Freight Demand Modeling: State of the Practice within Federal Agencies
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1. Introduction and Overview

The state-of-practice in freight demand modeling within federal agencies is represented by two sets of models—the Freight Analysis Framework (FAF) built and maintained by the Federal Highway Administration (FHWA); and the Ohio River Navigation Investment Model (ORNIM) and the Navigation Economic Technologies (NETS) program supported by the U.S. Army Corps of Engineers (Corps).

These two modeling systems take different approaches to freight demand modeling to serve different needs at the federal level. Freight models provided by federal agencies serve numerous purposes—including base freight estimates and forecasts for use by state and metropolitan governments and private sector firms, and for use by decision makers at the federal level who make freight policy. Freight forecasts are key inputs to policy decisions about macroeconomic growth, land use, transport congestion, environmental externalities, national security, etc. Of equal importance, freight forecasts are critical to federal decisions about investments in transport infrastructure.

FAF consists of a set of models that are based primarily on survey data and statistical approaches to estimate freight flows at a significant level of detail. The 2002 FAF consists of the following:

1. Three four-dimensional matrices (for tons, ton miles, and value) in which the four dimensions are origin, destination, commodity, and mode—referred to as the Freight Flow Database: Origins and destinations consist of 114 regions as defined and used in the 2002 Commodity Flow Survey (CFS) plus 17 additional international gateways. Commodities are defined at the 2-digit SCTG (Standard Classification of Transported Goods) level. Modes are defined as in the 2002 CFS—i.e. 11 separate modes, multimodal combinations, and unknown modes. The 2002 CFS serves as the foundation of the Freight Flow Database. Unfortunately, the CFS has several major commodity gaps, referred to as out-of-scope commodities. In addition, the CFS is known to undercount some categories of trade and movements of freight—for example imports, in-transit movements between Mexico and Canada, petroleum products, and movements from ports to auxiliary warehouses. These CFS out-of-scope commodities and undercounts are estimated using a variety of economic and statistical methods.

2. A Network Flow Database that assigns the freight flows developed in (1) at the level of detail as given in (1): This database requires assignment for all modes and for both inter-zonal and intra-zonal movements. Total tons miles are estimated in this step.
3. **Forecasts of both freight flows and network flows in five year increments for the 2005 to 2035 time frame.** Forecasts are at the geography, commodity, and mode levels as in (1).

4. **Annual Provisional Estimates for the Freight Flow Database for 2005.**
Annual provisional estimates will be provided for the year 2005 by tons and value. The Network Flow Database, which requires freight assignment, will not be updated annually.

FAF’s four-dimensional freight flow matrices are supplemented by the results of several out-of-scope studies and by other data sources for freight, water movements, air movements, etc. Nonetheless, the resulting freight flow matrices have numerous gaps at the four-dimensional level. Significant gaps also exist at the two and three dimensional levels. Missing cells are estimated by a combination of commodity-specific spatial interaction models, log-linear modeling, and iterative proportional fitting.

Models associated with NETS and ORNIM take a different approach to freight demand modeling. Whereas FAF is based on survey data and matrix filling, ORNIM and NETS are based on economic and engineering models. The purpose of ORNIM is to estimate the benefits of improvements to the navigation infrastructure of the Ohio River System—e.g., extended or new locks, channel improvements, replacement of key lock and dam components, alternative maintenance policies, etc.—and to balance those benefits against the estimated costs of those improvements. By doing so, ORNIM can suggest the optimal set of infrastructure investments over time. ORNIM begins with base-case freight flows from external economic models.

The ORNIM System is composed of three modules—the Lock Risk Module (LRM), the Waterway Supply and Demand Module (WSDM), and the Optimal Investment Module (Optimization). LRM takes engineering inputs—e.g., reliability estimates, component hazard functions, and repair protocols—to determine the probabilities of unplanned closures for each lock for each year. WSDM utilizes detailed information about the Ohio River network, towboat/barge operations, lock operations, and cargo forecasts to estimate the annual equilibrium traffic that moves on the river. Optimization, which can be budget constrained, identifies the optimal set of investment options (e.g., construction, rehabs, and maintenance) at each lock for as much as a 50-year horizon. ORNIM’s major economic assumptions are embedded within WSDM.

NETS uses a hierarchical approach consisting of three tiers of modeling, one that moves from a broad regional and global geography in Tier 1 down to a detailed project and facility specific level of detail in Tier 3. Tier 1 modeling is focused on econometric estimation and forecasting of future year commodity production, consumption, and broad transglobal trading patterns. Tier 2 modeling disaggregates these forecasts to a point where they can be assigned as freight traffic to specific modes and routes within the U.S. transportation network. Tier 3 uses these mode and route specific forecasts to assess the viability of actually moving the freight flow from the Tier 2 models. If the inland navigation system cannot accommodate the freight flows from Tier 2 models due to congestion, some freight flows are diverted to rail. Tier 3 models also estimate the
optimal investments in navigable waterways and seaports and in operational and maintenance policies associated with structures such as locks and harbors.

