The Navigation Economic Technologies Program

July 2006

NETS

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VISUALIZATION FOR NAVIGATION SIMULATION MODELS -- WHY, WHAT, AND HOW

US Army Corps of Engineers®

IWR Report 06-NETS-P-01

Navigation Economic Technologies

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

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

Expanding the Body of Knowledge

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

Creating a Planning Toolbox

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

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

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

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The NETS program was overseen by Mr. Robert Pietrowsky, Director of the Institute for Water Resources.

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Abstract

In search of improved methods of analyzing coastal and inland waterway improvements, the Institute for Water Resources (IWR) of the US Army Corps of Engineers has developed a variety of engineering-economic simulation models for navigation projects. These models are complex, and the internal workings of the models are not easily understood. This is often the case with such models, and until recently the assumption was that model developers and users were the only ones who needed to understand and evaluate model behavior. In recent years, however, the importance of model transparency and validation has increased as stakeholders and decision-makers require greater confidence in analytical tools and a better understanding of model inputs and outputs. To provide such added confidence in the tools that are used, the Corps has developed a model certification process to ensure the technical accuracy of all models before they are applied to a study. Both for the certification process and the actual use of a model, it must be clear what the models do, and precisely how they do it. To this end, graphical visualization of model data and behavior has been integrated as a fundamental aspect of model design and usage. Visualization techniques have evolved over time, as new insights into what would be worthwhile are learned by usage, and as new users with different perspectives and desires apply the various navigation analysis tools.

Sommaire

A la recherche des méthodes améliorées d'analysant les améliorations de voie navigable côtières et intérieures, l'Institut pour les Ressources d'Eau (IWR) du Génie Civil Américain Corps (U.S. Army Corps of Engineers) a développé un assortiment de modèles de simulation ingénierie-économiques pour les projets de navigation. Ces modèles sont complexes, et les fonctionnements internes des modèles ne sont pas facilement compris. Ceci est souvent le cas avec tels modèles, et jusqu'à ce que récemment la supposition était que les entrepreneurs et les utilisateurs modèles étaient la seule une qui a eu besoin de comprendre et évaluer le comportement modèle. Dans les années récentes, cependant, l'importance de transparence et la validation modèle a augmenté comme les groupes d'intérêt et les décideurs exigent la plus grande confiance dans les outils analytiques et une meilleure compréhension d'entrées modèles et de productions. Pour fournir telle confiance supplémentaire dans les outils qui sont utilisés, le Génie Civil a développé un procédé de certification modèle pour assurer la précision technique de tous modèles avant qu'ils sont soit appliqués à une étude. Pour le procédé de certification et le véritable usage d'un modèle, ce doit être clair que les modèles font, et précisément comment ils le font. A cette fin, cette visualisation graphique de données et le comportement modèles a été intégrée comme un aspect fondamental de modèle conception et l'usage. Les techniques de visualisation ont évolué progressivement, comme les nouvelles perspicacités dans quel serait de valeur est appris par l'usage, et comme les nouveaux utilisateurs avec les perspectives et les désirs différentes appliquent le modèle.

KEYWORDS**:** Visualization, Animation, Navigation, Simulation

1. Introduction

Navigation modeling involves numerous dimensions and scales. It is at heart a geographic process, best interpreted with respect to an underlying map of the system under study, but often the nature of modeling requires simplifications and aggregations that make it difficult to associate events with real locations. Time scales of interest may be very different within different types of modeling. All of this presents challenges to the nature of the visualizations required. Visualizations of navigation simulation models require flexibility to adapt to the needs of analysts. The visualization components of a single model will evolve over time, as users ask different questions, desire windows into the functionality of various calculations, or wish to see output displayed in innovative formats.

