quantities associated with dock times stored in VCDB, to explore these functional relationships, should be considered.

At present, costs are rolled up by vessel class and unit of measure. It is desirable that an individual vessel call (which can, within the HarborSym structure, carry multiple commodities) carry only commodities measured in the same units (passengers, tons, containers, vehicles, etc.). Examination of Tampa call data shows that each vessel class carries only one type of unit, so this may not be a particularly constraining requirement. If all calls by a given vessel class are in commensurate units, then analysis is simplified. Outputs can then be generated showing class-related and unit-related statistics, as in the sample output developed from the HSD proof-of-concept as shown in Table 4 (some data bogus):

TABLE 4
CLASS LEVEL SUMMARY OUTPUT FROM HSD PROOF-OF-CONCEPT

Vessel Class	Statistic	Description	N	Average	SD	Max	Min
ContainerLg	AverageVesselPortCost		5	17966.95	586.87	18482.45	17151.36
ContainerLg	AverageVesselQExport	Containers	5	347.24	1.10	348.21	345.93
ContainerLg	AverageVesselQImport	Containers	5	686.10	1.40	687.35	684.44
ContainerLg	AverageVesselSeaCost		5	835021.99	368228.71	1268084.83	546962.10
ContainerLg	AverageVesselTonsExport	Containers	5	5555.75	17.63	5571.40	5534.83
ContainerLg	AverageVesselTonsImport	Containers	5	10977.64	22.47	10997.61	10951.00
ContainerLg	AverageVesselTotalCost		5	852988.93	367656.50	1285236.19	565386.95
ContainerLg	AverageVesselValueExport	Containers	5	5555.75	17.63	5571.40	5534.83
ContainerLg	AverageVesselValueImport	Containers	5	10977.64	22.47	10997.61	10951.00
ContainerLg	CostPerTon	Containers	1	51.59	0.00	51.59	51.59
ContainerLg	OverallTotal	ContainerLgTotalClassCost	1	4264944.66	0.00	4264944.66	4264944.66
ContainerLg	TotalPort	ContainerLgTotalClassCost	1	89834.74	0.00	89834.74	89834.74
ContainerLg	TotalSea	ContainerLgTotalClassCost	1	4175109.93	0.00	4175109.93	4175109.93
LargeBulk	AverageVesselPortCost		10	29873.68	4272.75	36416.29	21898.82
LargeBulk	AverageVesselQExport	Tons	10	4731.13	14961.16	47311.34	0.00
LargeBulk	AverageVesselQImport	Tons	10	36509.14	17362.36	55432.80	0.00
LargeBulk	AverageVesselSeaCost		10	978099.52	309543.57	1358788.22	599084.69
LargeBulk	AverageVesselTonsExport	Tons	10	4731.13	14961.16	47311.34	0.00
LargeBulk	AverageVesselTonsImport	Tons	10	36509.14	17362.36	55432.80	0.00
LargeBulk	AverageVesselTotalCost		10	1007973.20	309718.55	1390259.04	634511.60
LargeBulk	AverageVesselValueExport	Tons	10	52042.47	164572.74	520424.69	0.00
LargeBulk	AverageVesselValueImport	Tons	10	401600.51	190985.91	609760.77	0.00
LargeBulk	CostPerTon	Tons	1	24.44	0.00	24.44	24.44
LargeBulk	OverallTotal	LargeBulkTotalClassCost	1	10079731.99	0.00	10079731.99	10079731.99
LargeBulk	TotalPort	LargeBulkTotalClassCost	1	298736.82	0.00	298736.82	298736.82
LargeBulk	TotalSea	LargeBulkTotalClassCost	1	9780995.17	0.00	9780995.17	9780995.17

Outputs are also available, organized slightly differently by unit of measure and iteration of the simulation. The following information is available.

1. Current Iteration Number
2. Unit of Measure Description (tons, containers, passengers, etc.
3. Vessel class name or "Total"
4. Total units imported (all vessel calls leaving system)
5. Total units exported (all vessel calls leaving system)
6. Total units imported + Total units exported (all vessel calls leaving the system)
7. Total value imported (all vessel calls leaving system)
8. Total value exported (all vessel calls leaving system)
9. Total value imported + Total value exported (all vessel calls leaving the system)
10. Total Tons imported (all vessel calls leaving system)
11. Total Tons exported (all vessel calls leaving system)
12. Total tons imported + Total tons exported (all vessel calls leaving the system)
13. Cost of calls, allocated based on tonnage, for import tons
14. Cost of calls, allocated based on tonnage, for export tons
15. Total cost of calls, allocated based on tonnage, for export + import tons

16. Cost of calls, allocated based on value, for import tons
17. Cost of calls, allocated based on value, for import tons
18. Total cost of calls, allocated based on value, for export + import tons
19. Allocated Cost By Import Tons/Tons Imported
20. Allocated Cost By Export Tons/Tons Exported
21. Total Cost Allocated By Tons/Total Tons
22. Allocated Cost By Import Value/Value Imported
23. Allocated Cost By Export Value/Value Exported
24. Total Cost Allocated By Value/Total Value

An example subset of this information is shown in Table 5 (selected columns, first iteration only), again developed from the proof-of-concept HSD. Information is separated out by unit of measure, import/export/total, and vessel class.

TABLE 5
ITERATION-LEVEL OUTPUT BY VESSEL CLASS AND UNIT OF MEASURE

Unit of Measure	Vessel Class	Tons Imported	Tons Exported	Total Tons	Allocated Cost By Import Tons	Allocated Cost By Export Tons	Total Cost Allocated By Tons	Cost Per Ton Import	Cost Per Ton Export	Cost Per Ton Total
Tons	Total	7204126	3150742	10354868	511436149	84762470	596198619	70.992	26.902	57.577
Tons	SmallBulk	80704	95560	176264	4352874	2815603	7168478	53.936	29.464	40.669
Tons	MediumBulk	409370	1178362	1587733	12138993	22792205	34931199	29.653	19.342	22.001
Tons	LargeBulk	573356	303603	876960	9011590	3689535	12701126	15.717	12.152	14.483
Tons	SmallGenCargo	36542	95413	131956	4592023	7537399	12129423	125.662	78.997	91.92
Tons	MediumGenCargo	277813	415476	693289	25927607	17149519	43077126	93.327	41.277	62.134
Tons	LargeGenCargo	112114	21825	133939	11496427	1099778	12596205	102.542	50.389	94.044
Tons	OceanDryAll	952888	1028807	1981695	40654435	27757641	68412077	42.664	26.980	34.522
Tons	OceanTankSmall	185770	0	185770	24642908	0	24642908	132.653	0.000	132.653
Tons	SmallTanker	0	2614	2614	0	509308	509308	0.000	194.793	194.793
Tons	MediumTanker	364063	3334	367398	25799565	629788	26429353	70.865	188.871	71.936
Tons	LargeTanker	2031683	5744	2037427	107548424	781689	108330114	52.936	136.085	53.170
Tons	SmallLPG	264809	0	264809	9885395	0	9885395	37.330	0.000	37.330
Tons	LargeLPG	306310	0	306310	6510298	0	6510298	21.254	0.000	21.254
Tons	OceanTankLarge	1608697	0	1608697	228875603	0	228875603	142.274	0.000	142.274
Passengers	Total	0	0	0	0	0	0	0.000	0.000	0.000
Passengers	Protocol1	0	0	0	0	0	0	0.000	0.000	0.000
Passengers	Protocol2	0	0	0	0	0	0	0.000	0.000	0.000
Containers	Total	121664	131271	252936	4141201	3819061	7960263	34.038	29.093	31.471
Containers	ContainerSmall	1043	68162	69206	29174	1788854	1818028	27.948	26.244	26.270
Containers	ContainerLarge	120620	63108	183729	4112027	2030207	6142235	34.091	32.170	33.431
Automobiles	Total	22323	7558	29882	2214694	916799	3131493	99.207	121.289	104.793
Automobiles	VehiclesCarrier	22323	7558	29882	2214694	916799	3131493	99.207	121.289	104.793

Section 6
HarborSym Deepening Version

6.1 Deepening Version Enhancements

The following are the major enhancements to the widening version that have been implemented in the proof-of-concept version of HSD:

1. Incorporation of the "route group" concept to add vessel distance at sea and associated cost for a vessel call. Each vessel call is assigned to a route group and individual distances are generated from the distributions for the route group, for each vessel call and the total distance (sum of prior port, next port and additional sea distance) is used in cost calculations for the vessel call.