The following sections give a more detailed discussion of freight demand modeling within FAF, ORNIM, and NETS.

2. Freight Analysis Framework

As discussed above, the Freight Flow Database consists of three four-dimensional matrices (for tons, ton miles, and value) in which the four dimensions are origin, destination, commodity, and mode. Figure 1 illustrates the geographic detail within FAF. Table 1 gives the commodity and mode detail within FAF. This section summarizes the data used to construct FAF and the methodology employed to estimate freight flows.¹

2.1 Data Overview

The Freight Flow Database is derived from three categories of data: CFS Within-Scope Data, Auxiliary Data, and CFS Out-of-Scope Data.

2.1.1 CFS Within-Scope Data

CFS Within-Scope Data at the state level comes from CFS Table 17. Please see:


or


STATE Table 17. Shipment Characteristics by Destination State, Two-Digit Commodity and Mode of Transportation for State of Origin: 2002

At this level of detail, the majority of cells are empty or suppressed for one or more of several reasons, including disclosure rules and suppression due to a lack of statistical significance.

¹ See Census Bureau (2004), Curlee et al (2005), and Federal Highway Administration (2006) for additional information. Much of this section is based on Curlee et al (2005). Section 2.1.2 is based on a section of Curlee et al (2005) that was drafted by co-author Frank Southworth. FAF as discussed in this paper is based on work by Oak Ridge National Laboratory and as documented in January 2006. Modifications to FAF after January 2006 may have altered FAF as compared to the description given in this paper. While the overall state-of-practice per FAF is accurately summarized in this paper, those interested in exact details of FAF as of this date should consult with the Federal Highway Administration.
2.1.2 Auxiliary Data

The very spare nature of CFS Table 17 calls for additional information from other sources to help fill the missing cells. This additional information, termed Auxiliary Data, comes from various sources and is used in the Log-linear Model to estimate effects at the 2, 3, and 4 dimensional levels of the Freight Flow Database.

**Census Bureau “True-Zero” CFS Cells:**

FHWA issued a special request to the U.S. Census Bureau to identify those cells within CFS Table 17 for which there were no observations per their 2002 survey. With the strong cooperation of Census, this request was filled.

Per the methodology, it was assumed that any cell within Table 17 for which the 2002 CFS survey had no responses is declared a “true zero.” The combination of Table 17 with this “True Zero” version of Table 17 allows many of the cells in the Freight Flow Database to be identified. This is of value during the Log-linear and Iterative Proportional Fitting steps by which gaps in Table 17 (disaggregated from the state level to the FAF level) are filled.

**Database: Carload Waybill Sample**

The Surface Transportation Board's (STB) Carload Waybill Sample is a stratified sample of carload waybills for terminated shipments by U.S. railroad carriers. Waybill data is collected annually for STB by the Association of American railroads (AAR), from railroads that have moved at least 4,500 carloads each year for each of the previous three years, or which move 5% or more of any State’s total rail traffic. Sample stratification is based on the number of railcars a railroad moves and on the number of carloads in a movement. Waybills reporting a large number of carloads, such as unit train movements involving more than 100 carloads, have a higher probability of selection than smaller movements.

AAR generates both a Public Use waybill sample, and a more detailed dataset for the same sample that is restricted to internal government use. The Public Use File provides estimates of annual origin-to-destination tonnages and revenues received by specific railroads at the State-to-State and BEA (Bureau of Economic Analysis) region-to-region levels. Commodities are reported at the 5-digit level using STCC (Standard Transportation Commodity Codes). The restricted dataset incorporates added geographic detail for both O-D identification and railway routing. This more detailed data set can be used, for example, to assign annual O-D rail flows to specific FAF Regions. It also can be used to improve the selection of specific routings for the purposes of rail traffic assignment (and subsequent rail ton-mileage estimates). Expansion factors are provided for both datasets that allow users to expand the sample data to national totals. While the sample covers all commodities carried by in-scope U.S freight railroads, it does not
capture export shipments carried on Canadian railroads operating inside the United States.

For FAF use, STCC commodity codes had to be converted to SCTG codes. This was done by assigning each 5-digit STCC code to a specific 2-digit SCTG commodity class.