Experience has shown that there is no single "one size fits all" visualization methodology that works for all models. Some information is best presented as an animation with the ability to pause and drill down to retrieve additional information about the displayed elements (for example a particular vessel in a harbor, or the status of all vessels in a channel). Other information must be presented as a static snapshot. Some information must be mapped, with a geographic underlay, as shown in Figure 1, an example of post-processing animation, while other information needs to be presented in a more abstract and symbolic format as in the example of within-simulation animation depicted as Figure 2. Different approaches to animation are employed to assist a variety of users: developers, analysts, reviewers, and decision makers. Visualization should be far more than an afterthought, but in fact should be an essential component of model design, development, training, and usage.

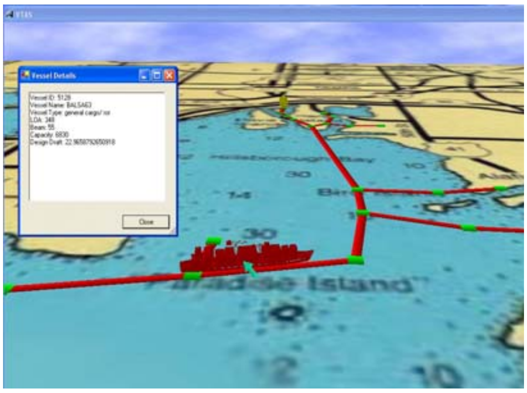

Figure 1

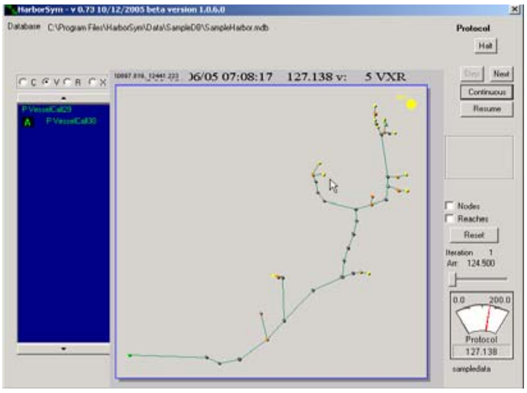

Figure 2

2. Need

The contemporary problems surrounding navigation planning and analysis in the United States have become increasingly complex and require more effective communication strategies in the decision making process. The increase in stakeholder involvement, budgetary constraints and greater competition for limited funding has lead to heightened scrutiny of public investments at all levels. An increase in the abundance and accessibility of electronic data has heightened analytical expectations, while the real-world complexities these types of problems embody has remained. These problems have given rise to the need for more effective, defensible decision making methods. A critical aspect to improving the decision making is in enhancing the ability of analysts to understand the models/data they use as well as communicate more effectively results of these models to stakeholders and decision makers.

The US Army Corps of Engineers (USACE) Institute for Water Resources (IWR) plays a critical role in developing innovative economic-engineering tools to support planning, policy and operations decisions for the USACE navigation mission. In response to the demand for enhanced data visualization capacity, several tools and technologies were developed and implemented by IWR. These tools have been developed to support decision making for inland and deep-draft navigation as well as lock analysis and were developed under the Navigation Economics Technologies (NETS) program of IWR. The NETS program was established within IWR to provide the necessary research, data development, and tools to assist Corps planners in the analysis of navigation problems and ultimately provide for more informed investment decision making capabilities. A fundamental driver in the development of these tools is to increase credibility and stakeholder confidence with data/model validation and certification. These solutions share a common goal of transparency, illuminating underlying relationships and impacts of alternative actions to decision makers with fully integrated graphical visualization of model data. These tools and technologies include iconic in-simulation animation, spatially oriented graphic underlayment, and post-processing 3D animation. Each of these tools or technologies is designed to address the specific data visualization needs that arise as different aspects of the analysis is undertaken.