2. Development of new summary of information based on units of measure and commodity value. Each commodity category is associated with a specific unit of measure (e.g., tons, passengers, containers, automobiles, etc.). Value per unit and tons per unit are defined at the commodity category level. Commodity transfers are specified in the natural units for the commodity, e.g., number of passengers, number of containers. Internal to the kernel, calculations of tonnage and value transfers are made, to allow for commensurate comparisons.

3. Revision to the draft adjustment behavior at a dock to include incorporation of vessel class level minimum and maximum sailing drafts. Draft adjustment constrains the vessel departure draft to be between the minimum class sailing draft, at the low end and the minimum of the next leg controlling draft/maximum vessel design draft/maximum class sailing draft, at the high end. A vessel that imports to the port will have its draft reduced by the appropriate tonnage associated draft change amount, but is constrained to leave a dock at no less than the minimum sailing draft, which should reflect the need to take on ballast.

4. Additional outputs that help to trace/debug the new features and provide additional information useful for economic deepening analysis, in particular detailed cost elements summarized by vessel class and commodity units, tons and value.

6.2 Cost Allocation Calculations

The goal of the deepening version is to assist the user in evaluating the effects of proposed channel deepening in terms of transportation cost savings for various alternatives. While overall (port level) information is of primary interest, more detailed information can be associated with vessel classes, commodities and individual vessel calls, may also be of interest. Allocation calculations, carried out at the vessel call level, are the key to this procedure.

Each vessel call has a known (calculated) associated cost, based on time spent in the harbor and ocean voyage and cost per hour. Also for each vessel call, the total quantity of commodity transferred to the port (both import and export) is known, in terms of commodity category, quantity, tonnage and value. The basic problem is to allocate the total cost of the call to the various commodity transfers that are made. Note that it is recognized that deepening economic analysis may, at some point, deal not just with commodity quantities transferred, but also with total quantities carried on the vessels, including commodities that remain on board after the port visit. Placeholders for storing retained tonnage in the VCDB have been developed for possible future use.

Each vessel call may have multiple dock visits and multiple commodity transfers at each visit, but each commodity transfer record refers to a single commodity and specifies the import and export tonnage. Also, at the commodity level, the "tons per unit" and "value per unit" for the commodity are known, so that each commodity transfer can be associated with an export and import tonnage and an export and import value. As noted above, the process is greatly simplified (at least in terms of understanding) if all commodity transfers within a call are for categories that are measured in the same unit, but that need not be the case.

When a vessel leaves the system, the total tonnage, export tonnage, import tonnage and total value, export value and import value transferred by the call are available, as is the total cost of the call. The cost per ton and cost per value can be calculated at the call level (divide total cost by respective total of tonnage or value). Once these values are available, it is possible to cycle through all of the commodity transfers for the vessel call. Each commodity transfer for a call is associated with a single vessel class and unit of measure. Multiplying the tons or value in the transfer by the appropriate per ton or per value cost, the cost totals by class and unit for the iteration can be incremented. In this fashion, the total cost of each vessel call is allocated proportionately to the units of measure that are carried by the call, both on a tonnage and a value basis. Note that this approach does not require that each class or call carry only a commensurate unit of measure. Rather, the assumption is made that we can allocate based on cost per ton and cost per value.

The model calculates import and export tons, import and export value, and import and export allocated cost (both on a per ton and per value basis). This information allows for the calculation of total tons, total value and total cost, allowing for the derivation of the desired $/ton, $/value metrics at the class and total level. The model can thus deliver a high level of detail on individual vessel, class and commodity level totals and costs.

Section 7
Commodity-Driven Vessel Generator/Allocator
7.1 Background

The need to develop synthetic HarborSym inputs for widening analysis has been recognized for some time. Historical information on vessel calls is the appropriate starting point for analysis, but forecast changes in commodity transfers and fleet change must be reflected in a generated VCDB. Initial work on such a generator started in 2004. Design considerations were:

- Output needed to be a VCDB, capable of being run through HarborSym;
- The user would provide annual commodity forecasts at the dock level;
- The user would provide forecasts of annual fleet availability at the vessel class level, in terms of the number of vessel calls in a year made by the class;
- The model would develop synthetically generated vessels with explicit physical characteristics based on statistical models;
- The model would attempt to load the available fleet in order to satisfy dock level import and export forecasts

The design of the initial version incorporated a two-step process:

1. Generate a synthetic fleet of vessels that could service the port;
2. Allocate commodity forecast demand to individual vessels from the generated fleet, creating a vessel call and "using up" an available call from the synthetic fleet.

After development of the initial version, it was recognized that a CDVG/A could also be useful in doing deepening studies, if it incorporated a capability to load vessels constrained by draft. It has since become a central feature in the proposed deepening design.

At the same time, it was also recognized that the VCDB data structure would allow exploratory data analysis on vessel calls, for example to look at vessel inter-arrival times and to develop needed statistical data used in generation of synthetic vessels. This capability has subsequently been conceptualized as a set of visualization, statistical analysis, data checking and summarization tools that can be applied to the various input and output databases used with HarborSym.

The CDVG/A process required the addition of yet another database, the forecast database (FCDB), to provide input information to the process and tools were also needed to populate the FCDB. A prototype methodology was built (using Microsoft Access and the R Statistical Package) to take an historical VCDB and populate the needed tables of the FCDB, with the intent that the resultant FCDB would be a starting point for modifications by the user. This was later expanded to store additional queries that would be useful in checking and analyzing the historical VCDB.

The initial efforts have been modified, as part of the design/proof-of-concept effort, to develop a CDVG/A that does load based on draft limitations. To date, this has been lightly tested and examined.

7.2 Commodity-Driven Vessel Generator/Allocator Proof-of-Concept

7.2.1 Overall Process

The general approach used is roughly as follows:

The user provides specification of:

1. Commodity forecasts (annual import/export) at each dock
2. Dock depth limitations at each dock, for the project alternative being considered
3. Description of the available fleet, by vessel class:
    a. Statistical data describing the cumulative distribution function for capacity (deadweight tons, or DWT) of vessels within the class
    b. Regression information for deriving length overall (LOA), Beam and Design Draft from capacity
    c. Regression information for calculating TPI based on Beam, Design Draft, Capacity and LOA
4. The number of potential calls that can be made annually by each vessel class
5. Logical constraints describing:
    a. Commodities that can be carried by each vessel class
    b. Vessel classes that can be serviced at each dock
6. Parameters, defined at the vessel class/commodity level, for determination of how individual calls and commodity transfers are generated.

Most of this information is stored in an Access database referred to as a forecast database, with an .fcdb extension. Procedures exist, using the R statistical package and some Access routines, to populate much of this information, based on an examination of an existing VCDB created from historical data. That is, statistical measures, commodity transfer amounts and logical constraints can all be derived from an examination of a set of historical calls that have been stored in a VCDB.

Given the above information, the process is as follows:

1. Generation of a fleet of specific vessels.

2. The number of vessel calls by class is known (item 4 above), as is a statistical description of the characteristics of the vessel class.

    a. One specific vessel is generated for each call in the class.

    b. Capacity of the vessel is set by making a random draw from the cumulative density function that is stored for the class.

    c. Based on the regression coefficients that are stored for the class, each of which is of the form log (parameter) = a + b* log (Capacity), LOA, Beam and Design Draft are determined for the vessel.

        i. A linear regression of the form:

            TPI = a + b*Beam + c*Design Draft + d*Capacity + e*LOA

            Is used to calculate the TPI based on the previously generated physical characteristics and coefficients stored, at the class level, for this regression model. This regression model was proposed and tested by Shana Heisey of IWR in August of 2004 (personal communication). The fundamental approach is not altered if other, more complex models, are used.