Information on this data can be found at:


http://www.stb.dot.gov/stb/industry/econ_waybill.html

Database: Domestic Waterborne Commerce of the United States

Data on U.S. waterborne commerce is provided by the U.S. Army Corps of Engineers (USACE). This includes the transport of goods by inland barge and ship over the nation’s navigable rivers, across the Great Lakes and within the U.S. Intra-Coastal Waterway. Domestic O-D movements are created by USACE from its Vessel Operating Reports, as well as from its Lock Performance Monitoring System (LPMS) database. Data are in theory reported by all vessels and provide estimates of annual tons moved by 5-digit commodity code for all commodities transported on U.S waterways, on a dock-to-dock basis. This data was aggregated geographically and used to supply the FAF with State-to-State as well as FAF Region-to-Region annual commodity tonnage totals. For this purpose the data were converted from 4-digit Waterborne Commerce (WCUS) commodity codes to 2-digit SCTG commodity classes.

Information on these data can be found at:


Database: International Waterborne Commerce of the United States

International waterborne commerce data is provided by the U.S. Army Corps of Engineers (USACE) International Waterborne Transportation Statistics Program, based on data supplied to it by the U.S. Census Bureau. This covers data on all vessels engaged in U.S. foreign trade and transportation, including cargo data by type of service, by U.S. and foreign port, by country of origin/destination, commodity, value and tonnage, for both bulk and containerized cargo. Data is provided according to the Harmonized Schedule (HS) of reporting. A conversion from HS to SCTG commodity classes was carried out for FAF use, as was an assignment of foreign counties to the 7 FAF Foreign Regions.

Information on these data can be found at:
The import and export data are found at:

http://www.iwr.usace.army.mil/ndc/db/foreign/data/

Database: Transborder Surface Freight

The Transborder Surface Freight database is provided by the Bureau of Transportation Statistics (BTS), who obtains the data by the U.S. Customs Service, via the U.S. Census Bureau. The data provide the FAF with the dollar value of both imported and exported freight crossing U.S.–Canadian and U.S.–Mexican borders, as well as the tonnage of freight imported. These data are broken down according to truck, rail, pipeline, mail and other moves by the 2-digit harmonized Schedule (HS) of commodity classes. Geographically these O-D data are broken down by U.S. State, Canadian Province, and Mexican State of origin and destination (Mexican state of origin for U.S. imports is not reported). The BTS public domain database also identifies total annual mode specific movements through each U.S. port of entry or exit by U.S. state of origin or destination. Imports valued at less than $1,250 and exports valued at less than $2,500 are not included in these data, nor are transshipments.

Information on these data can be found at:

http://www.bts.gov/transborder/

Database: U.S. Air Freight Movements

The volume (payload weight) and O-D pattern of domestic and international revenue-generating air freight within the U.S. is available from the Office of Airline Information (OAI), Bureau of Transportation Statistics. The data applicable to FAF is taken from Form 41 Air Carrier, the T-100 Market Data. These data report the annual payload tons of mail as well as freight flown between each pair of U.S. airports over the course of a year. No commodity disaggregation is available, nor is any data on the value of the freight involved. The database identifies the State of originating U.S. airport and State of destination U.S. airport for these cargo movements.

Information on these data can be found by selecting ‘Aviation” and “Air Carrier Statistics (Form 41 Traffic)” once at the following website:

http://www.transtats.bts.gov/

Both combined and separate annual T-100 Domestic and International Freight Payload data by O-D market are also available at this site.
2.1.3 CFS Out-of-Scope Data

“Auxiliary data” (discussed above) complement CFS Table 17 and allow missing cells within Table 17 to be estimated via Log-linear Modeling and Iterative Proportional Fitting (IPF). Waterborne Commerce, rail waybill, and Air Carrier data help to address some of the known weaknesses of the CFS survey in terms of mode coverage. The Census Bureau “True Zero” data provide one approach to address Table 17 cells that are suppressed for disclosure and statistical reasons.

Other CFS gaps remain. Several commodities were totally absent in the 2002 CFS survey. In some cases, one or more shipments in a commodity’s supply chain were absent from the CFS survey. In other cases, whole categories of shipments were omitted from the survey, such as the movement of retail commodities from the point of final purchase to the home, business, etc. In yet other cases, there was evidence that the 2002 CFS undercounted some commodities and types of shipments—based on significant differences with other reliable data sources.

Earlier research suggested that previous CFS surveys undercounted total U.S. freight by a significant amount. A study by Oak Ridge National Laboratory completed in 2000 estimated that the 1997 CFS captured only 75 percent of total U.S. freight shipments measured in tons, 74 percent when measured in ton miles, and 81 percent when measured in value.2

As part of the 2002 FAF, a significant effort was launched to bridge the most serious of these CFS gaps. The following 15 CFS gaps and undercounts were addressed in a series of special studies.3

Farm Based: CFS omits shipments of farm commodities from the farm to the first point of sale, e.g. a grain elevator or a stockyard.