3. Geographic Underlays

In early phases of navigation modeling/analysis, the analyst is primarily concerned with the configuration of the analytic engine, the data stores, and navigational structures that will be used in the actual simulation process. While in the current set of IWR-developed navigation simulation systems, the actual spatial relationships between the elements of the navigation network are irrelevant, the approximation of these relationships in terms of distance and orientation enhances the analyst's ability to efficiently and effectively define the network. The analyst is presented with a workspace on which to place the elements of the navigation network. This involves the use of a pointing device such as a mouse or trackball to select objects such as docks, turning basins, harbor bars, and anchorages and to place them on the workspace with appropriate approximations to relative distance and orientation. In a similar fashion, the analyst lays out the waterway reaches that connect these navigation nodes.

Figure 3

The addition of an underlay graphic, as shown in Figure 3, to the workspace has been shown to greatly enhance the work experience. This enhancement comes from familiarity – when the underlay graphic is a depiction of the geographic region in which the simulation is to take place, the analyst is provided with visual cues to guide the placement of the necessary elements. Further enhancements to the work experience are gained by engaging the human visual processing facilities at a subconscious level. Analysts are enabled by *seeing* where navigational elements should be positioned in a familiar environment. Accuracy, in terms of relative placement and orientation, as well as speed of data entry are greatly enhanced through the use of appropriate graphic underlayments during network configuration at a relatively low cost in terms of tool customization and graphic production.

4. Within-Simulation Visualization

Visualization of the simulation process while the simulation is in progress provides a sense of satisfaction and security for the user. The focus of this type of data visualization is very different from the techniques used during simulation configuration and post processing analytical tasks. The analyst needs feedback that the simulation is progressing and that the simulation appears to be operating as intended. In the HarborSym navigation simulation tool, the analyst observes the progression of the simulation through a graphical dashboard system. The dashboard system employs an iconic interface to display both progression and simulation status. Selection of an appropriate level of data summarization during visualization is a critical decision. Over summarization hinders the analyst by hiding needed information while insufficient compression buries the user in torrents of extraneous data. The use of the iconic display condenses larger amounts of information into a series of quickly interpreted visual summaries. In a long running simulation it is important to know that progress is being made in the simulation process. HarborSym uses a "fuel gauge" style display to provide the users with progress to completion based on the percent of simulation iterations completed. With a large number of potential iterations or a non-uniform rate of completion, additional information is required to maintain the confidence of the analyst during the execution of the simulation. In a situation where the number of iterations is extremely high, a progress bar or gauge type display of simulation activity can appear fail to update within the patience interval of the analyst giving the appearance that the simulation is not making progress while in actuality, the granularity of the display element is merely masking the detail of the situation.

HarborSym employs an iconic visualization of the individual simulation iterations. This visualization is a window into the simulation as execution progresses. The navigation network is presented as a set of simple geometric shapes representing the navigation nodes with line segments connecting those nodes where valid waterway segments have been defined. Vessels are shown in motion on the network as distinct geometric shapes. Iteration progress statistics and characteristics such as time within the current iteration, current iteration number, and daylight status are also displayed within this viewing window. The visualization also employs interactivity with the analyst in that progression of the simulation can be slowed down to observe vessel movements with a finer grained time progression as well as paused to allow the user to investigate individual simulation elements in more detail through a "drill-down" query capability. The ability of the system to graphically display configuration and in-process vessel movements allows the analyst to make judgments as to the validity of the simulation based on intuitive insights into the patterns of vessel movements – are they reasonable or not. This ability allows the analyst to terminate simulations that have gone awry due to improper configuration without waiting for the potentially long running simulation to complete. An example of the within-simulation display used in HarborSym is shown as Figure 4.