3. Attempt to assign a portion of the commodity forecast at a dock to a vessel

    a. Each commodity forecast at a dock is processed in turn. If a vessel is available that can serve the commodity at the dock, it is loaded for either export only, import only or both export and import. Potential vessels that can carry the forecast are assigned in a user-specified (at the class level) allocation order, so that the most economical vessel classes will always be used first. Under the assumptions currently applied, a vessel call handles a single commodity at a single dock, i.e., each call consists of a single dock visit and a single commodity transfer (which may contain both an export quantity and an import quantity). The specification of the actual call assignment and commodity loading is described in detail later in this report, but is dependent upon the maximum that a vessel can draft and still reach and leave the dock.

    b. The amount of the commodity forecast that is actually carried on the vessel is used to decrement the remaining quantity to be allocated for that particular forecast.

    c. After a single vessel call is assigned to a particular forecast, the total number of remaining available vessels for the class is decremented (recalling that each vessel makes a single call) and the next forecast in turn is processed. That is, each forecast gets a chance to have a portion of its demand satisfied by a single vessel call and then the next forecast is handled. This is to prevent all of the most efficient vessels from being assigned to a single forecast.

d. This process proceeds, in a loop, continually attempting to assign commodity to a forecast from the remaining available fleet. Whenever a successful assignment is made, this generates a vessel call, dock visit and the associated commodity transfer. Forecasts that have not been fully satisfied are re-visited, as long as there are available vessels that can attempt to satisfy the forecast.

e. This effort continues until no more assignments to a vessel call can be made, either because all forecasts have been satisfied or there is no available vessel that can service the remaining quantities (because there is no vessel of the required class that can handle the particular commodity/dock combination of the forecast or because no vessel can be loaded to satisfy the dock controlling depth constraint).

4. At the end of the process, when no more assignments are possible, arrival times are assigned for each vessel. At present, a simplified algorithm is used to assign arrival times, assuming a uniform inter-arrival time for all calls within a class. After the allocation process is complete, the number of calls made by each class of vessel is known. This is used to calculate the inter-arrival time of vessels for that class (recall that the model is an annual model). The arrival of the first vessel in the class is set randomly at a time between the start of the year and the calculated inter-arrival time, but all subsequent vessel arrivals for the class will have the identical inter-arrival time. A proposed enhancement is to provide seasonality in commodity forecasts, specifying a start and end date for the dock-level commodity forecast, to be more reflective of actual patterns. Under that approach, the calls within a class that serve the particular seasonal forecast would have their arrivals uniformly distributed over the season.

5. The generated vessel calls are written to a VCDB and the user is presented with information on which forecasts were satisfied, any remaining unsatisfied forecasts and detailed information on each vessel loading and the vessels that were used to satisfy each forecast.

The intended approach is to work iteratively within the CDVG/A, making runs, examining the forecast satisfaction that is achieved and varying the fleet character and composition for subsequent runs, so that the final result is a balanced, reasonable projection of vessel calls to satisfy the input forecast demand. The CDVG/A provides extensive output to assist the user in this regard, as described in a later section.

7.2.2 Detailed Specification of Vessel Call Loading Assignment

Once a vessel is determined to be available for loading for a particular forecast, it is necessary to determine the type of loading, the quantity loaded and the initial draft of the vessel. The process is somewhat complex. The user can control certain aspects of the behavior through data specification, in particular the type of call (import, export or both) and the percent of capacity that is loaded for import and export.

Recall that it is possible for a given vessel call to attempt to satisfy an import demand, an export demand or simultaneously an import and export demand (as for a passenger or containership). Four possibilities are defined for this behavior, with specification at the Vessel Class/Commodity Category level:

1. Export Only
2. Import Only
3. Random
4. Both Export and Import

A cruise ship carrying passengers would typically be defined as "Both Import and Export," as it is normal for it to both drop off and acquire passengers on a single call. Note that, for passenger ships specifically that depart and return from the same port of call, the same passenger is counted as an export on departure and as an import to the port on the return. Care must be taken in interpreting results in this case, to insure that unintended "double-counting" of passengers does not take place.

Certain combinations of class and commodity category might be import only or export only. A "Random" assignment designates that calls from the class/commodity combination can be either import or export at a dock, but not both simultaneously. If a "Random" type is assigned, then the ratio of calls that will be randomly generated as import is specified.

The quantity of a vessel's capacity that is to be loaded for satisfaction of the import and export demands is described, again at the Vessel Class/Commodity Category level, by a triangular distribution that specifies a loading factor. A minimum, most likely, and maximum, in percent of total available capacity, is defined for both export and import.

Specification of this information is provided in the Vessel Class Commodity Category table (in the FCDB), shown as Table 6.

TABLE 6
VESSEL CLASS COMMODITY CATEGORY LOADING CONTROL SPECIFICATION TABLE

Vessel Class	Commodity Category	Loading Factor Import P1	Loading Factor Import P2	Loading Factor Import P3	Loading Factor Export P1	Loading Factor Export P2	Loading Factor Export P3	Import Export Control Type *	Percent of Randomly Generated Calls that are Imports
ContainerLarge	Containers	100	100	100	30	30	30	Both	100
ContainerSmall	Containers	25	25	25	100	100	100	Both	100
LargeBulk	DryBulk	100	100	100	100	100	100	Random	50
LargeGenCargo	GeneralCargo	100	100	100	100	100	100	Both	100
LargeLPG	LPG/NH3	100	100	100	100	100	100	Import	100
LargeTanker	LiquidBulk	100	100	100	100	100	100	Import	100
MediumBulk	DryBulk	100	100	100	100	100	100	Random	50
MediumGenCargo	GeneralCargo	100	100	100	100	100	100	Random	70
MediumTanker	LiquidBulk	100	100	100	100	100	100	Import	100
OceanTankLarge	LiquidBulk	100	100	100	100	100	100	Import	100
OceanTankSmall	LiquidBulk	100	100	100	100	100	100	Import	100
OceanDryAll	DryBulk	100	100	100	100	100	100	Random	70
Protocol1	Passengers	100	100	100	100	100	100	Both	100
Protocol2	Passengers	100	100	100	100	100	100	Both	100
SmallGenCargo	GeneralCargo	100	100	100	100	100	100	Import	100
SmallLPG	LPG/NH3	100	100	100	100	100	100	Import	100
SmallTanker	LiquidBulk	100	100	100	100	100	100	Import	100
VehiclesCarrier	Vehicles	100	100	100	100	100	100	Import	100

*** Both Export and Import = Both; Import Only = Import**

When a vessel is available for satisfying a demand, first the type of satisfaction (import only, export only, random or both) is determined, as noted above. If “random” is associated with the current class/commodity, then a random draw is made from a uniform distribution and compared with the user-specified import ratio, to determine if the call is import only or export only. For example, if the user has entered a value of 70 percent for imports, indicating that 30 percent of the calls are exports, then a random draw is made from a uniform (0,1) distribution. If the random number is less than or equal to 0.7, then the call is assigned as an import, otherwise it is assigned as export.

Once the type of call is determined, the next issue is to ascertain how much capacity can be loaded on the vessel while satisfying the draft constraints. The process is similar for both export and import. First, a draw is made from the respective triangular distribution to get a percentage loading factor. This is then applied to the vessel DWT to get a tentative quantity to be loaded. The additional draft implied by this quantity is calculated, based on the vessel TPI. A value of minimum draft for each vessel has previously been calculated, based on an assumption that the vessel DWT is associated with the vessel design draft. The minimum draft from which loading can start is then calculated as:

$$\text{Minimum Draft} = \text{Design Draft} - (\text{DWT}/\text{TPI})/12.0$$

The total draft associated with the tentative loading is then calculated as:

Total Draft (tentative loading) = Minimum Draft + Underkeel Clearance + Additional Draft associated with Tentative Loading

If this tentative draft is greater than the limiting depth to the dock (user input), then the quantity loaded must be reduced, so that the calculated draft is less than the limiting depth to the dock. This calculation is carried out, to determine if the tentative loading can be reduced sufficiently to meet this goal. If so, then the vessel is loaded to that level. If not, then the vessel cannot service the allocation. Note that the CDVG/A does not explicitly incorporate tide.

At this point, the loading is known and the initial draft (at the bar) must be determined. A class level "minimum sailing draft" has been specified by the user at the vessel class level. This minimum sailing draft reflects the ballasted draft at which a light vessel will sail. If a vessel is handling an export only, then it is assumed to arrive light, at the minimum sailing draft. If a vessel is handling an import to the port, then it arrives at the draft associated with the import loading (which may have been reduced to the limiting depth at the dock).

