A Multimodal Regional Routing & Multi-Port Analysis Model

December 6, 2005

Prepared by:
Frank Southworth
Oak Ridge National Laboratory
Oak Ridge, TN 37831
sou@ornl.gov
Tel: 865-946-1246

Prepared for
Institute for Water Resources
United States Army Corps of Engineers
Fort Belvoir
Alexandria VA 22315-3868

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6073
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-00OR22725

A Multimodal Regional Routing & Multi-Port Analysis Model

Abstract

This paper described development of the Regional Routing and Multi-Ports Analysis Model. The model is under development for the U.S. Army Corps of Engineers as one in a suite of models for analyzing the relationship between waterway flows and their costs. The paper describes the creation of a set of mode and commodity specific flows based on existing data sources, the assignment of these flows to a detailed multimodal (truck, rail, water) representation of the United States transportation network, and an estimation of the costs of such movements over the respective modal sub-networks on the basis of this assignment. The model will be used to analyze the effects on waterway flows and transportation costs due to changes in the levels of regional commodity production and consumption, as well as changes in conditions on the transportation network (changes in capacity, carrier rates and other shipper impacting costs). To accomplish this, the model must re-solve shippers' mode and route as well as market choice based on the results of a series of shipper response surveys and associated shipper choice models. The paper describes the current approach to data collection and model specification, and progress to date.

1. Background

The NETS (Navigation Economics Technologies)[1] suite of models is being developed by the U.S. Army Corps of Engineers (USACE) to bring state-of-the-art analytic models to the process of evaluating and planning navigation investments. 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 3. Figure 1 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 trans-global 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.[2] This paper describes an approach to developing Tier 2 models within this framework.

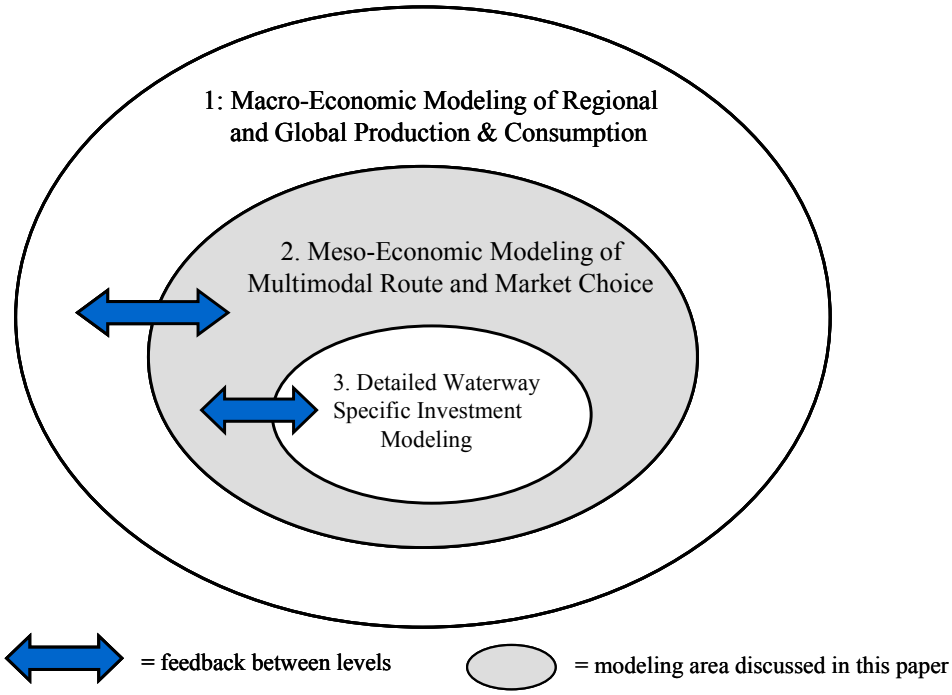


Figure 1. A Nested Three-Tier Spatial-Economic Modeling Framework

The Tier 2 model described below is termed the Regional Routing and Multi-Port Analysis Model (RRM for short). The principal outputs of this model are:

- a set of origin, destination, commodity and mode specific annual traffic flows;

[1] http://www.corpsnets.us/

[2] Candidate Tier 3 models are the Corps ORNIM and its Harbor Sim models.

- an assignment of these flows to the appropriate sections of the nation's multimodal transportation network;
- the estimated costs of movement associated with these assigned flows; and
- estimates of the effects of changes in commodity production, consumption (market demand) and network conditions (network capacity, carrier rates, shipper costs) on the pattern of commodity flows, as they across modes, routes and between sources and markets.

The modeling will also generate a set of spatially detailed transportation benefit measures, notably measures of the surplus accruing to shippers of commodities as a result of a well maintained national and regional waterway infrastructure. The modeling is based on estimating a set of annually based U.S. county-to-county and county-to-seaport commodity flows and their associated transportation costs. Visualization of the modeling results will take advantage of the latest in geographic information systems' (GIS) software.

To create these outputs the RRM incorporates each step in the traditional transportation planning model, i.e. estimates of commodity production and consumption by region, estimates of commodity flows based on these two distributions, and assignment of these flows to specific modes and routes within the U.S. transportation network (see Southworth and Vogt, 2005). To do so it must determine the effects of transportation distance-related costs on the resulting origin-to-destination flow pattern. An iterative process is usually required to bring the resulting origin-to-destination (O-D) flows and costs into compliance. Figure 2 shows the basic idea.

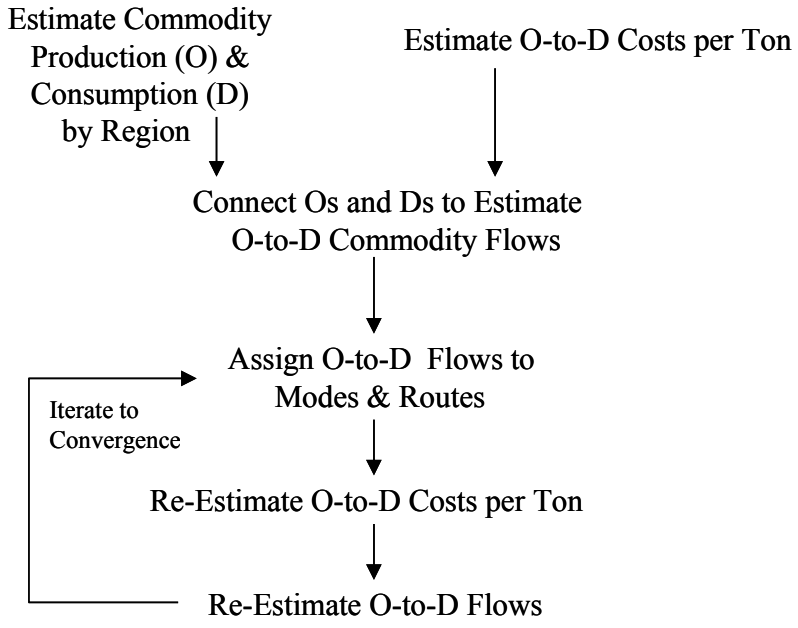


Figure 2. The Basic Flow and Cost Estimation Process

Whether the iteration mechanism shown in Figure 2 is needed depends on the extent of the changes in the original O-D flows and/or O-D costs. If significant traffic congestion exists on the network, as is anticipated, this may require a number of iterations between flow and cost estimation steps to obtain a stable solution.

In practice the implementation of such a framework requires a good deal of data acquisition, manipulation, model calibration and data gap filling, all prior to any mode and route assignments. This paper described how these data tasks are being handled, and how the process in Figure 2 is being implemented, initially for a series of agricultural product shipments that collectively use the U.S. waterway, railway and highway networks. The description focuses on two major tasks:

- Development of the forecasting/scenario analysis model (section 2)
- Creation of a base case from which to calibrate and validate the model (section 3)

These descriptions emphasize three key technical challenges:

- creating a high quality data base that can be maintained over time;
- incorporating results from other pieces of the NETS modeling puzzle (notably the results of NETS' shipper response surveys and associated econometric choice models); and
- developing an effective mode/route/market choice process at a level of (spatial-, commodity- and mode- based) resolution suitable for Corps' planning purposes.

Section 4 of the paper described progress to date. Efforts to date have focused on a) the parallel development of a data set for the base case and on b) the development of a simplified version of the proposed congestion-sensitive combined mode, route and destination market choice model.

2. Simulating Mode, Route and Market Shifts in Commodity Movements

2.1 Traffic Generation: County-Based Production and Consumption

While various data sources provide regionally based annual (and sometimes also seasonal) commodity production totals, obtaining regional consumption totals is more challenging. Let S_{*j}^{m} refer to the annual dollar value of commodity m consumed in county j. We can estimate this consumption using the following relationship, based on supply side input-output modeling (see Vilain, Liu and Aimen (1999); Sorratini and Smith (2000); Vogt et al, 2002; Liu and Vilain, 2004, for examples):

$$S_{*j}^{m} = \sum_{n} a_{j}^{mn} * \sum_{k} S_{jj'}^{n} + y_{j}^{m} \qquad \text{for all sectors n, and all receiving regions j'} \qquad (1)$$

where a_{j}^{mn} = the dollar amount of industry n needed to produce a dollar of commodity m in region j; $S_{jj'}^{n}$ = the volume of m sold by region j to industry n in regions j' =1,2,,i,..j,…J; and

where y_j^m = final (government plus household) demand for m in region j. Where commodity m must be produced elsewhere, then region j needs to import it from other regions in order to satisfy its customer. The volume of commodity m received in county j from these other counties is defined as S_{ij}^m, and we therefore have the following relationship in order to balance up the various county-specific demands and supplies of commodity m:

$$S_{*j}^m = \sum_i S_{ij}^m = \sum_n a_j^{mn} * \sum_i S_{jj'}^n + y_j^m \quad (2)$$

The purpose of a market destination choice model is to determine this distribution of sources from among the i=1,,2,….I possible supply regions. To capture the effects of transportation costs on this distribution it is necessary to convert from dollars to tons shipped, including the effects of tonnage on line-haul, storage and transfer costs. Doing so gives us the annual tons of commodity m demanded at region j, as:

$$X_{*j}^m = (S_{*j}^m / q_j^m) \quad (3)$$

where q_j^m = the average traded value of a ton of commodity m in county j. Similarly, we can generate estimates of the tons of commodity m produced in each county, where such data is not directly available or reported in such data sources as the US Department of Agriculture's (USDA) on-farm production estimates and the Department of Commerce's (DOC) county business patterns.

Using an input-output model for this process ensures a consistency in accounting across multiple (and potentially all) commodity classes and industrial sectors. It also allows us to alter the demands for certain commodities in the future should the relationship of inputs to outputs change within the industrial process. Its' chief drawback is the otherwise static nature of these relationships and the practical difficulty of specifying region-specific industry-to-commodity conversion coefficients. Its value to the RRM is its ability to supply county and seaport level demands for commodities based on a good deal of readily available economic activity data.

For RRM purposes these production and/or consumption forecasts may come from broad regional, Tier 1, econometric modeling efforts. This means allocating these forecasts to the individual county level for Tier 2 analysis. Specific seaports enter this picture as additional sources and destinations for commodity flows: requiring that we separate out the flows passing through these locations from flows entering, leaving and being otherwise consumed within the county containing the port.

2.2 Combined Mode, Route and Market Choice Modeling

This section describes the conceptual and mathematical basis behind the proposed RRM model. The approach is developed in a series of steps, each adding one more piece of the puzzle to be solved. A key attribute of the approach is its flexibility when it comes to implementation of the full set of model capabilities. This allows for a certain degree of pragmatism in making the model operational at an early stage, without precluding more advanced solutions should they become warranted. In any case the best overall solution approach will not be clear until a good deal of experimentation with the data has gone on. This is not simply a practical matter. Given a

system as complex as the one we are simulating, some solutions may represent actual behaviors better than others. Given a wide range of commodity types to be modeled a conceptual framework is required that allows a variety of detailed model specifications to be applied within a single unifying and theoretically sound framework. Translating theory into practice in this instance means being able to employ more than one sequence of cost-to-flow adjustment computations as part of the model equilibration process outlined in Figure 2. This will become clear below. Of note, the mathematical framework allows a range of shipper-based behavioral response functions to not only be included in the modeling, but ultimately to drive some of the decisions about overall model structure.

2.2.1 Congestion Sensitive Multimodal Traffic Assignments

To evaluate the benefits and costs of adding, upgrading and maintaining new waterway infrastructures, the RRM traffic assignments need to offer congestion sensitive solutions that capture the effects both traffic growth ("demand") and changes in network throughput capacity ("supply"). These demand or supply changes can alter the delivered price of commodities either directly, through higher freight rates, or indirectly, through the market shifts in traffic they induce.

At the county-to-county level of the RRM a set of representative, mode specific and congestion-sensitive network link transit curves are required for each of the three modes. Figure 3 shows the sort of curves commonly used to simulate (a) mixed barge adn recreational traffic movements through locks; (b) traffic movements along mixed automobile and truck highways. The lock congestion function shown is one of a variety of curves frequently used by USACE to simulate transit time through navigable river locks using a model such as WAM (USACE, 1983). The similarity of the functional forms across modes is obvious: although the details involved in computing the delays are somewhat different.