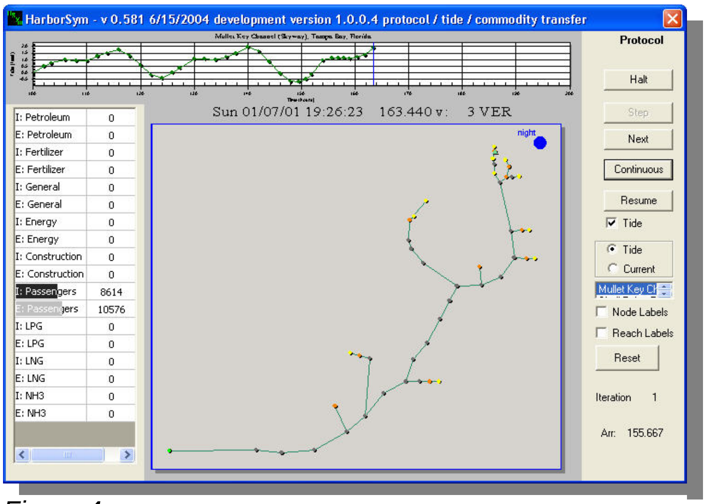

Figure 4

Visualization of information amplifies cognition through the enhancement of pattern recognition – recognition instead of recall, abstraction and aggregation, visual schemata for organization, value, relationship, and trend [Card, et al, 1999]. The primary purpose of this visualization technique is to engage the cognitive pattern recognition capacity of the analyst. To that end, the ability of this specific visualization to perform detailed data extraction is limited. The analyst has the ability to extract vessel and navigation node identification information while the visualization of the simulation is in progress. In-progress visualization for any purpose is a diversion of available computational resources from the primary purpose of the interface – the efficient and effective crafting and execution of a complex simulation. With this in mind, the analyst is empowered to redirect resources between the simulation and the visualization tool to control the balance between the need for assurance that the simulation is progressing toward successful completion and the actual execution of the simulation. These simple tools and implementation techniques provide the analyst with an exceptional work experience. They are in complete control of the process, they are empowered to verify that work is progressing, and they are assured that the simulation is progressing in a direction that appears to be valid.

5. Post-Processing 3D Visualization

Time based data resulting from a complex spatially oriented simulation lends itself well to exploration, analysis, and presentation through interactive 3D animated information visualization. In order to provide integrity and sophistication while avoiding graphic mediocrity it is important that the visualization tool not be designed on the premise that the intended audience is unintelligent or that they find detailed statistical data to be boring [Tufte, 1983]. With that in mind, two post processing animation modules were designed to assist in exploration and communication of outputs. First, the HarborSym Animation Module (HSAM) was developed to convey results of a HarborSym simulation, including traffic patterns. More recently, the Inland Navigation Animation Module (INAM) was developed to investigate inland navigation movements through locks, including vessel queuing operations. Both animation packages portray information in a fashion and environment familiar to an audience ranging from subject matter experts with deep knowledge of the processes involved and the details of navigation issues through high-level officials with extreme constraints on available time and strong needs for information condensation. Both systems were designed to use a common architectural framework so that enhancements over time can be easily shared by both applications. HSAM and INAM, respectively are simple, elegant, versatile, and cost effective solutions for the analysis and presentation of vessel traffic movement data for various purposes.

The HSAM and INAM animation packages were developed by the Institute for Water Resources of the U.S. Army Corps of Engineers. The guiding design principles were to provide a data-driven information visualization tool for the analysis and presentation of vessel traffic patterns generated by the HarborSym navigation simulation tool as well as outputs from the USACE Lock Performance Monitoring System (LPMS). The animation tools were designed to be customized without alteration and recompilation of the underlying codebase by field analysts to allow for portability from study to study and dynamically update the animation based on modifications to the simulation without the need for programmatic alterations. Finally, a key design issue was to allow the packages to be freely distributable without license fees, proprietary components, or other restrictions.