7.2.3 Outputs from the CDVG/A

The CDVG/A generates a synthetic VCDB. In addition, it generates a number of ASCII and CSV (Microsoft Excel-compatible) files to allow for examination and checking of the process and writes information on the allocation results into an Allocation Results table in the forecast database. An Allocation Output database should be created to store these results, similar to the scenario output database associated with an individual run of HSW or HSD. At present, there is little or no user control over the generation of output files and similar user output control to that currently contained in HSW and HSD should also be developed (individual control over each output file/format).

7.2.3.1 Allocation Results

The primary output is the summary of allocation results. This output shows the degree to which each dock/commodity forecast is satisfied as shown in Table 7:

TABLE 7
ALLOCATION RESULTS SATISFACTION OUTPUT

Commodity Category	Dock Code	Import Quantity	Import Allocated	Import Deficit	Export Quantity	Export Allocated	Export Deficit	Number of Unique Vessels
Passengers	St. Petersburg	68.00	0.00	68.00	0.00	0.00	0.00	0
LiquidBulk	St. Petersburg	86275.40	86275.40	0.00	0.00	0.00	0.00	10
GeneralCargo	Port Manatee	1084341.03	1084341.03	0.00	105012.89	105012.89	0.00	47
LiquidBulk	Port Manatee	1216780.63	1216780.63	0.00	25798.09	0.00	25798.09	38
DryBulk	Port Manatee	1164658.58	1164658.58	0.00	436200.09	436200.09	0.00	52
DryBulk	Port Tampa	583030.88	583030.88	0.00	224153.82	224153.82	0.00	31
LiquidBulk	Port Tampa	1565778.83	1565778.83	0.00	0.00	0.00	0.00	58
GeneralCargo	Port Tampa	490.00	490.00	0.00	0.00	0.00	0.00	1
LPG/NH3	Alafia	27331.04	27331.04	0.00	0.00	0.00	0.00	2
LiquidBulk	Alafia	350620.00	350620.00	0.00	0.00	0.00	0.00	15
DryBulk	Alafia	365614.01	365614.01	0.00	1361075.80	1361075.80	0.00	82
GeneralCargo	Big Bend	383382.88	383382.88	0.00	41046.56	41046.56	0.00	15
DryBulk	Big Bend	3847984.87	2613121.00	1234863.87	2440842.44	1994869.66	445972.79	178
LPG/NH3	Port Sutton	1072592.39	1072592.39	0.00	0.00	0.00	0.00	35
LiquidBulk	Port Sutton	1642049.44	1642049.44	0.00	0.00	0.00	0.00	46
Passengers	Port Sutton	29737.00	29737.00	0.00	30014.00	30014.00	0.00	31
GeneralCargo	Port Sutton	30423.79	30423.79	0.00	280535.23	280535.23	0.00	9
DryBulk	Port Sutton	2170203.49	2170203.49	0.00	2230216.64	2230216.64	0.00	132
DryBulk	East Bay	659002.85	659002.85	0.00	3556314.70	3556314.70	0.00	129
GeneralCargo	East Bay	263164.48	263164.48	0.00	1183954.62	1183954.62	0.00	51
LPG/NH3	East Bay	377154.68	377154.68	0.00	0.00	0.00	0.00	11
Containers	East Bay	41838.20	28388.58	13449.62	18806.21	18028.91	777.30	53
LiquidBulk	East Bay	57565.20	57565.20	0.00	35218.55	0.00	35218.55	2
Vehicles	East Bay	24497.46	24497.46	0.00	4281.10	0.00	4281.10	12
DryBulk	Hills Cut D	738080.34	738080.34	0.00	31742.34	31742.34	0.00	32
LPG/NH3	Hills Cut D	1104146.92	1104146.92	0.00	0.00	0.00	0.00	37
Liquid Bulk	Hills Cut D	8197954.51	8197954.51	0.00	43391.81	0.00	43391.81	412
GeneralCargo	Hills Cut D	77958.85	77958.85	0.00	241479.52	241479.52	0.00	7
GeneralCargo	Sparkman	217800.00	217800.00	0.00	0.00	0.00	0.00	15
LiquidBulk	Sparkman	3046881.20	3046881.20	0.00	0.00	0.00	0.00	124
DryBulk	Sparkman	157946.44	157946.44	0.00	0.00	0.00	0.00	6
DryBulk	Ybor	89205.20	89205.20	0.00	232337.72	232337.72	0.00	13
LiquidBulk	Ybor	3582382.11	3582382.11	0.00	0.00	0.00	0.00	153
Passengers	Ybor	351515.00	351515.00	0.00	331909.00	331909.00	0.00	201
Containers	Ybor	27.44	27.44	0.00	0.00	0.00	0.00	1

7.2.3.2 Vessel Class Utilization

Vessel class usage by the allocation process is shown in an output CSV (Microsoft Excel-compatible) file, showing the number of vessels generated by class and the number of calls assigned to vessels of that class. The number of vessels generated is equal to the user estimate of the fleet availability, while the number of vessel calls indicates the number of vessels that are actually utilized in the allocation process.

**TABLE 8
FLEET USAGE BY ALLOCATION PROCESS**

Vessel Class	Vessels	Calls
LargeBulk	90	90
MediumBulk	330	330
SmallBulk	61	0
ContainerLarge	37	37
ContainerSmall	18	17
LargeGenCargo	67	67
MediumGenCargo	248	77
SmallGenCargo	259	1
InlandDryAll	0	0
LargeLPG	50	50
SmallLPG	59	35
MiscAll	78	0
OceanTankLarge	391	391
OceanTankSmall	96	95
OceanDryAll	236	235
Protocol1	98	97
Protocol2	138	135
LargeTanker	280	280
MediumTanker	129	82
SmallTanker	10	10
VehiclesCarrier	26	12

7.2.3.3 Vessel Information

Vessel information is recorded in the Unique Vessels table within the generated VCDB. Note that each vessel is assigned a unique name, based on the class name and a model-assigned sequence number within the class, e.g., OceanDryAll000 (the first vessel generated in the class).

TABLE 9
UNIQUE SYNTHETIC VESSELS GENERATED BY CDVG/A

Vessel Name	LOA	Beam	Draft	DWT	TPI Factor	Minimum Draft
OceanDryAll000	548.9	85.8	31.4	33058.3	128.264	9.88
OceanDryAll001	511.7	82.8	29.1	26433	106.896	8.53
OceanDryAll002	446.6	77.4	25.3	17139.1	76.992	6.72
OceanDryAll003	473.1	79.6	26.8	20586.9	88.076	7.36
OceanDryAll004	434	76.3	24.5	15646.1	72.197	6.46
OceanDryAll005	539.4	85	30.8	31266.2	122.48	9.52
OceanDryAll006	555.3	86.3	31.7	34304.1	132.286	10.13
OceanDryAll007	462.9	78.8	26.2	19214	83.661	7.1
OceanDryAll008	509.9	82.7	29	26137.1	105.943	8.47
OceanDryAll009	552.2	86	31.6	33692.1	130.31	10.01
OceanDryAll010	276	60.9	15.3	3697.7	33.742	6.13
OceanDryAll011	546.6	85.6	31.2	32625.5	126.867	9.79
OceanDryAll012	555.3	86.3	31.7	34302.5	132.28	10.13

7.2.3.4 Vessel Call Loading

Vessel call loading information is reflected in the VCDB, but is also provided in a simpler to understand format in an output CSV file. The primary use of this file is to be able to check and debug the loading and draft determination process. The file contains a number of columns and is presented in Tables 10a through 10e.