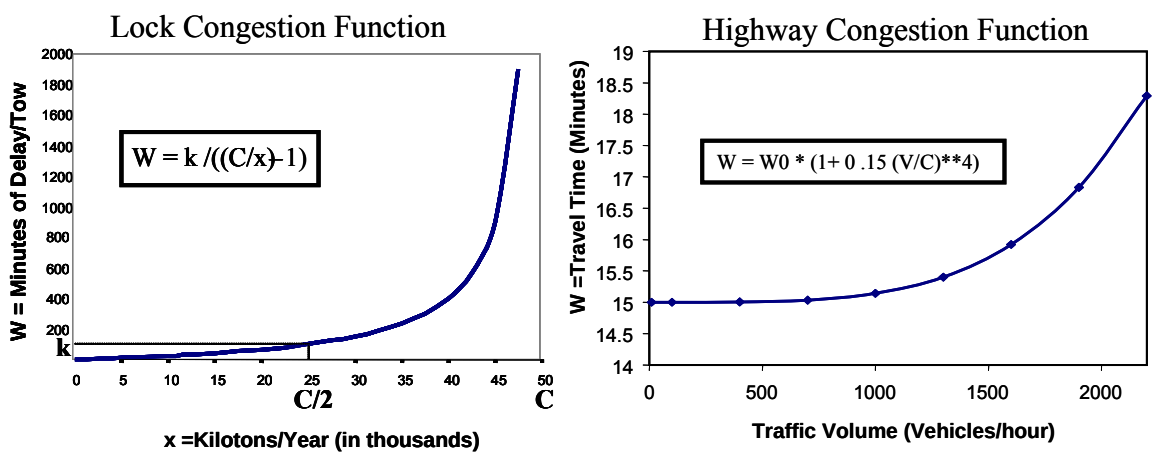


Figure 3. Traffic Cost-Volume Tradeoff Curves for Congested Network Links

Rail capacity modeling at this level of spatial and temporal resolution is less well documented, and will require some research to select viable forms of transit time delay function; although curves similar to those shown in Figure 3 have been used to movedl flows through transfer

terminals and consolidation yards as well as line haul operations (for example, Crainic, Florian and Leal, 1990; Fernandez, de Cea and Giesen, 2001). Whether occurring during line haul, terminal transfer, or consolidation of loads, each of these delays has to simulated as link delay functions within the RRM multimodal network. Applying a capacity constrained traffic assignment model using link congestion functions of the types shown in Figure 3 allows for direct interaction between freight flow volumes and freight cost changes. This is a key component of waterway infrastructure investment analysis.[3]

The most effective way to capture these effects is through a capacity constrained equilibrium traffic assignment model of the form:

$$Minimize_{V,X} Z(V,X) = \sum_{ak} \int_0^{Vak} S^{ak}(\omega)d\omega \tag{4}$$

subject to:

$$V^{ak} = \sum_i \sum_j \sum_r \delta_{i,j}^{akr} X_{ij}^{kr} \quad \text{for all links, a, and modes k, in the network} \tag{5}$$

$$\sum_r X_{ij}^{rk} = X_{ij}^{k} \quad \text{for i=1,2,...I, and j=1,2,...J} \tag{6}$$

$$\sum_k X_{ij}^{k} = X_{ij} \quad \text{for i=1,2,...I, and j=1,2,...J} \tag{7}$$

$$V^{ak} \geq 0 \tag{8}$$

$$X_{ij}^{kr} \geq 0 \tag{9}$$

where V^{ak} = the number of tons flowing over network link a, found on the modal sub-network k ; $S^{ak}(V^{ak})$ = the travel time on link a, at flow volume V^{ak}; X_{ij}^{rk} = the number of tons assigned to path r and mode k carrying freight from origination i to destination j; X_{ij}^{k} = the total tons shipped from i to j by by mode k; and X_{ij} = the total tons shipped from i to j, summed over all paths and modes. Equation (4) means that we are obtaining an equilibrium on the assumption that shippers act in such a way (and by implication have the necessary information) that they minimize their own transportation costs. To get this result we must solve simultaneously for link volumes, V^{ak} and i-to-j flow volumes, X_{ij}. Equation (5) ensures that the volume of traffic assigned to link a equals the flows on all r paths through link a, as assigned by the solution. Equations (6) and (7) ensure respectively that flows by all i-to-j paths sum to the total i-to-j flows by mode k, and that these i-to-j model flows in turn sum to the total tons shipped from i to j. Equations (8) and (9) prevent negatively valued link volumes and i-to-j flows.

Similar models are now in common use, notably in the simulation of highly congested highway systems. Multimodal versions of such models, while less common to date, are also becoming more popular for both regional and fully national freight modeling (Crainic, Florian and Leal,

[3] However, remembering the three tier approach being developed in NETS, it seems most appropriate to devolve any detailed congestion/delay analysis of specific facilities, such as locks, to the third tier of operational modeling and try to bring these effects back up into the MRR model level of analysis. What is required for MRR analysis is a suitable representation of such congestion effects across entire river systems for a represenative set of conditions. Calibration of such congestion effects might then be tied to more systemwide measures of reported delay.

1990; Beuthe et al, 2001; Fernandez, de Cea and Giesen, 2001; Geerts and Jourquin, 2001; Jourquin and Beuthe, 2001; Ham, Kim and Boyce, 2005; Russ et al, 2005). Tractability lies in being able to keep the problem convex.

The model represented by equations (4)–(9) is based on Wardrop's (1952) first principle, that users of the network (in this case, shippers), while each seeking to minimize their own transportation costs, will reach an equilibrium state in which the cost of getting from any origin i, to any destination j, is identical across all used routes: while more expensive routes between any O-D pair are unused. The major extension to Wardrop here is to include multiple modes k =1,2,3…. (water, rail, truck). Equilibrium solutions can be obtained to large problems in reasonable computational times, based on Frank-Wolfe, Partial Linearization and related methods, all incorporating a frequently called shortest path routine and using successive averaging over iteratively assigned flows and costs to bring about convergence. This includes both customized and commercial off-the-shelf software programs (such as Caliper Corporation's Transcad©, and INRO's STAN/EMME/2© programs). While the link transit time-versus-volume functions, $S^{ak}(V^{ak})$, must remain convex for such optimal solution to be readily obtained, this is usually an acceptable assumption given the way that traffic congestion affects costs on each of the modes.

Equations (4)–(9) represent the basic Wardrop solution to a single commodity route choice problem when faced with traffic congestion. To represent the Corps' real-world problem presented by the RRM we must expand this problem in four important directions:

- We must solve the problem for a range of different commodities or commodity classes, each with a potentially different per unit transportation cost (e.g. because of different per unit cargo carrying costs).

- We must find a way to explicitly estimate the modal choice being made by shippers (or being forced upon these shippers by their receivers, where this decision takes place at the destination end of a movement). To accomplish this and capture the true price-based competition between modes we need a) a consistent means of representing mode specific transportation cost functions, and b) an ability to measure the responsiveness of shippers to differences in the quality of service offered them by the different modes.

- We must find a way to capture the major routing decisions made by carriers once a set of O-D flows have been "captured" by them.

- We should also allow for sensitivity in market (i.e. destination) selection, based in part on the costs of moving commodities by the modes and routes available.

Treating multiple commodities, or commodity classes, within a single framework means that we have a multi-class as well as multimodal network equilibrium to solve for. The principal complexity this introduces to the modeling is that differently valued commodities may be differentially impacted by the same level of in-transit delay. This suggests that some cargos may be more responsive to time-based cost changes than others. Solving for this sort of response directly within the routing model is feasible, but at the price of model complexity and probably

also solution times (see Defarmos, 1982; Florian and Spiess, 1982; Toint and Wynter, 1996). However, not all components of mode specific transportation costs are congestion-sensitive, and if the more price-elastic commodities are those more likely to shift modes or markets then we can often handle the principal commodity-specific factors impacting mode and market choice within an iterative loop outside the route selection process per se. This will be our initial approach. Specifically, we can extend the above routing problem to also solve for both mode and market choice prior to the route assignment stage. In terms of model (4)-(9) above this means solving for the terms X_{ij}^{k} and X_{ij} and then using these solutions to estimate the route specific flows, X_{ij}^{rk}. This has appeal because it devolves the route assignment to the carrier of the freight, who will usually make this determination. The next two sections describe how these O-D specific mode and market shares are generated.

2.2.2 Modeling Commodity Specific Mode Choice

Let P^{km} = the probability of a shipper using mode k, out of the available modal set K(m) suitable for moving commodity m. A common mode choice model is the logit form:

$$P^{km} = \exp(-\theta^{m} c^{km}) / \sum_{k \varepsilon K(m)} \exp(-\theta^{m} c^{km}) \qquad (10)$$

Where θ^{m} is a commodity m specific modal cost sensitivity parameter used to fit the model to reported mode shares, and c^{km} is the utility or generalized cost of shipping by mode k. For example:

$$c^{km} = \alpha_0 + \alpha_1 r^{km} + \alpha_2 t^{km} + \alpha_3 v^{km} \qquad (11)$$

For r^{km} = freight rate (per ton) by mode k ; t^{km} = transit time by mode k; v^{km} = on time arrival variability (e.g. percent on-time arrival) of mode k; α_0 , α_1 , α_2 , α_3 = the model coefficients to be estimated.

Equation (11) represents the sort of utility or "generalized cost" function we are looking for: one that captures the empirically observed relationship between mode choice and freight rates, transit times and one (or more) measures of expected service quality. In equation (11) this last attribute is represented as the respondent's (shipper's) perception of on-time arrival variability (reliability). Each of these factors has been found to play an important role in previous freight mode choice studies (FRA, 2005), and each is a variable than can be affected, often significantly, by waterway investment decisions. This includes recent research into grain shipper behavior under the NETS program (Train and Wilson, 2004, 2005). In particular, the inclusion of both freight rate and transit time variables is of note, recognizing that the latter necessarily impacts the former. Other attributes of modal service can also be introduced, remembering that as we expand these survey results to the shipper population as a whole we may be forced to assume average or expected responses on such variables in order to use the model's remaining coefficients in planning and policy-motivated studies.

The value of equation (11) to the RRM is that it provides a means of relating the sensitivity of shipper response to key transportation service attributes, using the intercept, α_0, to control for other factors when estimating the effects of changes in freight rate, transit time or service

reliability on modal demand. Note also that in the absence of any i-to-j differences in the α_3 coefficient at the level of the RRM specification we can use the survey generated mean response value, effectively treating it as part of the unspecified intercept term. Given the interest in elasticity of demand for water transportation as a function of changes in freight cost (and the effects on the latter due to fuel cost rises, congestion, etc.) terms such as α_0 and α_3 play an important role in reflecting a realistic shipper response.

2.2.3 Modeling Commodity Specific Destination Choice

We can model market choice in the same way that we model mode choice above, substituting destination j for mode k in equations (10) and (11); or we can try to model both simultaneously, as described by Wilson and Train (2005) for example. The key for the RRM model is to receive a suitably developed set of shipper cost (utility) functions with which to work. However, for RRM purposes we need to make the resulting choices match reported county-to-county based commodity flows. We can do this using a doubly constrained spatial interaction model of the following type:

$$X_{ij}^m = O_i^m \; D_j^m \; F[\beta^m, \bar{c}_{ij}^m] \; A_i^m \; B_j^m \qquad (12)$$

where $D_j^m = X_{*j}^m$, the volume of good m demanded at destination j ; and $O_i^m = X_{*i}^m$, the volume of good m produced at origin i; and where A_i^m and B_j^m are balancing factors of the form:

$$A_i^m = 1/\{\textstyle\sum_j B_j^m D_j^m \; F[\beta^m, \bar{c}_{ij}^m]\} \quad \text{for all i} \qquad (13a)$$

$$B_j^m = 1/\{\textstyle\sum_i A_i^m \; O_i^m \; F[\beta^m, \bar{c}_{ij}^m]\} \quad \text{for all j} \qquad (13b)$$

which ensure that the observed trip end totals are retained by the subsequent i-to-j distribution of tons, i.e.

$$\textstyle\sum_j X_{ij}^m = O_i^m \quad \text{for all i} \qquad (14)$$

$$\textstyle\sum_i X_{ij}^m = D_j^m \quad \text{for all j} \qquad (15)$$

and where,

$$\textstyle\sum_{ij} (X_{ij}^m \; d_{ij}^m\} \; / \; \sum_{i,j} X_{ij}^m = \bar{d}_*^m \qquad (16)$$

β^m in this model is a parameter to be determined, representing the sensitivity of flows of commodity m to extra transportation cost. However, it is calibrated through equation (16) to ensure that the resulting flows reproduce $\bar{d}_*^m$, the average *distance* that commodity m is shipped when summed across all i-to-j (i.e. O-D) pairs because this is the only generally available observed information we have on such movements at the present time.[4] Here the costs $\bar{c}_{ij}^m$ in equation (12) refer to a weighted average of the various modal costs involved in each i-to-

[4] Based on 2002 U.S Economic Census's Commodity Flow Survey. http://www.census.gov/econ/www/cfsnew.html

j movement. If a logit model of the type given in equation (10) is used, then it is appropriate to create the following "composite cost" function to represent this cost[5]:

$$\bar{c}_{ij}^{m} = -(1/\lambda^{m}) \ \ln \ \{\sum_{k} \exp(-\lambda^{m} c_{ij}^{km})\} \tag{17}$$

This means that the market (destination) choice model implied by (10) recognizes the differences in modal bias across markets: so that a market (county, port), j, that offers lower costs per mile due to greater access to water transport attracts more freight to it, other things being equal.