Work in the field of scientific visualization has shown that appropriate condensation of large information fields into graphic form in such a fashion as to allow pattern recognition through the engagement of the human visual cognitive processes. The visualization of structure and context are more efficient than individual data element examination [Robertson, Card, and Mackinlay. 1993]. Several methods were examined for suitability to display large quantities of vessel movements. 3D animation of vessel movements with respect to time in a semi-realistic environment was selected for versatility and understandability across a wider range of audiences. A survey of existing rendering engines was conducted giving consideration to licensing issues, ease of implementation, longevity of the engine, and capability to produce an interactive semi-realistic user experience. HSAM and INAM are founded on the open source OGRE 3D project (www.ogre3d.org) which is sufficiently capable, extensible, well documented and supported, and licensed under the GNU limited general public license (LGPL). The licensing model for OGRE coupled with the data-driven environmental configuration of the animation tools has been hugely successful and allowed the development team to produce a robust animation solution that adhered to the guiding design principles at a relatively low investment.

Figure 5

A key design feature of HSAM is the ability to control the appearance and content of the animation from the parent simulation model, HarborSym, without the need to recompile any portion of the system or the need for a multi-media production engineer. HSAM is configured from within the HarborSym tool. The user first selects a graphic representing the geography of the harbor being simulated. This can be a navigation chart or an artistic rendering. This will be the surface on which system animates the movements of the vessels. Intrinsic to the development of the HarborSym simulation is the specification of the network of waypoints, docks, reaches, and turning basins. HSAM extracts this information to produce the navigation network along which the vessels will move. A screen-shot from the HSAM tool is shown as Figure 5. HarborSym uses a system of vessel classes and sub-classes to categorize the various vessels that appear in the simulation. HSAM allows the user to specify a visually distinctive 3D model, or avatar, for each class of vessel. An example vessel avatar is shown in Figure 6. The texture applied to the avatar is also user selectable.

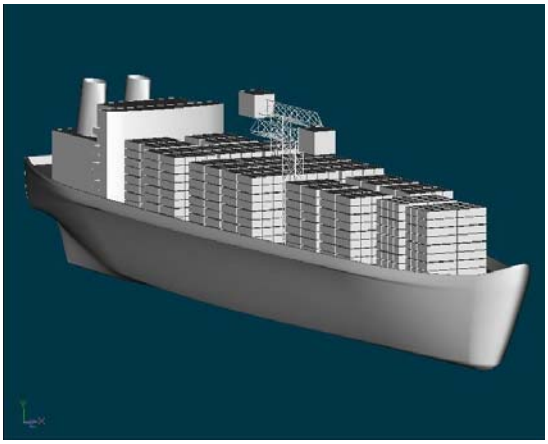

Figure 6

> Thoughtful selection of avatars and textures can have a strong impact on what is being demonstrated by the resulting animation. Simple coloration changes can bring the movement patterns of select classes of vessels sharply into focus. Relatively unique to the easily customized and data driven animation frameworks as implemented in HSAM is the ability to highlight and investigate certain motion trends. A simple example of this would be to highlight the movement patterns of a certain class of vessels. The operator would specify a bright color for the class of vessels that has piqued his or her curiosity while leaving all of the other textures set to a neutral gray. While all of the other vessel classes are still visible and the vessel interactions are still evident, the movement of the selected class of vessels is clearly enhanced and subtle patterns can more easily emerge. (Rogers, Woelbeling, Males, Hofseth, Heisey 2005)

The textures used to provide the sky and horizon are user selectable for both daytime and nighttime. HSAM allows distinctive day/night environment textures to emphasize alternate rule schemes. HSAM is directed to make vessel movements and environmental alterations through a time sequenced queue of event commands. This command queue is what puts the simulated vessel fleet into motion.