TABLE 10A
VESSEL CALL LOADING INFORMATION OUTPUT
(FIRST SET OF COLUMNS)

Vessel Name	Dock	Commodity	Class	QToBeAlloc Import	QToBeAlloc Export
OceanTankLg000	St. Petersburg	LiquidBulk	OceanTankLarge	86275.400	0.00
LargeGenCargo000	Port Manatee	GeneralCargo	LargeGenCargo	1084341.026	105012.90
LargeTanker000	Port Manatee	LiquidBulk	LargeTanker	1216780.631	25798.09
OceanDryAll000	Port Manatee	DryBulk	OceanDryAll	1164658.585	436200.10
OceanDryAll001	Port Tampa	DryBulk	OceanDryAll	583030.885	224153.80
LargeTanker001	Port Tampa	LiquidBulk	LargeTanker	1565778.826	0.00
SmallGenCargo000	Port Tampa	GeneralCargo	SmallGenCargo	490.000	0.00
SmallLPG000	Alafia	LPG/NH3	SmallLPG	27331.040	0.00

TABLE 10B
VESSEL CALL LOADING INFORMATION OUTPUT
(SECOND SET OF COLUMNS)

VesselName	Underkeel Clearance	Loading Factor Import	Loading Factor Export	Limiting Depth	DWT	TPIFactor
OceanTankLg000	0.5	1	1	19.0	21963.2	94.835
LargeGenCargo000	0.5	1	1	37.0	28788.7	117.525
LargeTanker000	0.5	1	1	37.0	32841.7	139.010
OceanDryAll000	0.5	1	1	37.0	33058.3	128.264
OceanDryAll001	0.5	1	1	34.0	26433.0	106.896
LargeTanker001	0.5	1	1	34.0	37042.6	145.740
SmallGenCargo000	0.5	1	1	34.0	679.0	14.471
SmallLPG000	0.5	1	1	29.6	19849.1	101.427

TABLE 10C
VESSEL CALL LOADING INFORMATION OUTPUT
(THIRD SET OF COLUMNS)

Vessel Name	Tentative Loading Import	Additiona l Draft Import	Total Draft Import	Excess Draft Import	Tons To Reduce Import	Quantity Loaded Import
OceanTankLg000	21963.2	19.30	30.19	11.19	12735.5	9227.618
LargeGenCargo000	28788.7	20.41	35.55	0.50	705.1	28083.58
LargeTanker000	32841.7	19.69	38.51	1.51	2524.0	30317.72
OceanDryAll000	33058.3	21.48	31.86	0.50	769.6	32288.77
OceanDryAll001	0.0	0.00	000	0.00	0.0	0.00
LargeTanker001	37042.6	21.18	39.24	5.24	9158.1	27884.51
SmallGenCargo000	679	3.91	11.73	0.50	86.8	490.00
SmallLPG000	19849.1	16.31	34.07	4.47	5442.3	14406.73

TABLE 10D
VESSEL CALL LOADING INFORMATION OUTPUT
(FOURTH SET OF COLUMNS)

Vessel Name	Tentative Loading Export	Additional Draft Export	Total Draft Export	Excess Draft Export	Tons To Reduce Export	Quantity Loaded Export
OceanTankLg000	0.00	0.0	0.000	0.0	0.0	0.00
LargeGenCargo000	28788.73	20.4	35.552	0.5	705.1	28083.58
LargeTanker000	0.00	0.0	0.000	0.0	0.0	0.00
OceanDryAll000	0.00	0.0	0.000	0.0	0.0	0.00
OeanDryAll001	26432.96	20.6	29.635	0.5	641.4	25791.59
LargeTanker001	0.00	0.0	0.000	0.0	0.0	0.00
SmallGenCargo000	0.00	0.0	0.000	0.0	0.0	0.00
SmallLPG000	0.00	0.0	0.000	0.0	0.0	0.00

TABLE 10E
VESSEL CALL LOADING INFORMATION OUTPUT
(FIFTH SET OF COLUMNS)

Vessel Name	Minimum Draft	Design Draft	Minimum Class Sailing Draft	Maximum Class Sailing Draft	Initial Draft	Quantity Imported	Quantity Exported
OceanTankLg000	10.392	29.691	20	60.975	19.000	9227.618	0.00
argeGenCargo000	14.639	35.052	20	42.043	35.052	28083.580	28083.58
LargeTanker000	18.325	38.013	20	46.314	37.000	30317.720	0.00
OceanDryAll000	9.880	31.358	20	36.146	31.358	32288.770	0.00
OceanDryAll001	8.529	29.135	20	36.146	20.000	0.000	25791.59
LargeTanker001	17.556	38.737	20	46.314	34.000	27884.510	0.00
SmallGenCargo000	7.316	11.226	20	31.504	11.226	490.000	0.00
SmallLPG000	17.263	33.571	20	41.328	29.600	14406.730	0.00

7.3 Next Steps/Issues

The process followed by the CDVG/A is admittedly somewhat complex. A good deal of information is generated to allow the user to understand what is going on, but, to date, there is little experience of actual use in real-world studies to generate VCDBs and evaluate the process. This is in part due to the lack of a user interface that integrates this module, together with the associated data needs and output examination. Inasmuch as the process is integral to the proposed deepening economic analysis, details of the process need to be examined and understood.

Of particular concern is the ability to appropriately control the loading of each vessel. The CDVG/A incorporates some basic simplifying assumptions:

- One vessel call per vessel
- One dock visit per vessel call

The user ability to control the amount of quantity that is loaded on the vessel is currently handled by specification, at the vessel class—commodity level, of distributions of percentage of maximum loading that should be allocated for export and import. This may not be adequate to represent situations where ballast is discharged or taken on, bunker fuel is added, stores are taken on or there is retained tonnage on the vessel not transferred at the port. Historical data available for a port typically can provide information on arrival draft and quantities transferred but does not give information on the amount of ballast or retained tonnage. These may need to be imputed from external information or otherwise calculated. In outyears, as import demand for a commodity increases, ballast may be replaced by additional commodities transferred to the port.

The essential problem is thus the development, within the CDVG/A, of an arrival draft that is consistent with the vessel characteristics, the commodity transfers and reality-based practice relating to ballast, fuel, stores, etc. In order to make this data-driven under the control of the user, methodologies have been proposed (Heisey, 2007) to allow the CDVG/A to better assign arrival drafts on export and import movements. The fundamental proposal is to add user-specified distributions, at the class level, of arrival and loading drafts for net export movements. For net import movements, the assumption is that vessel loading draft is the light-loading draft (based on design draft and DWT capacity) and that the arrival draft is determined based on the commodity transferred.

It is essential that this aspect of the CDVG/A loading algorithms be reviewed and explored in depth, to insure that the methodology achieves consistency for all of the inter-related variables associated with loading. At the same time, the algorithms and data requirements must provide the user with the needed flexibility to allow the user to represent the known behaviors associated with ballast and retained tonnage.

Section 8
Statistical Analysis and Visualization
8.1 Background

Data checking capability is essential for effective use of HarborSym. Given the complexities and multiple sources of port traffic data, it is very easy to prepare datasets that have inconsistencies and errors. Information, once stored in the HarborSym database framework, represents a complete description of the vessel and commodity movements into and out of the port and the structure lends itself quite well to analysis in a variety of formats, including:

- Testing for inconsistencies, for example assignment of incorrect commodities to vessels that cannot carry that type of commodity;
- Checking for invalid or out of range data;
- Summarization of commodity flows by time, vessel class and type of commodity;
- Statistical analysis of the physical characteristics of the fleet calling at the port;
- Export of database information to spreadsheets for additional analysis.

As noted previously, the HarborSym database structure allows for a number of alternate views of traffic at the 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

Using the HarborSym relational database, queries can be developed for data checking and summarization. In addition, the data can be used 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 within the CDVG/A.

Initially, most of this effort was conducted on an ad-hoc basis, but it became clear that many of the queries, displays and statistical analyses are of value in multiple studies. The idea is to develop a set of reusable analysis tools that can be applied to any HarborSym dataset, within a framework where new capabilities can easily be stored. In this fashion, as new queries, displays and statistical analyses are developed, they can be generalized and used in other studies, providing a growing toolset. Accordingly, an initial attempt at developing a repository of such analysis capability was created as a rough proof-of-concept, making use of Microsoft Access™ and the R Statistical Analysis Package (R Project for Statistical Computing), an open source language and environment for statistical computing and graphics. The proof-of-concept does not at present have a simple user interface, in particular as regards the statistical analyses and graphical displays that make use of the R package, but exploratory work is being undertaken to provide a better-integrated and easier to use environment.

8.2 Example Outputs

It is probably easiest to explain the intended capability by showing examples that are indicative of some of the queries and graphs that currently exist, with the understanding that these outputs are achieved simply by identifying a particular HarborSym database and requesting the appropriate query or other output from a menu of possibilities that have been implemented in the proof-of-concept application. It should be noted that the outputs that are in the form of queries can easily be manipulated further by the user (sorted, filtered, summarized and exported to other formats), making the overall capability quite flexible and extensible.