2.3 Putting The Pieces Together

If we assume a negative exponential generalized cost function for destination as well as mode choice, i.e.:

$$F[\lambda^{m}, c_{ij}^{km}] = \exp(-\lambda^{m}, c_{ij}^{km}) \tag{18}$$

then we can state the complete mode, destination and route selection problem developed in parts above as a single mathematical program of the form (see, for example Ham, Kim and Boyce, 2005):

$$Minimize_{V,X} Z(V,X) = \sum_{ak} \int_{0}^{Vak} S^{ak}(\omega) d\omega + \sum_{m} 1/\beta^{m} (X_{ij}^{m} \ln X_{ij}^{m}) + \\ + \sum_{m} 1/\lambda^{m} (X_{ij}^{km} \ln X_{ij}^{km}) \tag{19}$$

subject to constraints (5) - (9), as well as (14) - (16) , and also to (1) and (3) , remembering our link to the supply side input-output model for estimation of county and port consumption by commodity m. The β^{m} and λ^{m} are as defined above for the destination and mode choice models given by equations (12) and (10) respectively. A number of solution algorithms exist to solve such combined problems (see Chang et al, 2001; and Ham, Kim and Boyce, 2005, for example). However, implementing a combined model such as that represented by equation (19) is challenging if we wish to capture real world details on flows and cost components. Sequentially solving for the mode, destination and route choices is likely to be the most effective practical approach, allowing iteration between the three choice dimensions to capture both the congestion-sensitive and non-congestion based user equilibrium costs and flows we are trying to reproduce. This sequential approach also allows for a wider range of different sub-model formulations within each choice process. In particular, the specific form of the shipper response models being developed within NETS needs to be accounted for. This topic is discussed below.

2.4 The Role of Shipper Response Modeling in the RRM.

Equation (11) represents one form of generalized transportation cost, or shipper "utility" function. Based on Train and Wilson (2004, 2005) we might represent shipper response to mode k and/or market cost j differences using a function of the form:

[5] See http://www.webtag.org.uk/webdocuments/3_Expert/10_Variable_Demand_Modelling/3.10.3.htm#1_9 for an explanation

$c_j^k = \alpha_0 + \alpha_1$ median $rate_j^k + \alpha_2$ mean $rate_j^k + \alpha_3$ median $time_j^k + \alpha_4$ mean $time_j^k + \alpha_5$ Rail dummy variable + α_6 Barge dummy variable + α_6 time coefficient if m not corn/wheat/soybeans + α_6 shipment $istance_j^k$ (20)

Similar or more complex functions may emerge from the NETS modeling of shipper survey-based responses; and the form of such non-linear regression models will determine the costs used in both mode and destination choice models. The β^m parameters used in equation (10) above can be seen in this context as scaling parameters that fit such empirically derived shipper response curves to the aggregate count-to-county flows data required for RRM purposes.

2.5 Model-Based Waterway Benefits Computations

A number of benefits measures can be derived from the above modeling system. A popular approach to measuring benefits in the transportation planning and economics literature is based on the notion of a consumer (e.g. shipper) surplus, CS. In applying the idea of CS, studies often use the "rule of a half" (Neuberger, 1971; Williams, 1977) which can be stated in terms of the above modeling variables as:

$$CS \approx (1/2) \sum_{ij}^{km} (X_{ij}^{km\ before} - X_{ij}^{km\ after}) (c_{ij}^{km\ after} - c_{ij}^{km\ before}) \quad (21)$$

We can generalize 'before' and 'after' conditions here to represent the changes in flows and costs between two competing projects, forecasts, or scenarios. Extensive research into CS measures such as (21) confirms a direct relationship to commonly used measures of the physical changes that take place in locational accessibility as a result of transportation system improvements.

2.6 NETS Feedback Loops

In constructing the RRM as described above we are creating a form of spatial price equilibration model, by balancing flows and their costs across the entire multi-modal network. This is of course only a partial equilibrium since many factors (of production and consumption in particular) are missing from the framework. However, by feeding RRM model results back to the Tier 1 NETS commodity demand and supply forecasting procedures (cf. Figure 1) we can create an "elastic" transportation supply framework in which significant alterations to the transportation infrastructure, such as a major lock closure or seaport expansion, serve to impact subsequent demand markets as well as supply routes.

Outputs from the RRM analysis process should also be able to feed annual O-D forecasts of mode and commodity flows to the more detailed, project specific models being used to support NETS Tier 3 analysis needs. At this stage these flows will need to be broken down into their vessel or vehicle equivalents for more detailed cost analysis. Just how this occurs is an important issue for RRM cost modeling, and specifically for the level of detail at which it is developed (see section 3.2 below).

3. Creation of the Base Case

An important basis for much USACE inland navigation and port-based economic modeling is the ability to tie a model to the best available empirical evidence; in effect, to establish that the approach can reproduce "ground truth" as a starting point for forecasting and policy analysis. This section of the paper describes the steps required and the data sources that need to be tapped, to create of a detailed geographic, multimodal, and commodity based representation of year 2002 U.S. freight movements, initially for five selected agricultural commodities. It also describes how this data can be used to carry out simple static analyses of a series of "what if" scenarios.

3.1 Data Sources

The objective for the base case modeling is to put year 2002 freight movements for specific commodities onto the US water, rail and highway (truck) networks, compute their expected costs, and identify the key network infrastructures (routes, terminals, port facilities) being used to support these flows. To accomplish this task requires bringing together data a) transportation network attribute data; b) freight origin-to-destination (O-D) commodity flow data, and c) freight O-D cost data. The county was selected as the basic spatial unit for this type of analysis, allowing the project to draw on economic activity data from the U.S. Departments of Commerce, Agriculture, Energy and elsewhere, with which to link freight movements to local area production and consumption. Greater spatial detail, notably at the zip code level, should also be possible in future efforts. A key to such efforts is the ability to represent consistently flows to and from reasonably similar spatial units across the entire United States. In addition to counties, each of which is represented as a traffic producing and/or receiving node on the model's representation of the U.S transportation network, additional nodes are also identified for U.S. seaports. This allows the analyst to separate, in particular, import and export shipments from purely domestic ones, an important distinction when analyzing the nature and value of economic activity through U.S. seaports.

3.1.1 Representation of the U.S Multimodal Transportation Network

The transportation network database being used is developed, maintained and updated on project by project basis by the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL). It consists of a linked national highway, waterway and railway network with link connections identified at many of the nation's major truck-rail and truck-waterway terminals (see Figure 4).
High capacity rail and highway routes links are continued into Canada and Mexico, allowing modeling of flows from and to major Canadian and Mexican metropolitan areas. The U.S. waterway network consists of a linked set of inland navigation, Intra-Coastal Waterway and Great Lakes links and nodes based on Crops' definitions. These networks are also connected to a trans-global deep sea network that connects U.S. seaports and the St. Lawrence Seaway to the world's largest foreign seaports. The network was developed and used to route individual shipments identified by the U.S. Commodity Flow Surveys of 1993, 1997 and 2002 (Southworth and Peterson, 2000).[6]

[6] This 2002 network (and a 1997 version) has been developed for viewing/downloading on the IWR/USACE website. The CFS 2002 version of the network is currently accessible at http://cta.ornl.gov/transnet/

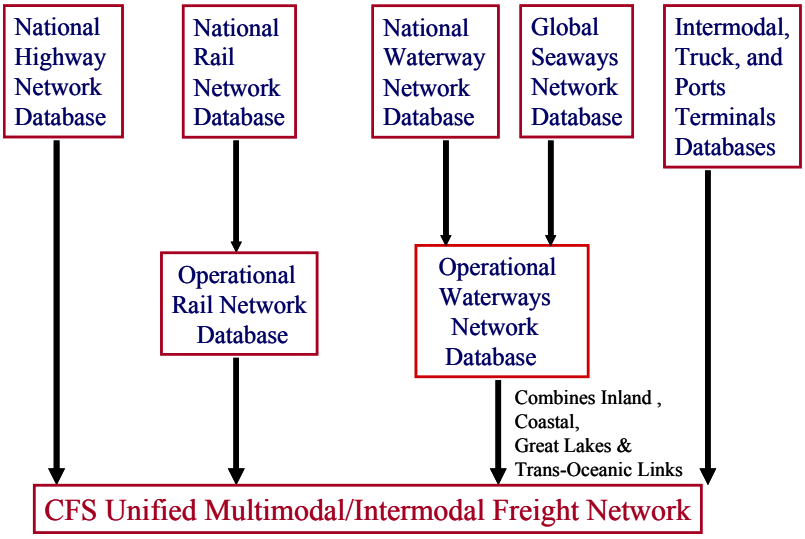


Figure 4. Components of the Intermodal Freight Network

Counties and seaports are connected to this network via a series of mode specific access/egress links. Each county and port of interest is assigned a network centroid, a term used to signify a source or final destination for freight traffic. Other network nodes for the most part simply connect links. These links carry the various network's physical and logical characteristics, including any traffic flows and costs estimated by the RRM. A useful feature of the network representation is its use of links to capture not only line-haul but also all bi-modal transfer costs (see Figure 5). A valuable benefit of the current project will be the addition of shipper cost-based impedances as well as estimated flows to the attribute list for each network link. Seaports can similarly be modeled as a series of interconnected network links. These are currently represented in a simplified manner that can be expanded without needing to alter the network's current "data model".

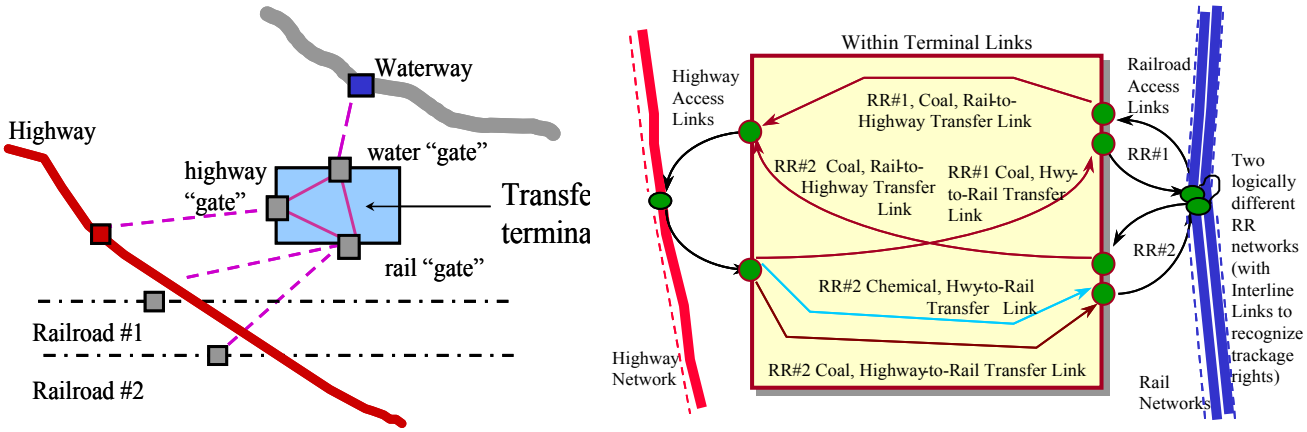


Figure 5. Network Representation of Intermodal Terminals and Transfers

3.1.2 Commodity Production and Consumption by County

County based annual commodity productions and consumption forms the basis of the O-D freight movements being modeled. These estimates will be a combination of reported data, notably for production, and modeled data where consumption estimates are required. During the initial prototyping effort five agricultural commodities are being modeled: corn, wheat, soybeans, poultry products, and fresh fruit and vegetables.[7] This data is being supplied to the project by staff at the Economic Research Service (ERS) within the US Department of Agriculture (USDA). Specifically, ERS/USDA is using its inter-regional input output model (see Canning and Wang, 2005) to produce both annual production and consumption data for each county, as described in section 2.1 above. Data on import and export activity is also being generated for use in separating seaport activity from other within county consumption.

3.1.3 Commodity Flow Data

The following, mode specific data sources are being used by the project:

Waterborne Movements: Two databases are being used: a) data on dock-to-dock annual shipment volumes (tonnages) by 4 digit Performance Monitoring System (PMS) commodity class. Source: USACE annual Vessel Operating Activity and Lock Performance Monitoring System data[8], as processed for USACE by the Tennessee Valley Authority; and b) annual shipment volumes (tonnages, dollar valued trades) to/from U.S. seaports and foreign countries, broken down by 4 digit Harmonized Schedule (HS) commodity codes. Source: USACE Institute for Water Resources, Waterborne Foreign Trade Data.[9]

Rail Movements: This data takes the form of railcar station-to-station annual shipment volumes (tonnages) defined according to Station Point Location Codes (SPLCs), by 4 digit Standard Transportation Commodity Codes (STCCs). Source: Surface Transportation Board (STB) Annual Carload Waybill Sample.[10]

Truck Movements: No data base on detailed truck movements exists for the entire U.S. or even for a large portion of it. These movements are estimated using spatial interaction models at the county to county level after water and rail origin-destination (O-D) movements have been determined (cf. equations (12)-(17) above). In doing so, data on average truck trip lengths and distance distributions need to be drawn from sources such as the U.S. Commodity Flow Survey[11], the U.S. the Vehicle Inventory and Use Survey (VIUS)[12] as well as other, commodity and region-specific sources. Both the 2002 CFS and 2002 VIUS provide data by 3-digit Standardized Classification of Transported Goods (SCTG) codes. The approach being taken

[7] By modeling at this level of commodity detail it is also possible to avoid some of the problems associated with combining data sets that use different commodity coding systems.
[8] http://www.iwr.usace.army.mil/ndc/wcsc/wcsc.htm
[9] http://www.iwr.usace.army.mil/ndc/data/dictionary/ddimex.htm
[10] http://www.stb.dot.gov/stb/industry/econ_waybill.html
[11] http://www.census.gov/econ/www/cfsnew.html
[12] http://www.census.gov/svsd/www/02vehinv.html

mirrors that described in the USDA's modal share analysis (Marathon, VanWechel and Vachal, 2004), but applied at a more detailed level of spatial resolution. Using this approach annual truck tonnages into a region are estimated as:

truck tons received = total tons consumed – (rail tons received + water tons received) (22a)

and,

truck tons generated = total tons produced – (rail tons shipped + water tons shipped +on farm consumption) (22b)

3.1.4 Freight Rates and Other Cost Data

Freight rate data is reported by O-D-C combinations in the STB railcar waybill file. O-D-C rates for navigable waterways shipments are also available for dock-to-dock movements using USACE vessel operating data processed (with some gap-filling) by the Tennessee Valley Authority (TVA). Representative truck rates are harder to come by. Only one source of U.S. wide truck rates could be found, and it applies only to a single truck type (KPMG, 2003). Mode specific transit times and distances are generated during the traffic routing phase, based on distances and time-based impedances found on the ORNL multimodal network.