The Inland Navigation Animation Module, INAM, extends the available informational subject matter of the animation over that of HSAM by providing for the animation of vessels and inland navigation structures such as locks, while fully preserving the design tenets of HSAM in terms of a data driven architecture, open interface specification, absence of restrictive license requirements, and a high level of cost effectiveness. INAM incorporates the visual flexibility of HSAM in that both vessel and simple navigation structure avatars, manifestations of real world entities in the visualization environment, are defined and customizable by the analyst without modifications to the codebase or recompilation. INAM is completely driven and configured by a set of well defined, extensible, well documented, and open XML data files. This use of non-proprietary intermediary command and control structures enhances the versatility and viability of the INAM tool in and environment of quickly evolving simulation tools. The differentiating feature of INAM over HSAM is the capability of INAM to visually depict the operation of navigations lock structures in a semi-realistic fashion. INAM supports the semi-parametric specification of lock structures thus sustaining the design specification that the tool should be easily applied to studies at any Corps area of interest. INAM comes with a set of lock component avatars including gates, walls, buildings, dams, and generic terrain sections. The analyst then directs the assembly of these components into a Lock Meta-Object or LMO. An LMO is the semi-parametric specification for a lock of a given physical and operational profile. INAM builds locks based on the LMO specifications on demand in the visualization environment. A screen-shot from the INAM tool is shown as Figure 7. INAM also incorporates dynamic vessel queue maintenance to prevent vessels from overlapping or stacking in order to provide a more visually appealing and realistic simulation environment. INAM's command set, a superset of the standard HSAM command set, also includes support for cargo manipulation and transfer. The addition to the command set allows for the display of period and cumulative cargo flows, perhaps facilitating economic analysis and display. INAM is a cost effective, versatile, extensible, and freely distributable tool for the visualization of inland navigation vessel, cargo, and lockage information.

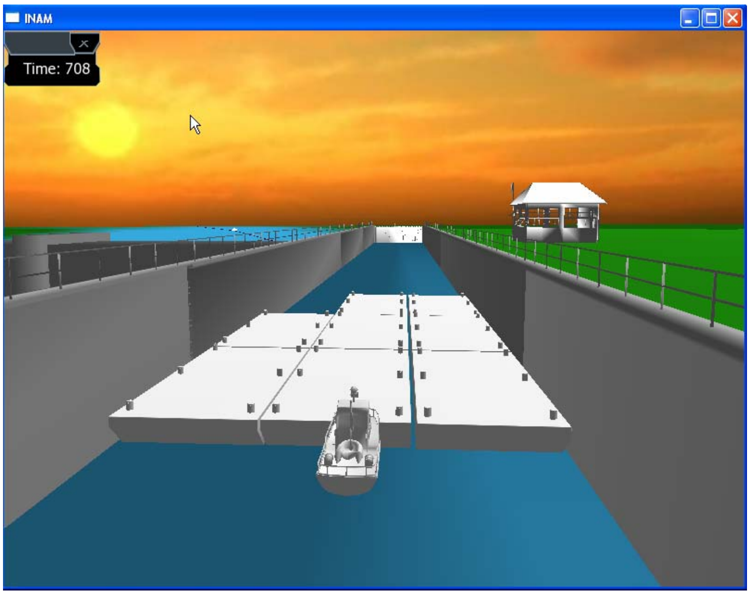

Figure 7

Interaction with the HSAM and INAM toolsets is easy, powerful, and visually engaging. Within the animated environment, the user controls a mobile virtual camera which creates the visual window into the simulated world. Camera position and orientation are controlled using simple key strokes or mouse movements. The camera can be directed to tilt, pan, dolly, and accelerate forward or back. The control implementation presents the analyst with a familiar set of game-oriented flight controls. The analyst has the ability to change the rate at which time passes in the simulated world as well as the ability to pause the simulation and interrogate specific vessels, navigation reaches, and navigation points. The interactive nature of these tools provides a fertile environment for simulation analysis and rich dynamic presentation.

6. Closing

The information visualization techniques and tools being incorporated into the navigation planning and analysis models for the U.S. Army Corps of Engineers have been designed and implemented to enhance the quality of the analytic simulation process. During the life cycle of a simulation project, specific tasks are required of the analyst such as configuration of the simulation of the system, execution and monitoring of the simulation, analysis of the results of a simulation, and presentation of findings. Suitable techniques for information visualization help engage the cognitive processes and increases the efficiency of the analyst while enabling the analyst to be more effective through rapid error identification and reduction.

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

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

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

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

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

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

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