Fisheries: CFS omits shipments of fish and seafood from the boat at the dock to the processor, or from the fish farm to the processor.

Crude Petroleum: Crude is completely outside the scope of the 2002 CFS.

Natural Gas: Natural gas is completely outside the scope of the 2002 CFS.

Municipal Solid Waste: MSW is completely outside the scope of the 2002 CFS.

Logging: CFS omits shipments of logs from the point of harvest to the initial point of processing.

2 See Oak Ridge National Laboratory (2000).
3 The out-of-scope studies were a joint effort of Oak Ridge National Laboratory and MacroSys Inc.
**Construction:** The CFS does not cover shipments originating from the construction sector. The construction sector includes construction companies or establishments engaged in construction of residential and non-residential buildings; utility systems; highway, street and bridge construction; and specialty trade contractors.

**Services:** The survey does not cover shipments originating from establishments involved in service industries. The missing services industries are finance and insurance; real estate, rental and leasing; professional, scientific and technical services; administrative and support, and waste management and remediation services; education services; health care and social assistance; arts, entertainment and recreation; accommodation and food services; other services (e.g., repair and maintenance, personal and laundry, religious, etc); and public administration. Also, the CFS does not include management of companies and enterprise services with the exception of corporate, subsidiary and regional managing offices.

**Publishing:** The CFS data gap on the publishing industry is primarily due to the adoption of the North American Industry Classification System (NAICS) in the 2002 CFS for selection of business establishments. In the 1997 and 1993 CFS businesses were selected based on their descriptions in the Standard Industry Classification (SIC).

**Retail:** The CFS does not cover shipments originating from retail trade stores, including motor vehicle and parts dealers, furniture and home furnishings stores, electronics and appliance stores, building material and garden equipment and supplies dealers, food and beverage stores, health and personal care stores, gasoline stations, clothing and clothing accessories stores, sporting goods, book and music stores, general merchandise stores, florists, used merchandise, manufactured home dealers, etc.

**Household and Business Moves:** The CFS is a survey of shippers, not carriers. Thus, the CFS does not capture freight movements by carriers that transport household and business furniture, equipment, etc.

**Imports:** Imports are completely outside the scope of the 2002 CFS. However, once import commodities enter the United States and change ownership, further shipments of those “imports” are captured within the CFS.

**Petroleum Products:** Petroleum products are technically within the scope of the CFS. However, previous research suggested that the 2002 CFS, like earlier editions, undercounted petroleum products.

**Exports:** The 2002 CFS collected data from U.S. business establishments located in the United States; thus the survey included exports from the United States by all freight modes. However, analysis of the 1993 and 1997 CFS export data suggests that the CFS underestimated U.S. export shipments.
In-transits: The CFS does not include shipments of commodities that originate outside of the United States, enter the United States by whatever mode, and then are shipped to some other country. Such shipments are called In-transits.

2.2 Methodology Overview

The methodology used to construct the Freight Flow Database includes several major steps and numerous assumptions. Figure 2 and this section provide an overview.

Step 1: CFS Table 17

The starting point for the 2002 FAF is CFS Table 17. Note that Table 17 reports shipments at the level of 2-digit SCTG and the required mode detail. However, Table 17 reports shipments at the state level—not the FAF regional level. The initial disaggregation from the state level to the FAF level was straightforward—i.e. divide shipments equally across all FAF regions that comprise each state. This simplistic assumption was followed by adjustments per log-linear modeling and IPF as discussed below.

Step 2: Identify “True Zeros” in Table 17

The Census Bureau identified those cells within Table 17 (disaggregated to the FAF regional level) for which the 2002 CFS had no samples. By assumption, those “true zero” cells were constrained to be “0”.

Step 3: Auxiliary Data and Conversions to SCTG

Auxiliary data were obtained from a variety of sources as discussed above. These data were converted to SCTG from the base commodity categorizations used by each data source. This allows a comparison of identical cells between Table 17 and non-CFS data for all modes. In those cases where direct comparisons were not possible at the four-dimensional level, comparisons were often possible at the 2 or 3 dimensional levels.

Step 4: Verify “True Zeros” with Auxiliary Data

For those cells within Table 17 that were marked true zeros per Step 2, data constructed in Step 3 were compared to verify agreement between the two data sources. Waybill data, Waterborne Commerce, and air freight data were compared for those particular cells to verify that neither of those datasets contradicts the true-zero conclusions based on Step 2. In cases of contradiction, i.e. where observations are found for cells previously marked as "true zero," the restriction on that cell or margin was lifted.