3.1.5 Other Data Sources

Other data used in specific steps within the modeling process, notably data required to build intermodal truck-rail and truck-water movements, are described below.

3.2 Construction of the Commodity Flow Matrices

Figure 6 shows the steps involved in constructing the base case mode and commodity specific flow matrices, freight rates and other freight movement costs from the above data sources. The grey shaded boxed along the left side of the figure represent the principal data inputs. The first task is to aggregate waterway dock-to-dock and rail station-to-station movements into county-to-county annual flow totals. A second task requires that these flows be assigned to specific counties of origination (production) and destination (consumption), including port specific production and consumption (i.e. port imports and exports, foreign or domestic).

3.2.1 Modeling Truck Drays

Both the available water and rail O-D data is restricted to within-mode activity. This means that the true origination and destination counties for shipments need to be identified if proper mode and market choice analyses are to be carried out. Otherwise a long and expensive truck drayage cost may fail to enter the analysis. This is important for many O-D movements because the distance that a shipper is from a rail or water transfer terminal appears to have a significant impact on the choice of mode used. This is clearly evident in the modeling literature (see Bitzan et al, 2003) as well from a mapping of current water versus rail originations for grain movements, for example (cf. Figure 14, Section 4, for example). Also, since truck O-D data is

not generally available, this assignment of water and rail movements to counties is anyway required in order to obtain an estimate of the volume of the truck traffic we can expect out of or into a given county (minus any on-site consumption). That is, we need a method for capturing across-county drays if a proper accounting of current mode shares is to be accomplished.

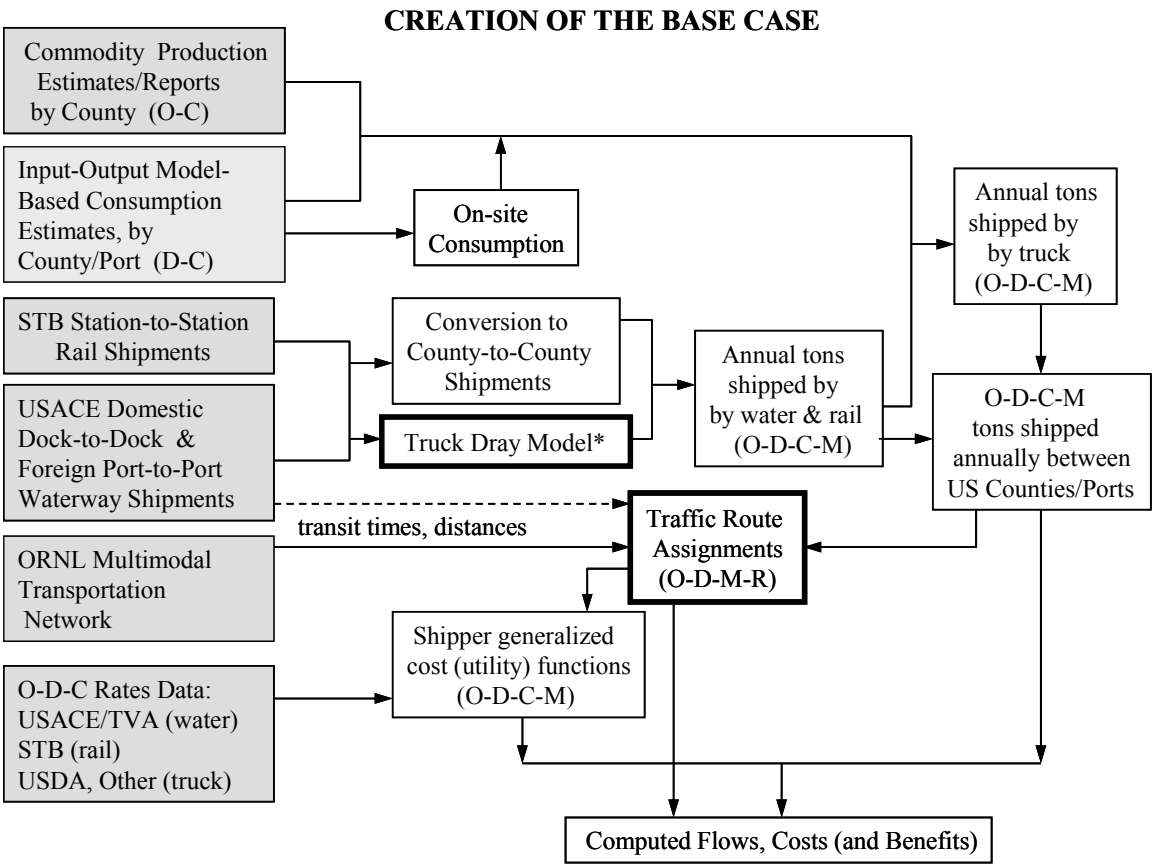


Figure 6. Creation of the Base Case.

The current dray model is being developed as a probabilistic allocation process that assigns a probability of a county sending its rail and/or water shipments to docks in the same or a nearby county, i.e.

$$P^{dm}_{i\,j} = [\, O_i^m * F(c_{ij}^m) \;\; / \;\; \sum i \, O_i^m * F[\,(c_{ij}^m)\,]\,] \tag{23}$$

and

$$G_{ij}^m = Dj^m * P^d_{i\,j}{}^m \tag{24}$$

where P^d_{ij} = the probability of shipping goods from location i to a water dock or rail intermodal connection located at j; O_i = the volume of commodity to be shipped from location i; c_{ij} = the cost of draying a unit of commodity from i to j, and F[ ] = a distance-decay based cost function.

Equations (23) and (24) represent a simple potential model, and one that ensures that the total flows into any intermodally active waterway or rail modal transfer location, j, sum to the observed interchange volume for such a site, Gj. A similar model can be applied at the trip's destination: although we would expect (and initially will assume) that for many commodities the county of offloading from dock or rail station is likely to be the final destination county.

Commodity production locations, i=1,2….I are based initially on zip code area data where this is available. The principal initial source of data is the USDA's zip code area data on farm production[13]. In expanding to more commodities the Census Bureau's 2002 zip code area-based economic activity data will also be used.[14] Modal interchange locations are based initially on the ORNL's coding of major waterway terminal locations (as part of its multimodal network model), but subsequently on the geographic detail contained in the Corps/TVA dock-to-dock file. (This latter is the same data used to construct the project's county-to-county O-D matrices. However, its current condition precluded other than a county based assignment of docks for many locations). Truck-rail intermodal interchange locations are based initially on the location of railway SPLC codes, for which we can cumulate the number of tons getting onto the rail system at such points (= the D_k values in equation (24)).[15]

Once counties have been linked to their long-haul rail and water terminals in this manner, the cost of shipping a unit of commodity from originating county, i, to final county destination, j, is computable as a combination of on-the-river or railway line-haul cost, plus the drayage cost, plus any truck-rail or truck-water transfer (loading/unloading) costs involved. i.e.,

$$r_{ij} = r_{i\,y1} + r_{y1\,y2} + r_{y2\,j} \tag{25a}$$

where r = the monetary cost (i.e. the rate) charged per mile, and y1 and y2 refer to the intermodal transfer points ("yards") at the origination and destination ends of the rail-inclusive or water-inclusive shipment. Similarly, we can estimate the transit time, t, and distance, d, involved in these intermodal moves as:

$$t_{ij} = t_{i\,y1} + t_{y1\,y2} + t_{y2\,j} \tag{25b}$$

$$d_{ij} = d_{i\,y1} + d_{y1\,y2} + d_{y2\,j} \tag{25c}$$

Statistically representative data on dray distances is currently limited. Bizman, et al (2005) report regionally averaged distances from grain producing county centroids (that use rail) to the nearest barge loading facility for corn, wheat and soybeans, based on USDA's 10 production regions. Sources citing drayage costs are also limited. They include a recent inland port feasibility study by Tioga Group Inc, et al (2003)[16] which concludes that dray costs are principally a function of time and the number of round trips the truck can make in a given working day. The study reports

[13] http://151.121.3.33:8080/Census/Create_Census_Zip.jsp
[14] Available in 2006: http://www.census.gov/econ/www/
[15] noting that the most appropriate locations are not always reported by the railroads, but assigned instead to the major SPLC for a given city.
[16] http://www.sjcog.org/sections/trans-planning/portfeasibilitystudy

dray costs in the range $1.64 to $4.05 per minute based on travel down two (I580, I-80) interstate highway corridors in central California, inclusive of expected wait times at either end of a trip: and implies that considerable variability is possible due to, among other things, loading and congestion delays. However, the study's principal concern was with containerized cargo. In contrast, the Federal Railroad Administration's (FRA) Intermodal transportation and Inventory Cost (ITIC) model (FRA, 2005) uses a flat rate truck to rail dray cost of $125 for the first 30 miles pus $1.38 per additional mile.

Given the current uncertain nature of the empirical evidence, the idea is to parameterize this process so that the USACE analyst can adjust/experiment with such drayage distances, or update them on the basis of new data sources.

3.2.2 Modeling Truck-Only Movements

The principal problem we face in modeling inter-regional freight movements is our lack of an observed set of truck flows against which to directly "fit" this model at the county/port level in the general commodity case. The assumption being made here is that, for bulk commodities such as grains and coal, significant truck shipment volumes are largely limited to local hauls: and that rail is the major competitor for this form of waterborne commerce. For many other commodities this is not the case and commodity specific versions of the spatial interaction model given by equations (12) – (17).

3.3 Construction of the Freight Cost Matrices

3.3.1 Consistency in Costing across Modes

For the purposes of simulating both modal and market competition a consistent treatment of each mode's costs is required. This means that the costs computed for each mode a) include the same generically defined set of cost elements, and b) apply a consistent approach to the inclusion of some percentage of fixed costs to the computation of traffic sensitive variable costs, in order to appropriately capture expected freight rates.

To meet these goals a two level approach is being pursued. This allows an initial modeling capability to be developed quickly, using a limited set of common cost factors, with a subsequent upgrade to incorporate more detailed cost computations once the initial RRM framework has been established.

Figure 7 shows this idea (without going into the many mode, commodity and situation specific details). Level 1 involves development of a set of mode and commodity specific O-D shipment rates and transit times based on network characteristics and reported rates data. One or more measures of service quality are also likely to be important, notably measures of service reliability (such as on-time arrival percentages). These costs will be based on regression modeling, and should include the combined primary mode line-haul plus truck dray plus associated intermodal transfer costs for each i-to-j movement, as discussed above.

Level 2 analysis requires the development of a detailed spreadsheet model of each mode's principal cost components from which these Level 1 rates and times can be computed. This will allow such costs to be varied by fleet composition, fuel prices, labor costs and other operating, maintenance and business logistics costs, as deemed useful. These are engineering cost models, an important attribute of which is an ability to compare such costs across the different modes. This is not an easy task and involves, among other things, being able to separate short range operating costs from longer term capital investment costs in a consistent, multimodal manner.