Note also that example outputs are only for illustrative purposes. The information is derived from databases originally developed for the Port of Tampa and for the Sabine-Neches, but the actual numbers are not necessarily realistic, as the databases used for these displays are taken from early versions before data scrubbing. The tables have been edited from their original generated format (rows and columns deleted) in order to reduce the amount of information shown. Note that individual illustrative tables may be taken from separate databases, thus there is no expectation of consistency in data from one table to another.

8.2.1 Port Traffic Summaries

Port traffic can be summarized by dock, commodity, vessel class and export/import quantity. (Table 11). This information is built up from the individual vessel calls and associated commodity transfers.

TABLE 11
PORT TRAFFIC SUMMARY – ROLLUP BY DOCK/COMMODITY/VESSEL CLASS

Dock	Commodity	Vessel Class	Total Export Quantity	Total Import Quantity
Big Bend	General Cargo	LargeGenCargo	7273.66	4368.88
Big Bend	General Cargo	MediumGenCargo	27625.90	379014.00
Big Bend	General Cargo	SmallGenCargo	6147.00	0.00
East Bay	Containers	Container Large	9841.34	39361.44
East Bay	Containers	Container Small	8964.88	2476.76
East Bay	General Cargo	LargeGenCargo	163906.00	55678.81
East Bay	General Cargo	MediumGenCargo	719924.76	157893.07
East Bay	General Cargo	SmallGenCargo	300123.86	49592.61
East Bay	LPG/NH3	LargeLPG	0.00	350053.32
East Bay	LPG/NH3	SmallLPG	0.00	27101.36
East Bay	Other	Misc All	0.00	0.00
East Bay	Vehicles	Vehicles Carrier	4281.10	24497.46
Port Tampa	General Cargo	SmallGenCargo	0.00	490.00
Sparkman	General Cargo	MediumGenCargo	0.00	217800.00
Ybor	Passengers	Protocol1	44262.00	48945.00
Ybor	Passengers	Protocol2	287647.00	302570.00

This information can be furthered rolled up at the commodity and vessel class level (Table 12):

TABLE 12
PORT TRAFFIC SUMMARY – ROLLUP BY COMMODITY/VESSEL CLASS

Vessel Class Description	Commodity	Total Import Quantity	Total Export Quantity
Container Large	Containers	39361.44	9841.34
Container Small	Containers	2504.21	8964.88
Large Bulk	Dry Bulk	2852159.14	1333596.52
LargeGenCargo	General Cargo	572725.37	358388.40
LargeLPG	LPG/NH3	1414704.91	0.00
LargeTanker	Liquid Bulk	8657625.54	5744.14
Medium Bulk	Dry Bulk	2244840.38	4792327.96
MediumGenCargo	General Cargo	1360839.72	1488530.81
MediumTanker	Liquid Bulk	1894981.05	78623.15
Misc All	Other	0.00	0.00
Ocean Tank Large	Liquid Bulk	8358189.84	0.00
Ocean Tank Small	Liquid Bulk	811391.94	0.00
OceanDryAll	Dry Bulk	4422056.36	4024677.60
Protocol1	Passengers	77602.00	73099.00
Protocol2	Passengers	303718.00	288824.00
Small Bulk	Dry Bulk	256670.79	362281.48
SmallGenCargo	General Cargo	123995.95	626564.78
SmallLPG	LPG/NH3	1166520.12	0.00
SmallTanker	Liquid Bulk	24098.95	20041.16
Vehicles Carrier	Vehicles	24497.46	4281.10

Rollup at the vessel type level is also possible (Table 13):

TABLE 13
PORT TRAFFIC SUMMARY – ROLLUP BY VESSEL TYPE

Vessel Type	Number of Unique Vessels	Number of Vessel Calls	Total Export Quantity	Total Import Quantity
Bulk	242	377	4519845.96	4478288.47
Container	8	58	64577.03	75300.70
GenCargo	252	644	1867928.43	4197506.69
LPG/NH3	32	107	0.00	2497878.44
Misc	16	120	0.00	23450.31
Ocean Tank Barge	17	342	4200.00	6842877.03
OceanDryBarge	16	315	4411702.45	4345070.28
Passenger	10	235	461513.00	457487.00
Tanker	89	600	195007.62	12303122.64

The number of vessel calls by class at individual docks can be reported (Table 14):

TABLE 14
PORT TRAFFIC SUMMARY – CALLS BY DOCK AND VESSEL CLASS

Dock	Vessel Class Description	Count Of Vessel Calls
Big Bend	OceanDryAll	156
Hills Cut D	Ocean Tank Large	152
Hills Cut D	LargeTanker	148
East Bay	Medium Bulk	145
East Bay	SmallGenCargo	143
Ybor	Protocol2	137
Port Manatee	MediumGenCargo	103
East Bay	MediumGenCargo	80
Ybor	LargeTanker	66
Port Sutton	Ocean Tank Small	63
Ybor	Ocean Tank Large	63
Sparkman	MediumTanker	59
Alafia	Medium Bulk	54
Port Manatee	Medium Bulk	52
Port Manatee	SmallGenCargo	51

Figure 3 shows weekly commodity flow by commodity (in this case Liquid Bulk) at individual docks at the port of Tampa:

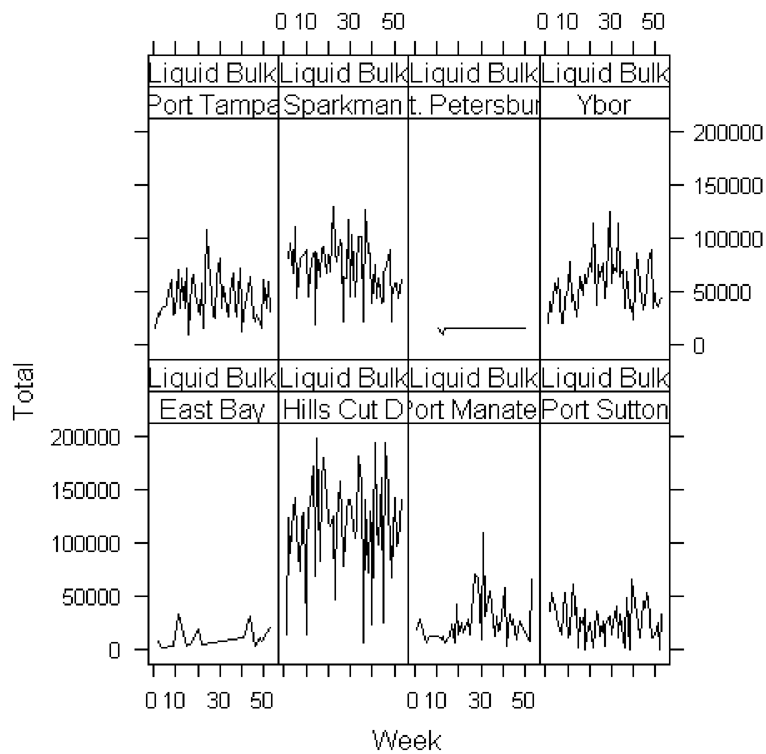

FIGURE 3
WEEKLY COMMODITY FLOW BY COMMODITY
(IN THIS CASE LIQUID BULK)
AT INDIVIDUAL DOCKS AT THE PORT OF TAMPA

8.2.2 Data Checking

Data checking queries are used to look for inconsistencies in the originally entered data. This information is often more easily identified by developing appropriate queries of the database than by individually checking each data entry item.

Table 15 shows some selected vessel calls where the commodity transfer that has been specified exceeds the specified vessel capacity.

TABLE 15
DATA CHECKING OUTPUT – COMMODITY TRANSFER EXCEEDING CAPACITY

Vessel Class	Commodity n	Arrival Date	Import Tons	Capacity
OceanDryAll	DryBulk	1/20/2004 11:10:00 AM	8439.00	5570
OceanDryAll	DryBulk	2/28/2004 11:10:00 AM	17292.60	5570
OceanDryAll	DryBulk	3/31/2004 11:10:00 AM	17292.60	5570
OceanDryAll	DryBulk	4/30/2004 11:10:00 AM	12755.00	5570

HarborSym expects unique descriptions of distinct vessels in the fleet. A query tests whether there are any vessels with identical names and different physical characteristics, as an aid to data-checking (Table 16).