Step 5: Augment Table 17 with Auxiliary Data

Table 17, as modified per Steps 2 through 4, was augmented with water, rail, and air freight data as constructed in Step 3. In the cases of water, rail, and air, cells at the 2, 3,
and 4 dimensional levels are available from both CFS and from our auxiliary sources. Table 17 per Step 4 was augmented (e.g. skirted) with cells at the 2, 3, and 4 dimensional levels based on available auxiliary data. In other words, for some cells there are two values—one from the CFS and one from an auxiliary source. (Note that the auxiliary data were not included in marginal totals. Thus, marginal totals were constrained to be those from the CFS. Auxiliary data contribute to the log-linear step, but not to the IPF step.)

**Step 6: Log-linear Modeling**

For those cells for which there was no observed value from CFS as augmented with Census “true-zero” information, statistical procedures were applied to estimate the most likely value of those missing cells, based upon statistical relationships extracted from cells with known values. For example, no information is available from CFS on the shipments of fertilizers from Iowa to Memphis; but information is available on the total shipments of fertilizer from Iowa to all other FAF regions, and information also is available on shipments of all commodities from Iowa to Memphis. By examining the statistical relationships at higher orders of aggregation, a maximum likelihood value for each missing cell can be estimated.

Log-linear modeling was used to estimate these statistical relationships among FAF regions, modes, and commodities at 2, 3, and 4 dimensional levels. Log-linear models are specialized cases of general linear models. More specifically, log-linear analysis is an extension of the more familiar two-way contingency table in which the conditional relationship between two or more discrete variables is analyzed by taking the natural logarithm of the cell frequencies within the table. Log-linear models are a convenient way to analyze multi-dimensional contingency tables and estimate maximum likelihood values for missing cells.

**Step 7: Iterative Proportional Fitting**

Step 6 provided a complete four-dimensional matrix, but not a matrix that is consistent with totals at higher levels of aggregation. Iterative Proportional Fitting is a well accepted approach to adjust values within cells while maintaining the relationships between variables and assuring that rows and columns are consistent with the appropriate marginals. A “marginal” of a table is the set of quantities obtained by adding across all categories of any one or more of the cross classifying variables in a table.

The IPF procedure produces new estimates for each cell in the table at the 2, 3, and 4 dimensional levels such that they are in agreement with the marginal constraints, and is done so in an iterative fashion. In a two dimensional case, the elements of each row of the table are prorated so that their totals equal the corresponding marginal; then the elements of each column are prorated so their totals equal their corresponding marginal. After this initial step, the estimates in the table no longer add across the rows to agree with the first marginal. The steps are repeated iteratively until the procedure converges.
to the unique solution that sums to the marginals while preserving the initial relationships between the variables in the table.

The product of Step 7 is a complete Table 17 (four dimensional) in which the initial values from Table 17 are maintained for those known cells at the 1, 2, 3, and 4 dimensional levels, including the true-zero values from Step 4.

**Step 8: Adding Out-of-Scope Shipments**

The table derived in Step 7 does not include out-of-scope shipments. Those 15 categories of shipments, which were estimated in out-of-scope studies, were added to the table from Step 7 to arrive at the final Freight Flow Database. Out-of-scope flows were estimated initially at the national level. These national totals were subsequently disaggregated to the FAF regional level. Integrating these out-of-scope findings within the Freight Flow Database is straightforward both conceptually and mechanically.

The out-of-scope studies resulted in shipments at the appropriate four-dimensional level. Take MSW as an example. Shipments of MSW were estimated for all modes and all FAF regions—both intra and inter-regional shipments (e.g., from New York to the remainder of Pennsylvania—in terms of tons, ton miles, and value). MSW falls within SCTG category 41. Thus, the results of these out-of-scope studies were simply added to the appropriate cells in the tables resulting from Step 7.

### 3. The Ohio River Navigation Investment Model (ORNIM)

The Ohio River Navigation Investment Model (ORNIM) represents a different approach and paradigm for modeling freight flows by federal agencies. Whereas FAF is based on detailed survey data in combination with sophisticated matrix filling methods, ORNIM is based on economic theory and utilizes data—some of the same data used in FAF—in econometric and other economic models to estimate current freight flows and to project how future flows may change based on economic incentives.

ORNIM was built by Oak Ridge National Laboratory (ORNL) working in collaboration with the USACE Planning Center of Expertise for Inland Navigation (Corps). The purpose of ORNIM is to estimate the benefits of improvements to the navigation infrastructure of the Ohio River System—e.g., extended or new locks, channel improvements, replacement of key lock and dam components, alternative maintenance policies, etc.—and to balance those benefits against the estimated costs of those improvements. By doing so, ORNIM can suggest the optimal set of infrastructure investments over time.4 Figure 3 provides a graphical description of ORNIM, its three main modules, and data provided from external sources.