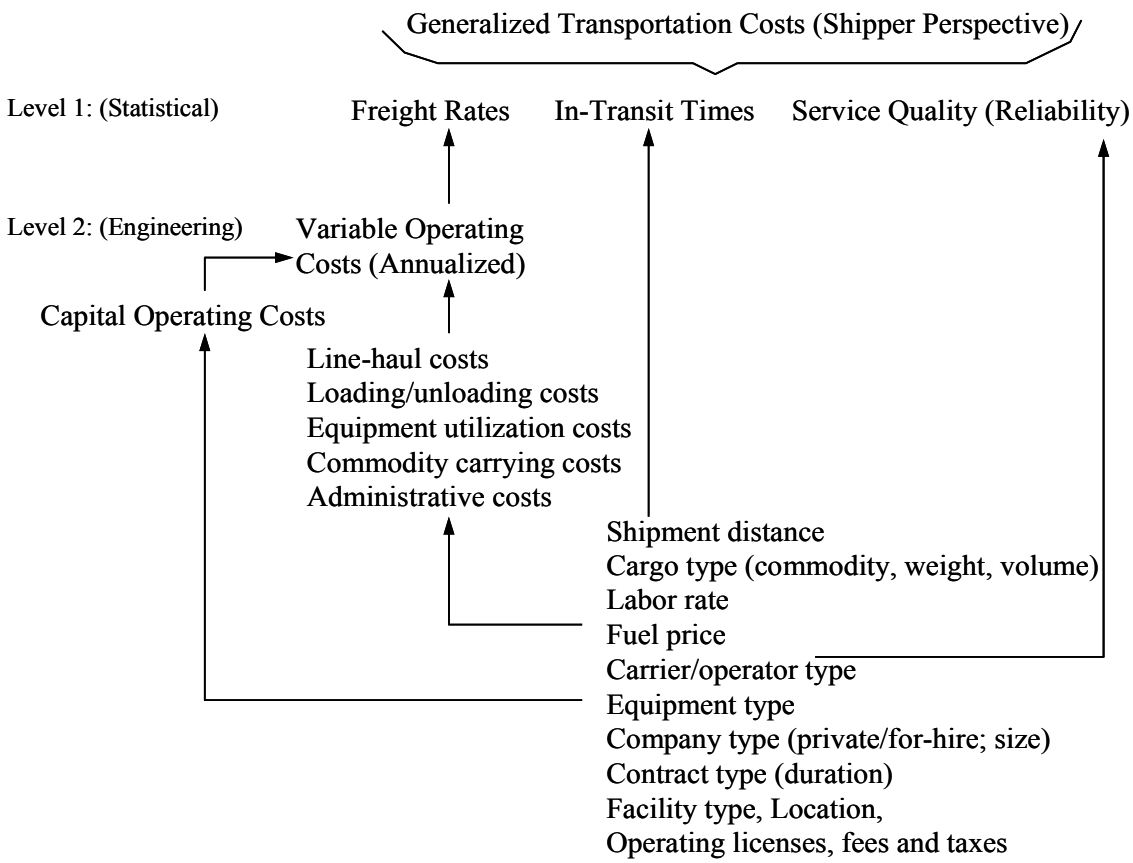


Figure 7. Relationships between the Components of Freight Movement Costs

Of note, when applied to a congestion-sensitive assignment problem the Level 1 O-D transit times (and perhaps also their variances) can be computed using the sort of link formulas shown in Figure 3 above. They will also be used in Level 2 to update not only O-D transit times but also the time-based components of estimated freight rates.

3.3.2 Level 1: Generalized Transportation Cost Functions

Level 1 cost elements supply data to a generalized transportation cost function of the form:

$$c_{ij}^{km} = \alpha 0 + \alpha 1 * r_{ij}^{km} + \alpha 2 * t_{ij}^{km} + \alpha 3 * v_{ij}^{km} \quad (26)$$

where the α's are model coefficients based on NETS shipper choice modeling studies, and where r = the per ton freight rate, t = transit time and v = a measure of variability in transit time. For the base case, the waterway volumes reported ("observed") by USACE and STB are assigned to the appropriate modal sub-networks using the routing algorithms developed by ORNL for the U.S. Commodity Flow Surveys. These route assignments treat link cost functions as static and derive O-D-M travel times on the basis of the ORNL path impedance model. Introduction of the convex link cost-volume functions and capacity constrained traffic routing procedure discussed in Section 2.2 above will then allow these costs to vary on the basis of traffic build-up on specific routes.

***Rail Rate Modeling**:* Alternative approaches to constructing a set of O-D mode and commodity specific freight rates are a0 to develop a model from scratch, or b) purchase access to a commercially available software model, or to the rates it generates. Examples of commercially available products include Reebie's CO$TLINE© family of cost models[17] and the Commonwealth Real Costing System.© [18] Examples of the sort of statistical rail rate models we are interested in are given by Fuller et al (2001) and Bizman et al (2003). ORNL has fitted rail rate models to specific agricultural commodities using similar regression equations of the form:

$$r^{Rm} = \alpha 0 + \alpha 1(\text{Miles}) - \alpha 2\ (\text{Carloads/Shipment}) - \alpha 3(\text{Tons/Carload}) \qquad (27)$$

where r^{Rm} = tons per mile shipped by rail for commodity m. Adjusted R^2 values of 0.5 to 0.6 are typical. Other attributes, such as railroads involved, and season shipped, can be added (based on examples in the literature) to improve model fits.

Truck Rate Modeling: The following equation relating grain shipment distances to truck rates is being used as an initial starting point, based on the work of Wilson et al (2005, page 50):

$$r^T = 4.12 - 0.472 * \ln(\text{miles}) \qquad (28)$$

where r = truck cost in dollars per loaded truck mile, and ln( ) = the natural log of.

The ability to link shipment distances to rates is an important aspect of the MMR, and well-fitted regression equations are common for all three modes of transport. Of note, a useful intermediate product of the network assignments are a series of ton-mileage estimates by mode. These estimates can also serve as one check on model reasonableness, by comparing them to ton-mile statistics reported or otherwise derivable from USACE and the US Department of Transportation (Federal Railroad Administration; Bureau of Transportation Statistics) sources. It is proposed to continue to explore the further use of this same approach to rate estimation in forecasting/scenario analysis.

Water Rate Modeling: An initial set of waterway rates have been provided to the project by the Tennessee valley Authority (TVA) for specific shipments, including the estimation of missing rates for some O-D-C pairs. No rate data exists currently for the western river system (Columbia-

[17] http://www.reebie.com/
[18] http://www.commonwealthlogistics.com/crcs.html

Snake) and further rate modeling will be required to fill this hole. Such rates can be estimated by using the detailed water freight cost accounting system employed by TVA, or by the Corps' ORNIM model. A number of models of ocean freight shipping rates exist. This literature suggests that complex set of variables besides distance shipped interact to determine actual rates charged, including commodity type (bulk vs container),cargo unit value, weight and volume (stowage factor), ship size, and service frequency, contract type, season, cargo mix and number of destinations visited (Shneerson 1976; Winston, 1981; Jonnala, Fuller and Bessler, 2002; Park and Koo, 2004; Wilson et al, 2005). Wilson et al (2005) use ocean rate O-D data from the Maritime Research Institute to develop a set of double log regression equations for estimating ocean tariffs for grain movements based on vessel size, distance between ports, oil prices, trend, and a series of dummy variables representing origins and destinations. Benson, Vachal and Byberg (1999) have developed an MS Access© database model to assist USDA in accessing and using historical data to estimate container rates for agricultural commodity cargos. Rate calculators based on this work can be found on the USDA's Ocean Rate Bulletin website.[19]

3.3.3 Level 2: Engineering Cost Accounting Models

Linking rates to the basic costs of doing business in the freight industry requires a detailed cost accounting for each of the three modes of transportation. A literature search for previous freight costing models identified a number of candidate approaches. One bi-modal and three mode specific costing model programs were acquired for further evaluation:

ITIC-IM :The U.S. Department of Transportation's Intermodal Transportation and Inventory Cost Model Cost Model (ITIC-IM: FRA, 2005) bases its costing of freight shipments (truck, rail, truck-rail intermodal) on a combination of logistics plus transportation costs, incorporating the following components:

- *Logistics Costs*: ordering cost, in transit stock carrying cost, cycle stock carrying cost, capital cost on claims, safety stock carrying cost, and loss and damage claim costs.

- *Transportation Costs*: line haul costs + wait time + dwell time + interchange costs+ pickup costs (fixed cost + cost/mile) +delivery cost (fixed cost + cost/mile)+ loading and unloading costs

This is an appealing approach that captures the truck dray costs discussed in section 3.2.1 above. The model contains both rail and truck as well as truck-rail intermodal costing formulas. The approach also allows the analyst to enter a measure of service reliability into its modal cost comparisons. The measure used in the coefficient of variation[20] in transit time. This measure is then tied to the required size and hence cost associated with a receiver's safety stock-up, thereby linking transportation costs to broader logistics (i.e. inventory carrying) costs. In doing this the approach recognizes the importance of the type of receiver as well as shipper in the selection of transportation mode. On the debit side, the software currently offers input data for only one truck configuration–a conventional 5-axle (3S2) tractor trailer combination. The approach also relies on access to a level of shipment detail currently found only in the STB's restricted waybill data.

[19] http://www.ams.usda.gov/tmd/Ocean/calculations.htm
[20] defined in the model as the standard deviation of transit time divided by the mean transit time.

ORNIM: The Corps' Ohio River Navigation Investment Model (ORNIM: ORNL, 2001) uses a similar set of cost elements and shipment detail in computing movement costs per mile, distinguishing between line-haul costs, loading and unloading cost, equipment carrying cost and commodity carrying costs. And like the ITIC-IM model's cost elements, as listed above, each is itself a composite, made up for the most part from time to complete components multiplied by an operating cost per unit of time. For example, an important component of water movement costs in ORNIM is the line haul travel time multiplied by the sum of the barge cost per hour times the number of barges, plus the per hour towboat operating cost. Usefully, commodity specific carrying costs are included in both the ITIC-IM and ORNIM approaches.

Truck Load Analysis Model: Berwick and Faroog (2003) have developed a similarly detailed truck tractor-trailer costing model that lets the user vary the vehicle configuration. They provide inputs for the following cost components:

- *Variable Costs*: fuel, labor, tires, maintenance and repair
- *Fixed Costs*: equipment, licenses and fees, insurance, management and overhead costs

The spreadsheet model includes separate calculations covering deadhead and backhaul miles and the effects of empty versus loaded miles on fuel and tire costs. Different cost profiles can be obtained for owned versus leased tractors and/or trailers. Developed for analyzing grain shipments, they also allow for different commodity densities when translating from bushels to pounds shipped. As with other models of this type they also allow the user to set interest rates on leased equipment, estimated useful vehicle life, and equipment depreciation and salvage rates. They note that while the make-up of fixed versus variable costs are similar for many trucking companies they can differ in the areas of management and overhead charges, and where the company operates terminals. They distinguish as fixed costs components that accrue charges whether or not the truck is moving. Transport Canada uses a similar approach in computing grain transportation by truck.[21] Specifically, it includes the following items:

- Driver wages, vehicle fuel, tire and repair costs, capital costs, overhead and other (commercial licenses, insurance, and administration) costs.

A reasonable profit margin is also required to bring rates up to costs. Transport Canada's modeling suggests a target profit (or return on investment) for the firm of 5% of revenues.

URCS: The reasonableness of such profit margins where U.S. railroads are concerned led the Surface Transportation Board to develop its Uniform Railroad Costing System (URCS) software, which allows analysts to derive a representative cost of shipment based on a large number (some 73) of different operating parameters. Many of these parameters are provided with the software. Key variables, besides the cargo weight, distance and commodity shipped are railcar and railroad ownership, and the type of rail service being offered. Service types include single railcar loads, multi-car loads, and unit train (> 49 car) movements. For example, locomotive switching costs at both ends of a movement may be reduced by 50% for a multi-car shipment and 75% for a unit-

[21] http://www.tc.gc.ca/pol/EN/Report/truckGrainCosting1999/C4.htm#4.1

train. Attention is also paid to interlining activity involving transfers between railroads en route. Tolliver and Bizman (2002) provide a description of these and other details along with an application of URCS to wheat transportation. They note that train size is also found to be a significant variable, since crew train-mile costs don't vary much with size of train, and larger trains gain economies of utilization in locomotive power and train supplies. They also note that URCS costs reflect an intermediate-run time period during which equipment investment is considered to be 100% variable. Roadway investment costs are considered to be 50% variable with traffic: and thus reflect a return on investment for half of the railroad's roadway, track and structures. The allocation of full costs over the long-run includes variable cost plus a percentage allocation of fixed costs to each shipment.[22] This provides a means of estimating reasonable profit and hence rates, with the latter often in the range of 180% of longer run "variable" costs.

No readily available software modeling of ocean shipping rates has been found. Saggar (1970) describes a detailed cost accounting framework for conventional ocean cargo liners, which would still seem to apply. The following components are listed:

- *Ship Ownership Costs*: Capital charges, insurance
- *Running Costs*: Crew wages and provisions, ship repair and maintenance, fuel, stores and supplies, administration, handling costs, port dues (pilotage, towage, mooring costs, etc.)
- *Miscellaneous Costs*: Brokerage (cargo handling commissions), insurance on cargo, claims, other expenses.

Load factors, time in port (maneuvering and cargo handling time) and on the sea are key variable cost items, as therefore is number of stops en route. Ship horsepower and storage size play a major role in economies of scale.

Engineering cost-based approaches such as the ones discussed above can avoid some of the short term idiosyncrasies that occur frequently in rates, such as carriers subsidizing specific commodity/O-D corridor flows based on a broader regional marketing strategy, or in response to a changing demand for services due to a rise or fall in at–market commodity prices or seasonal levels of production. On the debit side these idiosyncrasies play an important role in determining the responsiveness of the current commodity flow pattern to transportation costs. Certainly it will be necessary at some point to "calibrate" the selected cost functions to ensure that they are compatible with observed and suitable averaged (annual, seasonal) freight rates.

3.3.4 Selecting the Right Level for RRM Analysis

Detailed Level 2 freight cost modeling of the type discussed above may also be carried out, and in even greater detail, by Tier 3 NETS models (cf. Figure 1). At the level of project specific analysis implied by these Tier 3 simulation models a specific mix of vessel/vehicle equipment types may be needed to simulate the effects of, for example, vessel horsepower and tow size on

[22] Adequate revenues in theory should include a return on all capital equipment and roadway investments evaluated at the current rate of capital.

fuel consumption; or the effects of stevedore wages on port/cargo handling costs. A method for averaging these costs up to the RRM level of analysis would then be required.