TABLE 16
DATA CHECKING – UNIQUE VESSEL IDENTIFICATION

Name	LOA	Beam	Capacity	TPI Factor	Design Draft
Vessel A	445	63	8991	56	21
Vessel A	445	63	9039	56	21
Vessel B	426	62	12150	50	38
Vessel B	490	74	16211	65	30.504
Vessel C	346	55	6830	39	23
Vessel C	346	55	6834	39	24
Vessel C	346	55	6834	39	23

8.2.3 Vessel Physical Characteristics Statistics

Summaries of information at the vessel class level can be reported (Table 17), with the vessel class statistics calculated based on physical characteristics of the individual vessels in the class. This can also be useful in identifying vessels wrongly assigned to a particular class.

TABLE 17
VESSEL CLASS LEVEL STATISTICS

Vessel Class	# Of Unique Vessels	Minimum LOA	Maximum LOA	Minimum Beam	Maximum Beam	Minimum Capacity	Maximum Capacity	Minimum Design Draft	Maximum Design Draft
Container	8	387	787	65	106	601	3352	24.73	41.06
LargeBulk	32	717	833	76	106	39043	81134	21.00	47.29
LargeGenCargo	37	600	700	87	106	15502	52885	20.00	42.04
LargeLPG	12	627	721	85	106	25846	41803	19.00	45.64
LargeTanker	42	178	750	35	122	2159	66414	10.82	44.60
MediumBulk	178	501	656	50	106	10361	57978	21.00	39.09
MediumGenCargo	145	417	597	52	95	3602	39283	16.00	40.00
MediumPassenger	4	448	691	70	113	376	2020	20.00	5.00
MediumTanker	37	433	599	65	106	8621	47346	25.00	38.00

Cumulative density functions of the distribution of vessel capacity in a class (Figure 4) are obtained through use of the R Statistical Package:

Regression coefficients are developed by using the R statistical package (Table 18), applying linear or log-linear models to the set of vessels within a class, to develop regressions on capacity (with capacity being estimated from the cumulative density function shown in Figure 4), for use in generating synthetic vessels in the CDVG/A:

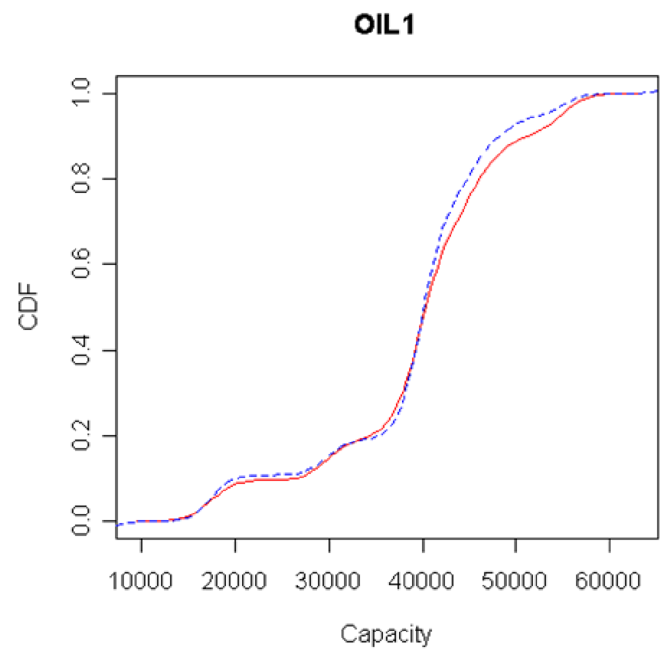

FIGURE 4
CUMULATIVE DENSITY FUNCTION OF CAPAPCITY

TABLE 18
ESTIMATED REGRESSION EQUATIONS

Vessel Class	Regression Type	Intercept	Slope
Container	log(Beam)~log(Capacity)	2.44	0.27
Container	log(LOA)~log(Capacity)	2.85	0.48
Container	log(DesignDraft)~log(Capacity)	1.37	0.28
Large Bulk	log(Beam)~log(Capacity)	0.69	0.36
LargeBulk	log(LOA)~log(Capacity)	6.24	0.03
LargeBulk	log(DesignDraft)~log(Capacity)	0.49	0.30
LargeGenCargo	log(Beam)~log(Capacity)	0.98	0.34
LargeGenCargo	log(LOA)~log(Capacity)	5.61	0.08
LargeGenCargo	log(DesignDraft)~log(Capacity)	0.11	0.34

8.2.4 Output Comparisons

HarborSym generates output for each alternative scenario that is run in standard formats (Microsoft Excel-compatible files, Microsoft Access databases). Because the format/content of each output data file or table is known, it is possible to develop displays that compare results between different runs. HarborSym records statistics on various time elements of all vessel calls and summarizes by vessel class. In Figure 5, a comparison of the average vessel time waiting, by class, is displayed for two different runs, one using historical vessel calls (lower bar, in cyan) and the other using synthetically generated vessel calls (upper bar, in magenta). Displays such as this can be used to rapidly identify those vessel classes that experience different delays under different alternatives. Note that, in the accompanying example, certain vessel classes (e.g., OIL5,

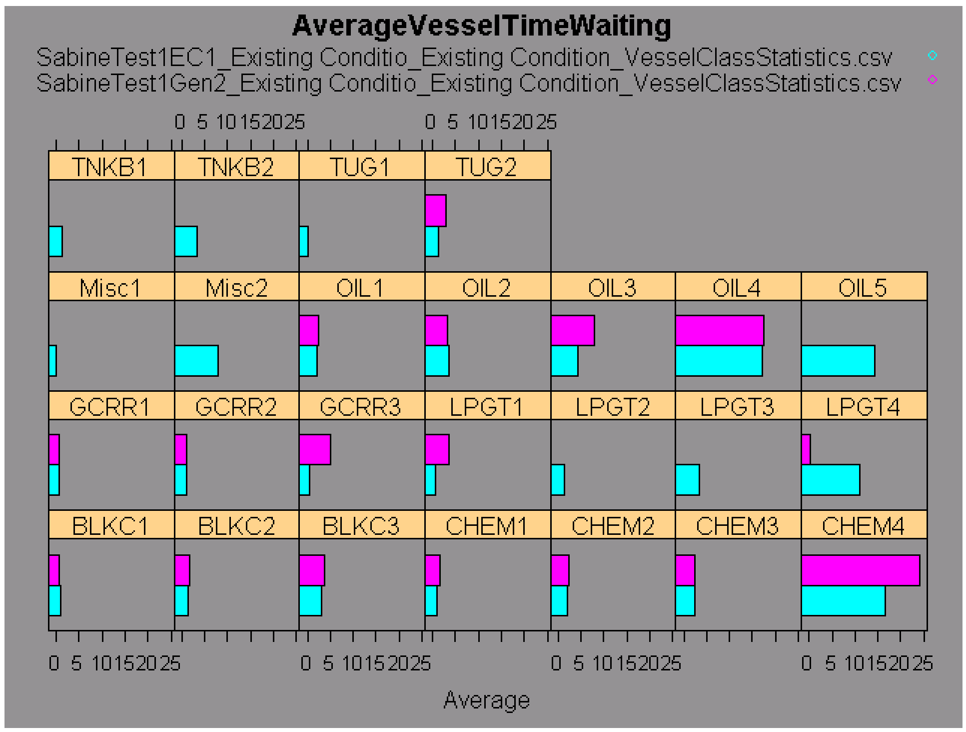

FIGURE 5

HISTORIC VS. SYNTHESIZED RESULTS COMPARISON

TNKB1, TNKB2, TUG1, Misc1, Misc2, LPGT2 and LPGT3) are not present in the synthetically generated set of vessel calls.

8.3 Discussion

Many other forms of graphical display and queries are possible. The R package provides a very rich environment for development of both statistics and many innovative graphic displays, and queries on a relational database, with capability to export to spreadsheets, also provides a powerful environment for analysis and display.

It will be important, when moving beyond proof-of-concept models and applications, to define the appropriate level of precision that should be displayed in outputs, such that it is consistent with the inputs used.

This capability should also provide the ability to develop standard sets of displays comparing traffic at an individual port under different assumptions, as well as the ability to compare information at different ports. Many of the outputs are built up from the historical vessel call information. The development of this historic data is a fundamental part of any deepening analysis. The proposed framework provides a basic structure for storing and analyzing this information in a repeatable fashion. It should be noted that HarborSym already provides spreadsheet import capabilities that will generate VCDBs from port data, simplifying the process considerably.