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4 See Curlee, Busch, Hilliard, Oladosu, Southworth, and Vogt (2004) for a detailed discussion of ORNIM, the economic assumptions employed within the model, and the potential biases in National Economic Development (NED) benefits presented by these assumptions.
ORNIM is based on a long history of model development within the Corps. The Tow Cost Model (TCM) and the Equilibrium Model (EQ), which had their beginnings in the 1970s, served as a starting point for ORNIM. ORNIM takes advantage of additional and more refined data, in combination with state-of-the-art computer software, hardware, and computational algorithms, to move to a new frontier of navigation modeling. However, this new frontier is built on the same basic economic assumptions employed in TCM, and ORNIM remains a partial equilibrium model. These assumptions include:

- The demand for individual movements—each composed of numerous shipments—is provided exogenously and is perfectly inelastic with respect to the price of river transport.
- The willingness-to-pay for individual movements on the river is equal to the least-cost alternative rail rate, which is provided exogenously.
- The supply of rail for individual movements is perfectly elastic at the given rail rate.

These assumptions have been questioned per their real-world validity. Of equal importance, these assumptions may hinder the analysis of key issues facing navigation, such as the value of reliability and maintenance, and the response of shippers and other relevant decision makers to risk and uncertainty. Also at issue is the need to expand ORNIM beyond its current partial-equilibrium status—directly or by linking to other models.

The Corps is continuing to improve ORNIM and other navigation models by relaxing one or more of these basic assumptions. For example, the Corps is currently investigating options for incorporating any elasticity value within ORNIM—thus relaxing the first assumption.

Per freight demand, ORNIM is provided with current and projected future cargo movements (i.e., tons of cargo by type) that would “like to move” on the river from point A to point B. “Would like to move” means the cargo will be shipped by river if the total cost of river transport—including congestion cost—is cheaper than the alternative of rail. More specifically, ORNIM considers a set of about 1,900 annual origin-destination (OD) movements (each movement composed of many shipments) over a fifty year time period. Historical information on movements is available from Waterborne Commerce, as discussed in the section on FAF. The Corps typically develops “demand scenarios,” which depict different freight demand futures in terms of how much cargo would “like to move by river.”

Figure 4 provides a graphical description of how ORNIM reaches an equilibrium, and is included for the interested reader. For the sake of brevity, the author will not describe this figure in detail. The following steps are a gross oversimplification of the actual procedure, but may be instructive. First, ORNIM computes for each of the 1,900 yearly movements that “movement’s willingness to tolerate cost of delay per congestion” by taking the difference between that movement’s cost of moving by river (the river rate) and the “least cost alternative rail rate.” Second, the model rank orders the 1,900 yearly movements by the “movement’s willingness to tolerate cost of delay per congestion”
from highest to lowest. The model then obtains information from an external model which estimates how much delay each ton of traffic on the river is likely to experience—i.e., the two upward sloping curves. The model searches for an equilibrium at the point where the curve, “Benefits of River Traffic” intersects the curve, “Current System-wide Cost of Delay.” For this particular river system, a total of Q* will move by river in the without-project condition. The tonnage and movements represented by the difference between “River Tons” and Q* will be diverted to rail. The method is based on approaches used to identify a Wardrop equilibrium.

The process is repeated for all the alternatives considered in the study. Improvements to the river system by structural and non-structural measures will increase the total capacity of the river and thereby reduce the congestion realized on the river for any given total river tonnage; essentially the cost-of-delay curve shifts to the right. The intersection between “Benefits of River Traffic” and “New Capacity, System-Wide Cost of Delay” depicts a new with-project equilibrium level of system traffic for that particular alternative. This alternative results in two kinds of benefits. First, the tows on the river prior to the infrastructure improvements (per the specific Alternative) now experience less congestion and delay cost—the yellow shaded portion. Second, additional tons can move on the river, (Q*-Q*'), that would otherwise be diverted to rail at a higher per-ton rail rate—the lightly hatched area. The benefits of the Alternative can then be balanced against the estimated cost of implementing that alternative. Once discounted to reflect the decreasing value of costs and benefits over time, all of the Alternatives (each represented by a different cost-of-delay curve) can be ranked by their benefit/cost ratios.

The external freight demands that “would like to move by river” come from a variety of sources. Given that coal is the dominant commodity shipped on the Ohio River System, the Corps purchases forecasts from Hill and Associates. Freight demand forecasts for other commodities come from econometric models and professional judgment. See Figure 5.