4. Progress to Date

4.1 Database Development

The movements of five agricultural products were selected as an initial test of the proposed approach. Corn, Wheat, Soybeans, Poultry Products, and Fresh Fruit and Vegetables were selected for analysis. Of these commodities the three grains make extensive use of the nation's waterway system. The other two commodities add modal variety to the sort of source-to-market movements the modeling framework will need to handle. Testing began with an examination of the availability and condition of current data sources. The initial target year is 2002 (to take advantage of the 2002 Commodity Flow Survey, Vehicle Inventory and Use Survey, and other freight analysis projects using these data sources). The following summarizes the major findings of this data analysis.

Condition of the Commodity Flow Data. The water and rail flows data described in Section 3 above requires quite a bit of work to put it into a form suitable for RRM analysis. However, the end result is promising and is considered acceptable for the project's purposes. Truck flow data, which was known to be lacking, offers the major challenge. A lot rests on a successful matching of the county level production and consumption data to the "remaining" (in non-rail and non-water) flows. This activity awaits delivery of the production/consumption data by USDA. Additional sources of regional truck movement data that can be used for validation purposes would help here.

It remains to match domestic flows data with Crops data on the flows occurring between US and foreign seaport, as reported in the Foreign Waterborne Commerce dataset. Reconciliation with the export volumes estimated by the USDA for each US seaport will also be required, to ensure consistency across all three data sets. Knowing which foreign ports/countries are served by which U.S. seaports is essential to a planning model that needs to be able to identify the costs, and eventually also the likelihood, of cargo shifts from one port to another: as the commodity markets as well as transportation networks involved change, either temporarily or permanently, over time.

Initially, numerous county locations had to be added to many dock locations within the Corps' dock-to-dock, file in order to complete a county-to-county flow matrix for the base case. TVA provided the necessary flow data for this process. County-to-county flows by rail are now also available, and can be aggregated from the railcar waybills at the station-to-station level.

Similar data for other commodities moved by water and rail can also be created using the same computer codes. These data are also required to support congestion-sensitive traffic assignments: in order to generate the total traffic moving over each network link. A similar treatment of underlying highway traffic volumes is also desirable. This might be based on the soon to be released Freight Analysis Framework's 2002 commodity flow matrix (Southworth and Peterson, 2005), or on FHWA's prior FAF-based capacity sensitive truck assignments. Alternatively, we

can model truck movements in the RRM using the currently assigned average network link speeds, based on ORNL formulas that recognize such factors as functional class, access control, and truck route designation (see Southworth and Peterson, 2001). Where long distance trucking is not much of a competitor to waterway movement this approach may suffice.

Condition of the Transportation Cost and Rate Data. TVA have provided the project with the average freight rates reported for the majority of dock-to-dock waterway movements. Currently missing are rates for western rivers and for any shipments involving a foreign origination or destination. Average rail rates as well as statistically derived rail rate equations are also now available for each of the five agricultural commodities (cf. equation (27)). Shipment distances and approximate O-D transit times can be generated for each of these commodity and mode specific O-D pairs, based on routing these flows over the ORNL water and rail sub-networks. Link transit time functions are currently too rudimentary. There is a need to develop a matrix set of default, free-flow operating (space mean) speeds for different link types for water and rail, along the lines used by ORNL and others to estimate highway travel times.

Traffic Routing: Routing models have been set up to accept the O-D matrices and assign flows to the U.S. transportation network. A number of route control parameters are available to help with this process, including re-weightings of transfer costs between modes, between inland, Great Lakes and Deep Sea transfers, and between railroads (interlining and trackage rights effects). However, further analysis of the routes selected remains to be carried out, with some adjustments inevitably required on the basis of expert knowledge. The ability to incorporate all of the necessary mode specific route control parameters within the equilibrium assignment model (see Section 4.2 below) also need to be developed. This is principally an issue for rail routing as well as rail-inclusive intermodal routing.

Sample GIS Products. The results of the O-D matrix construction and subsequent traffic assignment process has been adapted to create geo-referenced data files suitable for importing to a GIS. Maptitude© is currently being used for this purpose. Figure 8 shows the inter-county movements of corn based on the Crops' 2002 dock-to-dock shipment data (the grey colored straight lines on the map) with the results of the ORNL routing model superimposed on these flows in blue. The orange circles show the major corn producing counties. Initial county production surrogates (tons produced in 2002) for all five commodities have also been obtained from the USDA website. This data, however, has numerous holes in it that need to be filled, and will be replaced with updated information from the USDA/ERS input-output modeling work described above. Figures 9 and 10 show the same results for Wheat and Soybeans respectively.

Suppressed in all of these maps is the volume of grain shipped to foreign countries other than Eastern and Western Canada, since the Corps dock-to-dock data does not (currently) contain specific destinations for these flows.[23]

[23] Each of these maps were developed using Caliper Corporation's Maptitude© GIS-based display software.

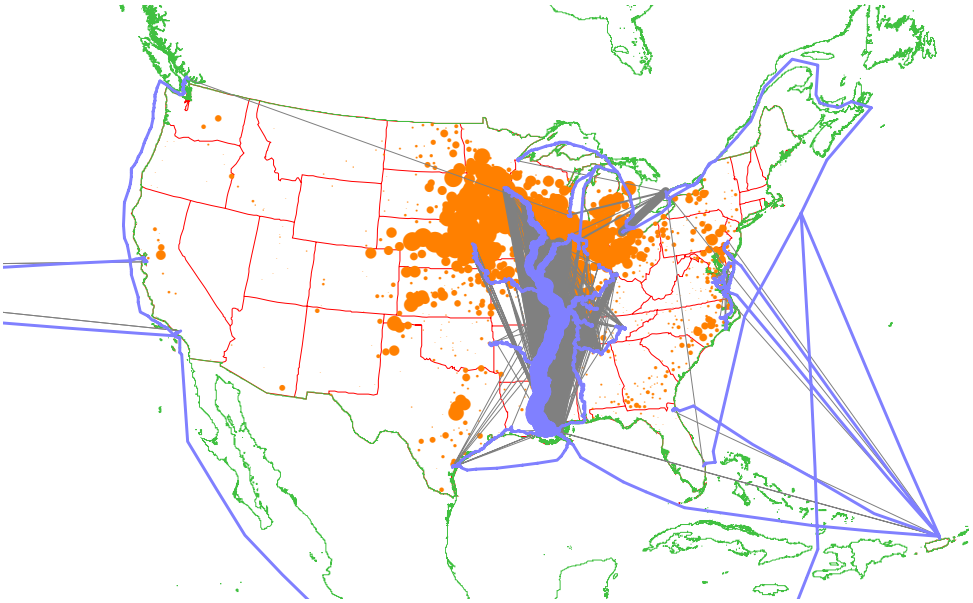


Figure 8. Simulated Waterway Movements of Corn (Maize) between U.S. Counties including Hawaii and Puerto Rico in 2002: scaled according to tons shipped.

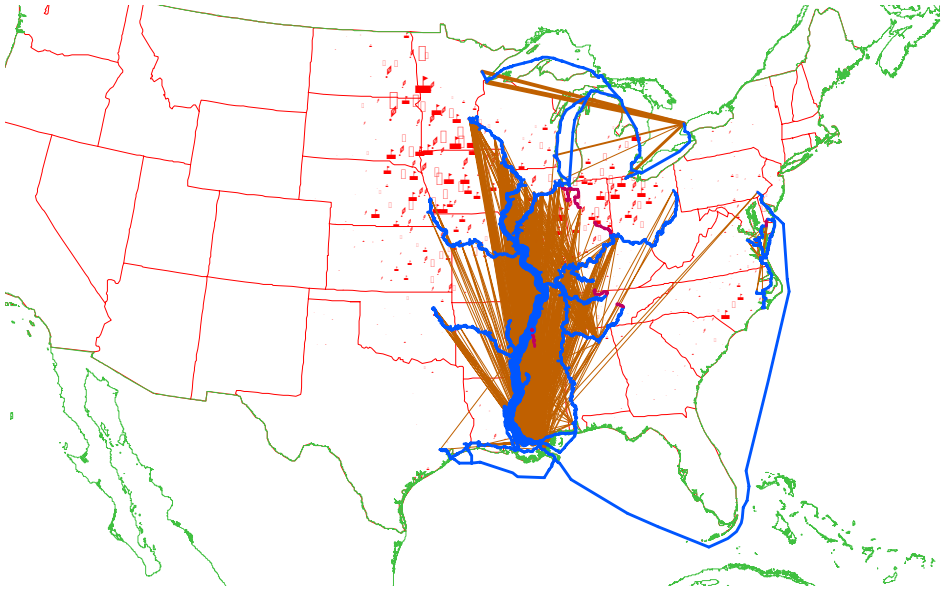


Figure 9. Simulated Waterway Movements of Soybeans between U.S. Counties in 2002: scaled according to tons shipped.

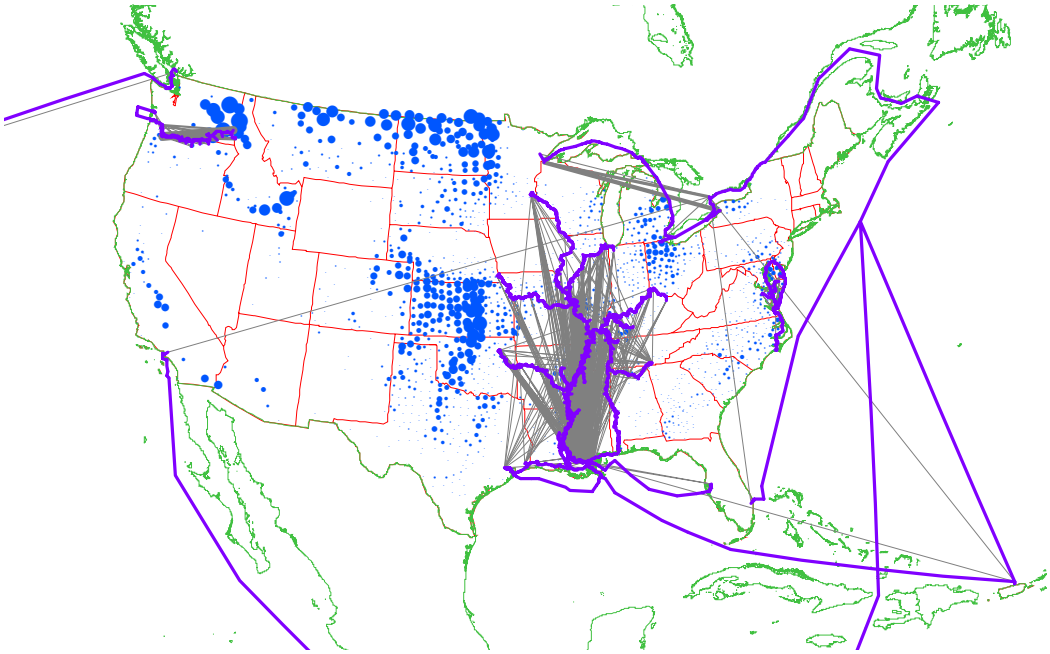


Figure 10. Simulated Waterway Movements of Wheat between U.S. Counties including Hawaii and Puerto Rico in 2002: scaled according to tons shipped.

Similar results and maps have also been developed for rail shipments. Defining the truck dray hinterlands more carefully for these water and rail movements is currently in progress. Intermediary products from this process are mileages and ton-mileages for each O-D-C-M quadruple. Some effort has gone into speeding up the process of creating these maps by each time extracting only links associated with positive O-D flows for subsequent GIS mapping.

Other products that can come out of the process are a back-tracing of the links associated with each O-D-C flow, from which the counties relying on a specific link in the network can be obtained. GIS products that can be derived from RRM outputs are maps or bar- pie-charts of the annual tonnages, and also the average rates charged, by mode and/or commodity for each originating or terminating region (see Figure 11). States are suggested as candidate regions in this case (see Figure 12), to even out some unusual county-and-commodity specific rate combinations that result from limited flows using less common equipment and/or shipper-carrier contract arrangements (e.g. due to an emphasis on single or smaller shipment multi-carload rail movements over unit train moves).[24]

Additional GIS products of interest include mappings of commodity specific seaport catchment areas (i.e. port hinterlands, see Figure 13) by mode(s): and through scenario analysis, the potential for significant shifts in these hinterlands due to changes in port capacity, destination market prices, and transportation rate-inclusive delivery costs. Such maps make it easier to

[24] And even at the level of States some recognition of these across equipment rate variations may still prove to be necessary.

appreciate, for example, those counties where modal competition is to be expected (see Figure 14).