Section 9
Conclusions and Recommendations

9.1 Summary

The elements of a methodology for economic analysis of deepening studies have been proposed, based on work with HarborSym, together with some initial proof-of-concept development of the needed tools to support this effort. The approach is believed to follow recommended Corps methodology for these types of analyses. The focus is still on a single port, given the complexities of a multi-port analysis, but should facilitate multi-port analysis.

The major advantages of the proposed approach are:

- All elements of the analysis are explicit and the methodology provides a clear structure for data gathering and checking;
- Variability/uncertainty is included through the Monte Carlo Simulation;
- The analysis is data-driven and thus can be applied at different ports;
- The approach is commodity forecast-driven but provides the user with information on the consistency of the forecast with the available fleet;
- The approach is scalable—it can be carried out with a detailed (i.e., dock level) or summary (i.e., entire port) representation of a port and the commodity import/export demands
- The nature of the analysis lends itself to standardization and a certification process

Disadvantages include:

- Complexity of the process
- Data requirements
- Questions about the validity of the statistical generation of vessels with defined characteristics, loading procedures and the degree to which synthetic sets of vessel calls are reasonable representations of future behavior. Such questions must, of course, be examined with any forecasting model, but the explicit, data-driven nature and interrelationship of multiple factors, particularly in the CDVG/A, at once makes the examination easier and more critical.

9.2 Simplified Analysis

The apparent complexity and data demands of the process may be discouraging to users. It is worthwhile to consider approaches that retain the essential behavior, but lessen the demands on the user. Two possibilities can be considered, one using a simplified default harbor representation with HarborSym and the other dispensing with a HarborSym representation, instead extending the capabilities of the CDVG/A to do additional cost estimation

9.2.1 Default Simplified HarborSym

A default port representation for HarborSym could be provided, with a single entry point, a single dock and a reach connecting them. A "wizard" (user assist tool) would generate representative data for a user-specified number of vessel classes, populating the VCDB and IDB, which could then be edited by the user as needed. By using a highly simplified port representation, the data demands are significantly lessened, while still retaining the essential character of the analysis and allowing for greater specificity if needed.

9.2.2 Simplified Analysis Using the CDVG/A

Work carried out to date suggests the possibility of an alternative form of simplified analysis, specifically for deepening. The work to date has been carried out under the general idea of developing synthetic VCDBs and running them through the deep draft version of HarborSym, for calculation of costs. The HarborSym contribution is to calculate the time (and costs) associated with movement within the harbor and to incorporate variability.

Given that costs associated with the sea portion of the journey are likely to be much greater than the harbor costs and the great majority of time in harbor is associated with commodity loading/unloading at the dock (as opposed to congestion-based delays), it should be possible to develop a simplified deep draft analysis procedure that does not require routing vessels through the harbor with a detailed HarborSym port representation, as in HarborSym.

The same procedures for developing commodity-based synthetic VCDBs would still be used, but a simplified calculation would be made for the harbor-related time/costs. The ocean-related time and costs are, within HarborSym, calculated on a vessel call basis, with no interactions with other vessels. Costs associated with loading/unloading time could be calculated as at present in HarborSym, with some cost assigned to the within-port movements to a dock. This could be incorporated in the CDVG/A kernel itself, resulting in a greatly simplified process, in that a port-level HarborSym database with reaches and rules would not be required. Further simplification in data requirements could be obtained by limiting the number of docks—a single dock would be equivalent to a "port-level" model. This could serve as a simpler initial screening tool, applicable for cases where congestion is not a major issue. The deep draft version of HarborSym would still be available for detailed studies and, as it incorporates all of the capabilities of the widening version, would also be available for widening studies and other studies where port congestion is at issue.

It should be noted that, even if this simplified option is considered and developed, there can be merit in first developing a HarborSym representation for the port under study. This serves dual purposes:

- It forces a level of specification of the problem at hand, which fosters increased understanding of, and ability to communicate, the nature of the issues;
- An existing HarborSym representation provides an excellent starting point for developing data needed for the CDVG/A and tools to support this data development have already been created in prototype.

In the absence of a HarborSym representation as a starting point, additional tools will need to be developed to assist in developing the needed supporting data for the CDVG/A.

9.3 Recommendations

The proposed design should be explored within a larger community of those interested in deepening analyses within the Corps, to obtain additional insight and feedback on the approach. A workshop reviewing the current status of HarborSym and the proposed extensions and additional tools, should be convened by the Deep Draft Center of Expertise to that end.

The ability to integrate the various elements of the design within a user interface is important, both for usability and to help in understanding of the information flows, inputs and outputs. A user interface is not only a method of entering data for a model, it provides structure to a problem that, it is hoped, simplifies and clarifies the problem for a user. A good deal of work will be necessary to develop a reasonable user interface for the elements of the deepening analysis

The above-noted simplified analysis options should be explored, as a simplified analysis of some kind may be needed.

The concept of an umbrella Navigation Analysis Tool Suite, using the database structures and methodologies developed to date should be explored. Such a tool suite would allow users to select the appropriate elements for a given study, for example simply balancing commodity and fleet forecasts, as a separable task.

Particular emphasis needs to be given to a review of the loading algorithms and associated data requirements in the CDVG/A, to insure that the representation is sufficiently robust to reflect an analyst's understanding of the behavior seen or expected at the port.

Most importantly, as is typical in this type of work, a test bed application is needed, that is, a real deepening analysis project in conjunction with a District, where the ideas and tools developed to date can be applied in a real-world situation to test their applicability and usability.

Section 10
References

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Appendix A
Spreadsheet Example

TABLE A
TRANSPORTATION COST TABLE-IAN
EXAMPLE OF TRANSPORTATION COST DIFFERENTIALS ON PER TON BASIS
TRANSPORT OF CONTAINERIZED CARGO VIA CONTAINERSHIPS
SAN JUAN HARBOR, PUERTO RICO

Cargo:	Containerized Cargo (General Cargo)		
DWT Class:	20,000.00	to	24,999.00
Vessel Draft Class	31.60	to	33.80
UKC:	3.00'		
Existing Controlling Depth:	32.00'		

	Existing Depth 32.00'	Alternative Depth 39.00'
Aggregate Physical Characteristics of Vessel Class:		
DWT (metric)	24100.00	24100.00
DWT (short tons)	26570.00	26570.00
GRT:	18510.00	18510.00
NRT:	N/A	N/A
Max Design Draft	32.20	32.20
LOA	594.40	594.40
LBP	558.60	558.60
Beam	89.70	89.70
TPI	104.90	104.90
Transit Speed	16.30	16.30
Max Sailing Draft due to Constraints	29.00	32.2.00
Max Tonnage Capacity	22380.00	22380.00
Light Load Differential (for specified cargo, short tons)	4053.00	0.00
Carriage and lading and/or cargo capacity due to channel depth constraints (short tons)	18326.00	22380.00
Aggregate/Average Vessel Costs at Sea:		
Vessel Operating Cost @ sea (hourly basis)	$1,346.00	$1,346.00
Vessel Operating Cost in port (hourly basis)	$1,148.00	$1,148.00
Applicable Distance, Nautical Miles		
Arrival Transit	1041.00	1041.00
Departure Transit	238.00	238.00
Average Time at Sea		
Arrival Transit	63.90	63.90
Departure Transit	14.60	14.60
		78.50

Aggregate/Average Vessel Costs in Port:			
Total vessel Operating Cost in Port:			
Min Time for voyage termination/preparation	0.75	0.75	
aggregate unloading rate	645.40	645.40	
Estimated time in Port	28.40	34.70	
Calculated Vessel cost in Port	$33,460.00	$40,680.00	
Pilot Charges and Other Port Costs:			
Pilotage	$1,140.00	$1,140.00	
Tug Assistance	$5,610.00	$5,610.00	
Line Handling	$250.00	$250.00	
Dockage	$2,280.00	$2,770.00	
Subtotal for pilotage & other port costs	$9,280.00	$9,770.00	
Cost of Transit and Cargo Transport:			
Total Voyage Costs, RT			
Cargo Tonnage Transported	$148,320.00	$156,030.00	approx = sea cost + port cost + pilotage/other
Unit Costs ($/ton), RT	14,434.00	17,626.00	
	$10.28	$8.85	
Net Transportation Cost Savings From Base Condition Per Short Ton			
Unit Savings: ($/ton), RT	N/A	$1.42	