The Navigation Economics Technologies Program is a multiyear effort led by the Institute for Water Resources, which is a Corps of Engineers laboratory. NETS is targeted at improving navigation models at all levels of geography and commodity detail. Economic theory and innovative empirical approaches are the foundations of these improvements.

The NETS program plan calls for three tiers of models. See Figure 6. Southworth and Vogt (2005) describe the approach:

A hierarchical approach consisting of three tiers of modeling has been proposed, one that moves from a broad regional and global geography in Tier 1 down to a detailed project and facility specific level of detail in Tier

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3. Figure 1 (Figure 6 in this paper) shows one interpretation of this concept, in which the three tiers of modeling each contain feedback loops for passing results between adjacent tiers. Tier 1 modeling is focused on econometric estimation and forecasting of future year commodity production, consumption, and broad transglobal trading patterns. Tier 2 modeling disaggregates these forecast trades to a point where they can be assigned as freight traffic to specific modes and routes within the U.S. transportation network. Tier 3 uses these mode and route specific forecasts to optimize investments in navigable waterways and seaports and in the operational and maintenance costs associated with structures such as locks and harbors.

NETS is developing more sophisticated econometric models to forecast freight demand for key commodities, such as grain. NETS also is developing new approaches to estimate navigation demand elasticity (for both own-price and trip-duration) using discrete choice random utility models.6

These Tier 1 models will be linked formally on informally with one or more Tier 2 models to estimate and project movements of key commodities from region to region. The Regional Routing Model (RRM) is currently being developed to serve as the primary Tier 2 model. Southworth, Peterson, and Lambert (2006) describe their model:

This paper describes the construction of a commodity flows database to support Tier 2 modeling. Called the Regional Routing Model, it takes spatial disaggregations of broad regionally forecasts of commodity flows to a point where they can be assigned to specific modes and routes over the U.S. transportation network. The paper describes the model structure and how it is being tied closely to a multi-source database constructed to support base year model calibration. A goal for the model is to be able to measure the effects on flows and transportation costs of changes to either the capacity of the transportation network or to the volumes of goods produced and consumed.

ORNIM is representative of a Tier 3 model. As described above, ORNIM is designed to confirm if exogenously generated freight demand forecasts (from Tier 1 and Tier 2 models) can be accommodated on the river system given the detailed estimates of congestion costs as calculated within ORNIM. If the exogenous freight demands cannot be fully accommodated, some movements will be diverted to rail and possibly truck. This diversion may call for one or more iterations with Tier 1 and Tier 2 models to reach a final equilibrium.

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6 See, for example, Train and Wilson (2004). For more information on NETS, please visit http://www.nets.iwr.usace.army.mil/
5. Final Observations

Clearly, the state-of-practice in freight modeling varies across federal agencies. Different agencies have different objectives and goals, which call for different approaches. Different agencies also base their freight models on distinctly different paradigms. For example, FAF begins with a sparsely filled matrix based on survey data and seeks to identify mathematical relationships across as many as seven dimensions—i.e. modes, commodities, origins, destinations, tons, dollars, distance, and alternative data sources. These mathematical relationships allow missing cells to be estimated, and freight demands can be estimated at a significant level of geographic, commodity, and modal detail. Alternatively, ORNIM and NETS are founded on a behavioral paradigm, which is based on economic theory. These models do not currently provide the level of geographic, commodity, and modal detail provided by FAF. Some would argue that modeling behavioral decisions based on economic theory is more defensible than alternative approaches, such as matrix filling. Others would argue exactly the opposite, suggesting that economic theory and models based on theory are overly abstract representations of the real world.

Economists, transportation planners, engineers and other disciplines bring their own academic and research backgrounds to efforts to improve freight models within federal agencies. This author suggests that freight modeling may best be served by an interdisciplinary approach, which calls upon the strengths of each discipline, each approach, and each paradigm. This author also suggests that significant opportunities exist for collaboration across federal agencies. While it is clear that federal agencies are making great strides in improving their specific methodologies and models, the greatest strides may come from the integration of modeling paradigms and the merging of efforts across federal agencies.
References