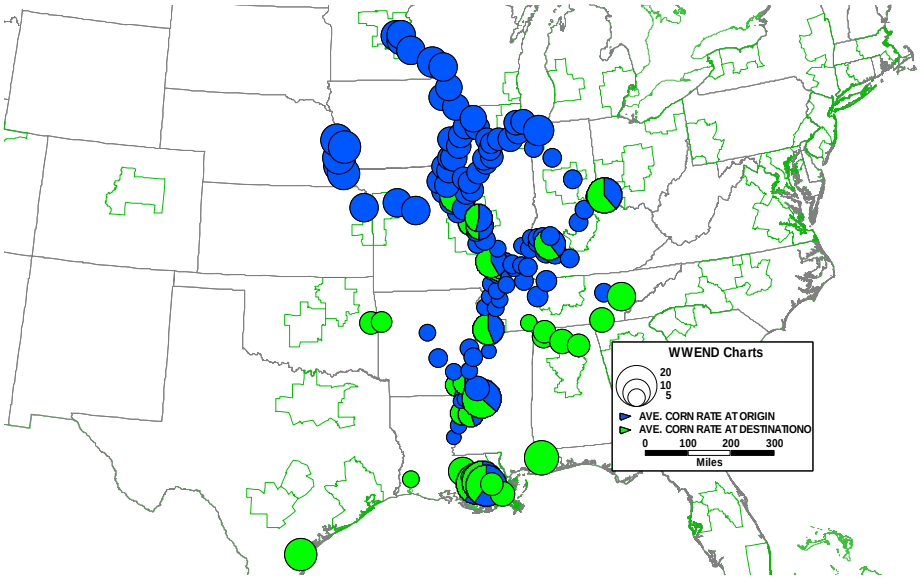


Figure 11. Average Corn Freight Rates by County of Origin or Destination (where data is Available) 2002.

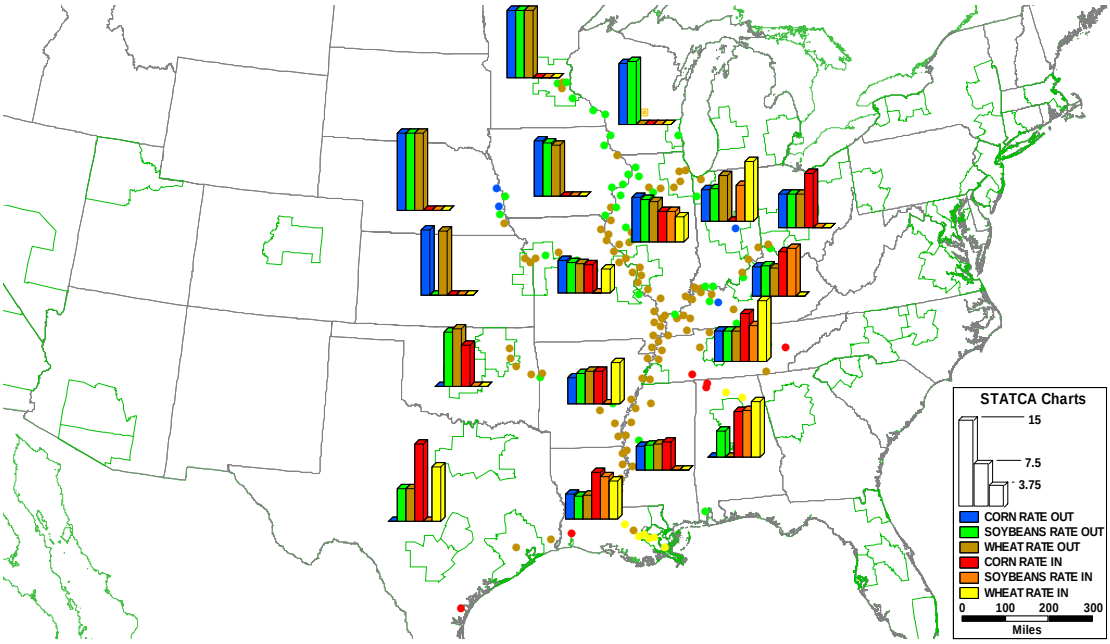


Figure 12. Average Freight Rates for Grain Shipments with Rate and Flow Data: Originating and Terminating States, 2002[25].

[25] No rate data is currently available for the Western rivers, and will need to be modeled.

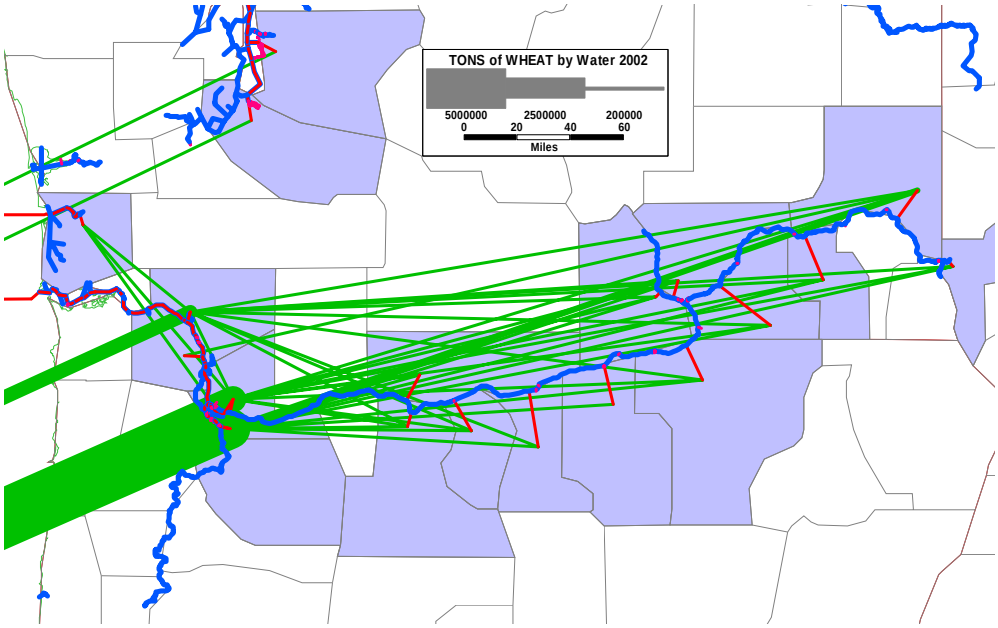


Figure 13. Counties Shipping Wheat by Water, Pacific Northwest

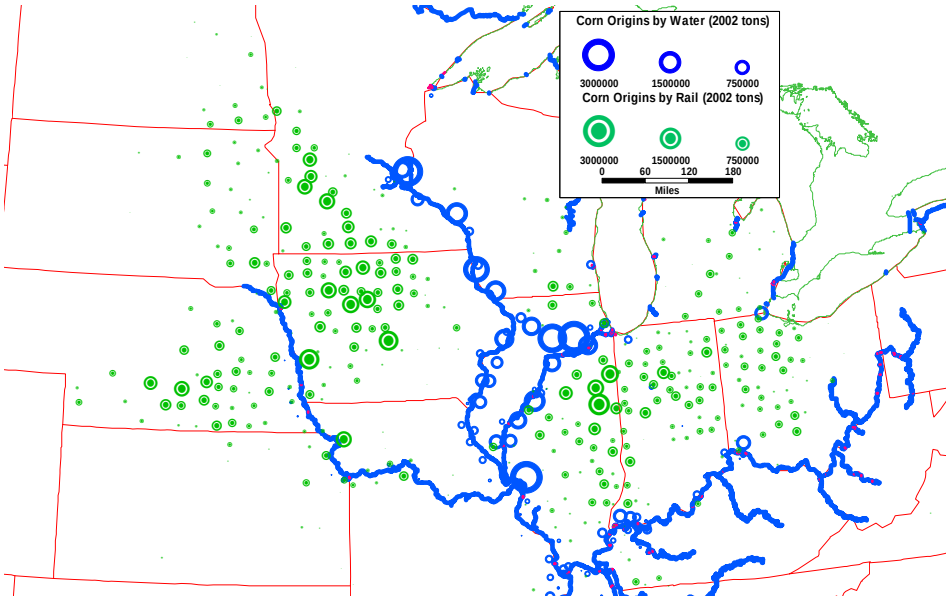


Figure 14. Mid-Western Corn Originations by Water vs. Rail, 2002 Tons.

4.2 Prototype Combined Multimodal Traffic Assignment and Market Choice Model

While selection of the final traffic assignment model and software are yet to be made, a series of initial test are under development using a version of the DYMOD dynamic traffic assignment code which began its development at ORNL in the early 1990's (Janson, 1991; Janson and Southworth, 1992). The idea here is to develop a single period run of the model to solve the

assignment problem defined by equations (4) -(9) above.[26] This process has just begun, using a 10 region, 112 link , 44 node test network built for the purpose (see figure 15).

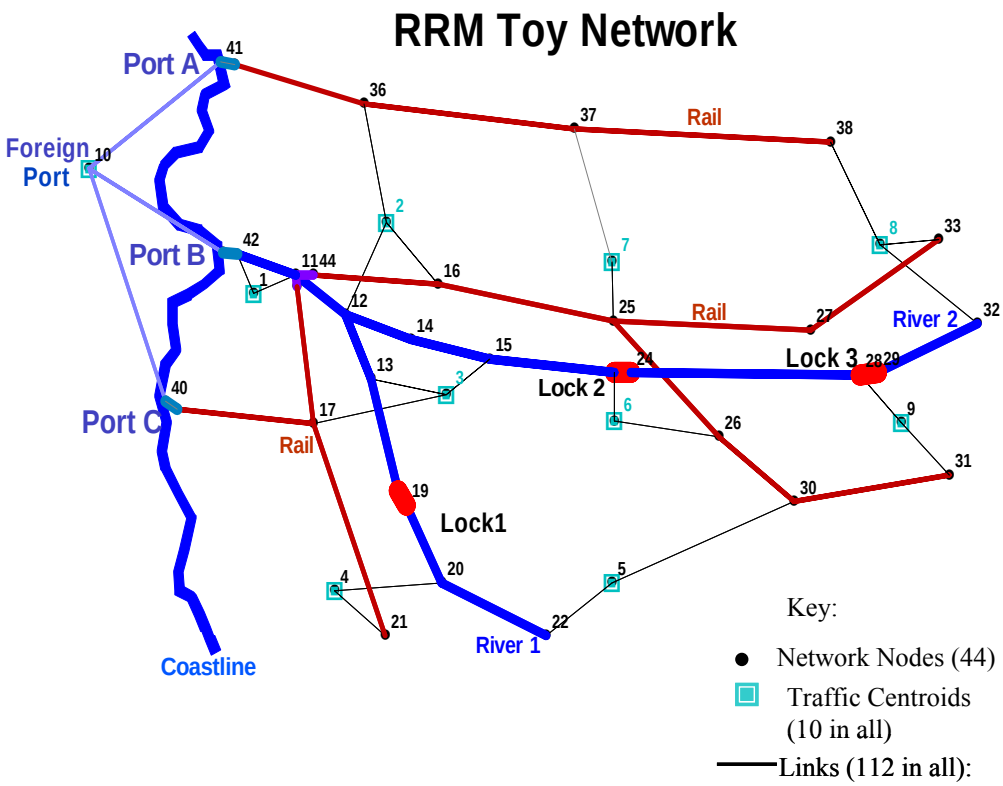


Figure 15. RRM Test Network.

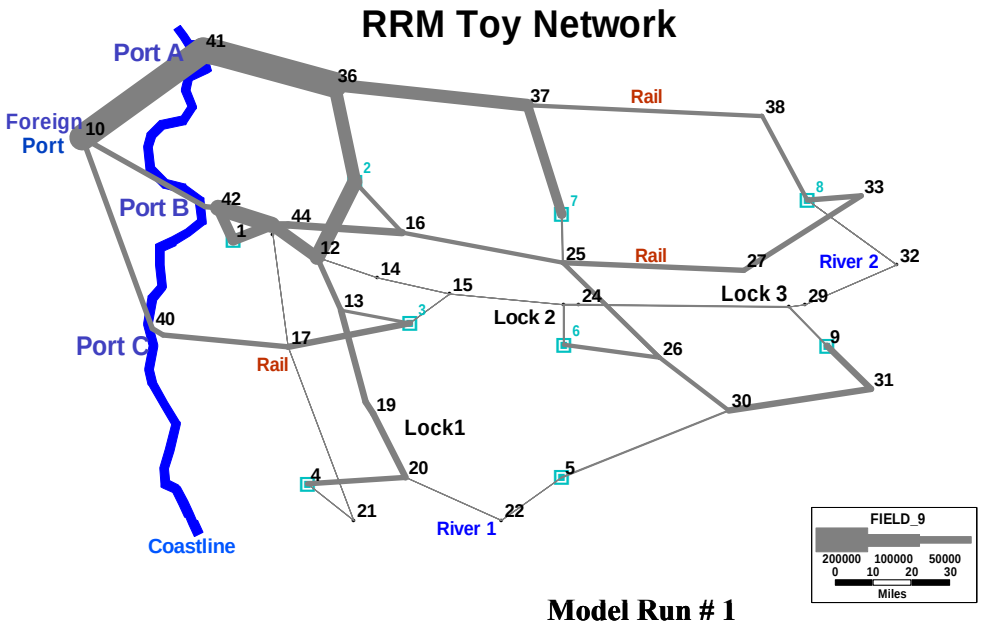
This test problem as currently designed includes 3 locks, three U.S. ports and one foreign port origin/destination. Truck movements in this example are limited to water and rail access links, and the modal choice being examined is between water and rail. A generic link transit time (congestion) function is proposed, of the form (Crainic, et al, 1990; Russ et al, 2005):

$$t_a = t_{ao} * [1 + \theta 1 * V_a + \theta 2 *(V_a / Cap_a)^{\gamma}] \qquad (29)$$

where t_a = link a's transit time, at traffic volume V_a ; t_{ao} = link a's free-flow (uncongested) transit time; Cap_a = the designed capacity or maximum throughput of link a; and θ1, θ2 and **γ** are model parameters. These parameters can be made mode/facility type (e.g. lock, port) specific. These transit times can also be combined with suitable rates to generate link specific generalized cost functions (cf equation 26) using a suitable value of travel time, also treated as an input by the user.

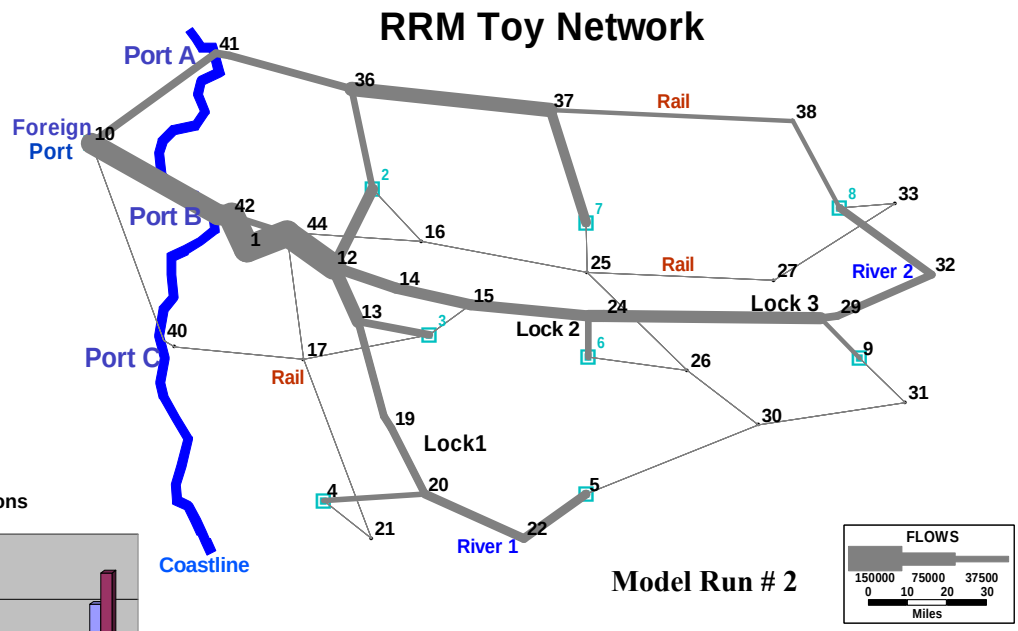
Figure 16 shows the sort of model runs and outputs possible using this toy modeling approach.

[26] Multi-period, such as multi-seasonal, modeling might also be considered in the future.



Model Run # 1

Origin Mode Split = 36.7% water
63.3 % rail



Model Run # 2

Origin Mode Split = 74.9% water
25.1% rail

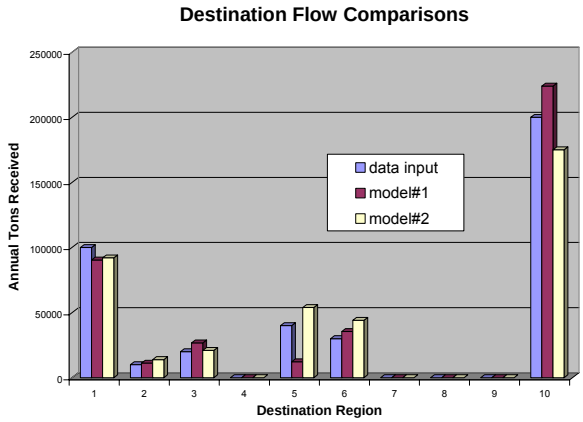


Figure 16. Toy Model Sample Runs: Combined Mode/Route/Destination Choice

References

Benson, D., Vachal, K. and Byberg, T. (1999) Ocean Freight Rate Database Phase I Technical Report. Upper Great Plains Transportation Institute, North Dakota State University.

Berwick, M. and Faroog, M. (2003) Truck Costing Model for Transportation Managers. Upper Great Plains Transportation Institute. North Dakota State University. http://www.ndsu.nodak.edu/ndsu/ugpti/MPC_Pubs/pdf/MPC03-152.pdf

Beuthe M., Jourquin B., Geerts J-F and Koul à Ndjang' Ha Ch. (2001), Freight Transportation Demand Elasticities: a Geographic Multimodal Transportation Network Analysis, *Transportation Research 37E*: 253-266.

Bitzan, J., Vachal, K., Van Wechel, T. and Vinje, D. (2003) The Differential Effects of Rail Rate Deregulation: U.S Corn, Wheat and Soybean Markets. Upper Great Plains Transportation Institute, MCP 03-114. North Dakota State University. http://www.ndsu.edu/ndsu/ugpti/MPC_Pubs/pdf/MPC03-144.pdf

Canning, P and Wang, Z. (2004) A flexible mathematical programming model to estimate interregional input-output accounts. Economic Research Service, U.S. Department of Agriculture, Washington D.C.

Chang, E., Ziliaskopoulos, A., Boyce, D. E. and Waller, S.T. (2001) Solution algorithm for combined interregional commodity flow and transportation network model with link capacity constraints. *Transportation Research Record 1771*: 114-123.

Commonwealth Group (2003) Commonwealth Rail Costing System (CRCS©) http://www.commonwealthlogistics.com/crcs.html

Crainic, T.G. (2002) A survey of optimization models for long-haul freight transportation. CRT 2002-05. Centre de recherche sur les transports. University of Montreal, Quebec, Canada. http://www.crt.umontreal.ca/~theo/cours/longhaul.pdf

Crainic, T.G., Florian, M. and Leal, J (1990) A model for the strategic planning of national freight transportation by rail. *Transportation Science 24:* 1-24.

Dafermos, S. (1972) The traffic assignment problem for multiclass-user transportation networks. *Transportation Science, 6*: 73-87.

Erlander, S., Nguyen, S., Stewart, N. (1979). On the calibration of the combined distribution-assignment model. *Transportation Research 13B*:259–267.

Fernandez, J.E., de Cea, J., and Giesen, R. (2001) A strategic model for freight operations on rail transportation systems. Paper at the 9th World Congress on transportation Research, Seoul, Korea.

Florian, M. and Spiess, H. (1982) The convergence of diagonalization algorithms for asymmetric network equilibrium problems. *Transportation Research 16B:* 477-483.

FRA (2005) ITIC-IM Version 1.0. Intermodal Transportation and Inventory Cost Model. Highway-and-Rail Intermodal, User's Manual. Federal Railroad Administration, U.S. Department of Transportation, Washington D.C.

Fuller, S., Yo, T-H, Collier, D., Jamieson, J. and Harrison, R. (2001) Texas Grain Transportation Study. University of Texas and Texqas A&M University. Report to the 77th Texas Legislature. http://www.dot.state.tx.us/mis/graintransp/study.htm

Geerts, J.F. and Jourquin, B. (2001) Freight Transportation Planning on the European Multimodal Network: the case of the Walloon Region, *European Journal for Transport Infrastructure Research, Vol 1, No. 1.*

Guelat, J., Florian, M. and Crainic,T.G. (1990) A multimodal , multiproduct network assignment model for strategic planning of freight flows. *Transportation Science 24*:25-39

Ham, H., Kim, T.J. and Boyce, D.E.(2005) Implementation and estimation of a combined model of interregional, multimodal commodity shipments and transportation network flows. *Transportation Research 39B: 65-79.*

Janson, B.N. (1991). Dynamic traffic assignment for urban networks. *Transportation Research 25B*: 143-161.

Janson, B.N. and Southworth, F. (1992) Estimating departure times from traffic counts using dynamic assignment. *Transportation Research 26B* :3-16.

Jonnala, S.. Fuller. S. and Bessler, D (2002)A GARCH approach to modelling ocean grain freight rate. *International Journal of Maritime Economics 4*: 103–125

Jourquin, B. and Beuthe, M. (2001) Multimodal Freight Networks Analysis with Nodus, a survey of several application, *Transportation Planning and Technology 4, No. 3*

KPMG (2003) The North American Truckload Index. KPMG LLP, Newark, NJ 07189.

Liu, L.N. and Vilain, P. (2004) Estimating commodity inflows to a substate region using input-output data: commodity flow survey accuracy tests. *Journal of Transportation and Statistics 7(1)*: 23-38.

Marathon, N. , VanWechel, T. and Vachal, K. (2004) Transportation of U.S. Grains: a Modal Share Analysis, 1978-2000. U.S. Department of Agriculture, Washington D.C.

Oppenheim, N. (1995) *Urban Travel Demand Modeling: From Individual Choices to General Equilibrium,* New York: John Wiley and Sons.

ORNL (2001) Ohio River Navigation Investment Model (ORNIM) Technical Manual. Prepared for the U.S. Army Corps of Engineers, Huntington District, Huntington WV.

Park, J.J. and Koo, W.W.(2004) An Econometric Analysis of Ocean Freight Rates for Grain Shipments from the United States to Major Importing Countries. *Journal of the Transportation Research Forum, 42.3*.

Railinc (2003) User Guide for the 2002 Surface Transportation Board Carload Waybill Sample. Report prepared for the Surface Transportation Board, U.S. Department of Transportation, Washington D.C. 20590. http://www.stb.dot.gov/stb/industry/econ_waybill.html

Reebie Associates. CO$TLINE® Family of Freight Cost Models
http://www.reebie.com/home.asp (website not dated)

Russ, B.F., Yamada, T. ,Castro, J.T. and Yasukawa, H. (2005) Optimizing the design of multimodal freight transport network in Indonesia. *Journal of the Eastern Asia Society for Transportation Studies 6*: 2894-2907.

Saggar, R.K. (1970) Turnround and costs of conventional cargo liners. *Journal of Transport Economics and Policy 4.1*: 53-66.

Shneerson, D. (1976) The structure of liner freight rates. *Journal of Transport Economics and Policy 10.1*: 52-67.

Small, K.A. and Rosen, H.S. (1981) Applied welfare economics with discrete choice models. *Econometrica 49*: 105-130.

Sorratini, A.J. and Smith, R.L. Jr. (2000) Development of a statewide truck trip forecasting model based on commodity flows and input-output coefficients. *Transportation Research Record 1707*: 49-55

Southworth, F. and Peterson, B.E. (2000) Intermodal and international freight network modeling. *Transportation Research Vol C8*:147-166.

Southworth, F. and Vogt, D.P. (2005) Multi-level modeling of waterway improvements: linking ORNIM to the broader regional transportation model paradigm. Prepared for the Planning Center of Expertise for Inland Navigation, U.S. Army Corps of Engineers. Huntington, WV 25701.
The Tioga Group (2003) Inland Port Feasibility Study. Final Report. Prepared for the San Joaquin Council of Governments, CA 94556.

Toint, P. and Wynter, L. (1996) Asymmetric multiclass traffic assignment: A coherent formulation. 13th International Symposium on Transportation and Traffic Theory, Lyon, France. J.B. Lesort, (ed.), Pergamon, Oxford: 237-260

Tolliver, D. and Bitzan, J. (2002) Analysis of revenues and costs for wheat shipments originated in North Dakota on the BNSF Railroad. Upper Great Plains Transportation Institute, North Dakota State University. http://www.ugpti.org/pubs/pdf/DP144.pdf

Train, K. and Wilson, W. W. (2004) Shippers' responses to changes in transportation costs and times: The Mid-America Grain Survey. Institute of Water Resources, U.S. Army Corps of Engineers. For Belvoir, Alexandria, VA.

Train, K. and Wilson, W. W. (2005) Transportation demand for grain shipments: a revealed and stated preference approach. Transportation Research Board Meetings CD-Rom, January 2005.

U.S. Army Corps of Engineers, (1983), Waterway Analysis Model, Pittsburgh, PA., January 1982; Pittsburgh District (with Modifications by the Huntington District, January 1983).

U.S. Army Corps of Engineers (2004) U.S. Waterway Data.
http://www.iwr.usace.army.mil/ndc/data/data1.htm

U.S. Census Bureau (1999, 2003) 1997 and 2002 Commodity Flow Surveys. Reports EC97TCF-US and EC02TCF-US. US Department of Commerce, Economics and Statistics Administration. http://www.census.gov/econ/www/cfsnew.html

Vilain, P., Liu, N. L. and Aimen, D. (1999) Estimation of commodity inflows to a substate region: an input-output based approach. *Transportation Research Record 1653*: 17-26.

Wardrop, J.G. (1952) Some theoretical aspects of road traffic research. *Proceedings of the Institute of Civil Engineering, Part II*: 325-378. London, England.

Williams, H.C.W.L. (1977) On the formation of travel demand models and economic evaluation measures of user benefit. *Environment and Planning 9A*:285–344.

Vogt, D.P., Southworth, F., Peterson, B.E. and Rizy, C (2002) Estimation of Regional Economic Benefits from Improvements in Great Lakes/St. Lawrence Seaway Navigation: Phase 1 Reconnaissance Study. Report prepared by Oak Ridge National Laboratory for the Ohio River Division, U.S. Army Corps of Engineers, Huntington, WV 25701.

Wilson, A.G. (1970) *Entropy in Urban and Regional Modelling.* Pion, London. England.

Wilson, W.W., DeVuyst, E. , Koo, W., Dahl, B. and Taylor, S. (2005) Longer-term forecasting of commodity flows on the Mississippi River: application to grains and world trade. North Dakota State University, Fargo, ND 58105.

Winston, C. (1981) A multinomial probit prediction of the demand for domestic ocean container service. *Journal of Transport Economics and Policy 15.5*: 243-252