Table 1. FAF Commodity & Mode Disaggregations

<table>
<thead>
<tr>
<th>SCTG Code</th>
<th>Commodity Classes</th>
<th>Transportation Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Live animals and live fish</td>
<td>01 Truck</td>
</tr>
<tr>
<td>02</td>
<td>Cereal grains</td>
<td>01 Private truck</td>
</tr>
<tr>
<td>03</td>
<td>Other agricultural products</td>
<td>01 For-hire truck</td>
</tr>
<tr>
<td>04</td>
<td>Animal feed and products of animal origin, n.e.c.</td>
<td>02 Rail</td>
</tr>
<tr>
<td>05</td>
<td>Meat, fish, seafood, and their preparations</td>
<td>03 Water</td>
</tr>
<tr>
<td>06</td>
<td>Milled grain products and preparations, and bakery products</td>
<td>03 Shallow draft</td>
</tr>
<tr>
<td>07</td>
<td>Other prepared foodstuffs and fats and oils</td>
<td>03 Great Lakes</td>
</tr>
<tr>
<td>08</td>
<td>Alcoholic beverages</td>
<td>03 Deep draft</td>
</tr>
<tr>
<td>09</td>
<td>Tobacco products</td>
<td>04 Air (inc. truck-air)</td>
</tr>
<tr>
<td>10</td>
<td>Monumental or building stone</td>
<td>05 Truck-Rail Intermodal</td>
</tr>
<tr>
<td>11</td>
<td>Natural sands</td>
<td>06 Other Multiple Modes</td>
</tr>
<tr>
<td>12</td>
<td>Gravel and crushed stone</td>
<td>Including:</td>
</tr>
<tr>
<td>13</td>
<td>Nonmetallic minerals n.e.c.</td>
<td>06 Parcel, USPS or courier</td>
</tr>
<tr>
<td>14</td>
<td>Metallic ores and concentrates</td>
<td>06 Truck-water</td>
</tr>
<tr>
<td>15</td>
<td>Coal</td>
<td>06 Water-rail</td>
</tr>
<tr>
<td>16</td>
<td>Crude Petroleum</td>
<td>07 Other and Unknown modes</td>
</tr>
<tr>
<td>17</td>
<td>Gasoline and aviation turbine fuel</td>
<td>Including pipeline</td>
</tr>
<tr>
<td>18</td>
<td>Fuel oils</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Coal and petroleum products, n.e.c.</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Basic chemicals</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Pharmaceutical products</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Fertilizers</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Chemical products and preparations, n.e.c.</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Plastics and rubber</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Logs and other wood in the rough</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Wood products</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Pulp, newsprint, paper, and paperboard</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Paper or paperboard articles</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Printed products</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Textiles, leather, and articles of textiles or leather</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Nonmetallic mineral products</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Base metal in primary or semifinished forms and in finished basic shapes</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Articles of base metal</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Machinery</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Electronic and other electrical equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and components and office equipment</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Motorized and other vehicles (including Parts)</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Transportation equipment, n.e.c.</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Precision instruments and apparatus</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Furniture, mattresses and mattress supports, lamps, lighting fittings, etc.</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Miscellaneous manufactured products</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Waste and scrap</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Mixed freight</td>
<td></td>
</tr>
<tr>
<td></td>
<td>— Commodity unknown</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. 2002 Freight Analysis Framework Regions, Including Gateways
Figure 2.

FAF² Methodology

Iterative Proportional Fitting

Log Linear Model

"True Zero" Cells from Census

CFS Table 17

Enhanced CFS Flows Matrix

CFS Out-of-Scope Sectors

Final FAF² Flows Table

CFS Alternatives: Railcar Waybills Waterborne Commerce
Figure 3:

The ORNIM System

- Lock Operations
- Cargo Forecasts
- Reliability Estimates
- River Network
- Waterway Supply and Demand Module
- Lock Risk Module
- Repair Plans and Costs
- Towboat/Barge Operations
- Optimal Investment Module
- Random Closures
- Optimal Investment in Projects and Maintenance
- Construction Plans
- Budget

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21
The Mechanics of Measuring Without and With-Project Benefits

- Total NED Benefits with Current River System
- Benefits of River Traffic (Land Rate - River Rate): Willingness to tolerate cost of delay
- Current System-wide Cost of Delay
- New Capacity, System-wide Cost of Delay

Total Commodity Demand Forecasts:
Sum of all movements that would like to go by river

- Total Benefits of New Capacity Resulting from Reduced Delays of Existing River Traffic
- Total Benefits of New Capacity Resulting from Additional Tons of River Traffic
- Total Benefits of New Capacity

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Figure 5:
The ORNIM System

Lock Operations → Cargo Forecasts → Reliability Estimates

- Tons Moved By Water
- Tons Diverted To Rail
- Waterway Supply and Demand Module
- Waterborne Commerce Statistics
- Hill and Associates Coal Model
- World Grain Model (NETS) (not currently used)
Figure 6:

1: Macro-Economic Modeling of Regional and Global Production & Consumption

2. Meso-Economic Modeling of Multimodal Route and Market Choice

3. Detailed Waterway Specific Investment Modeling

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Figure 1. A Nested Three-Tier Spatial-Economic Modeling Framework
From Southworth and Vogt (2005)