Development of a Regional Routing Model for Strategic Waterway Analysis

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ABSTRACT

The NETS (Navigation Economics Technologies) suite of models is being developed by the U.S. Army Corps of Engineers to bring new analytic tools to the process of evaluating and planning navigation investments. A hierarchical and potentially iterative approach consisting of three levels, or tiers, 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. This paper describes the construction a commodity flows database to support Tier 2 modeling. Called the Regional Routing Model, it takes spatial disaggregations of broad regional 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. Some preliminary results are shown.

Keywords: freight mode/route choice multi-commodity assignment freight data

INTRODUCTION

This paper describes an approach to freight flow simulation and estimation termed the Regional Routing Model (RRM for short). The paper focuses on the creation of a base case (= base year) set of commodity flows against which to calibrate a prototype RRM. Model parameters could then be used in subsequent forecasting and scenario analysis. The paper documents an exercise in trying to make the most of currently available commodity production, consumption, flow and transportation cost data in order to calibrate a freight mode/route and eventually also market choice model for calendar year 2002. The RRM is being developed as one component of a broader waterway investment modeling framework. Before describing the work on the RRM to date this broader framework is described briefly. Example model calibration results are presented. The paper concludes with a summary of lessons learned.

BACKGROUND AND RELATED RESEARCH

Interest in national freight flow modeling has increased substantially in recent years, leading to a number of advances in the way that commodity flows are estimated and how they get assigned to specific transportation modes and routes. In particular, a number of recent efforts in both the United States (FHWA [1], USACE [2]) and Europe (see de Jong et al [3], ME&P [4]) have put together multi-source databases against which to calibrate their increasingly comprehensive flow modeling formulations. One trend has been the growing popularity of input-output models as a method for generating consistent estimates of the location-specific demands for and supply of goods and services (Canning and Wang [5]; Jackson et al [6]; Liu and Vilain [7], Sorratini and Smith [8]; Vilain et al [9], Vogt et al [10], Tavasszy et al [11]). These models are often linked to spatial interaction models that allocate these flows between origins and destinations. Another trend has seen the development of increasingly detailed link-node representations of national, multimodal transportation networks, over which a variety of commodities are routed simultaneously on what are typically heavily congested freight movement infrastructures (Geerts et al [12], Guelat et al [13]; Jourquin and Beuthe [14]; Beuthe et al [15], and Southworth and Peterson [16]). A third line of research is trying to bring together these two advances: leading to internally consistent measures of congested, multi-commodity and multimodal network flows and costs tied to origin, destination and commodity specific demand models (Chang et al [17]; Ham et al, [18]; and Kim et al [19]).

In keeping with this general improvement in estimation methods and also with an expansion in the scope of transportation economic models, the NETS (Navigation Economics Technologies) suite of models is being developed by the U.S. Army Corps of Engineers (USACE) to improve the process of evaluating navigable waterway investments [2]. In a manner roughly analogous to the Great Britain Freight Model [20] a hierarchical approach consisting of three levels, or tiers, 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 this concept. Tier 1 modeling is focused on econometric estimation and forecasting of broad trans-global trading patterns. Tier 2 breaks these trading flows down to a level that allows the assignment of origin-destination-commodity (O-D-C) specific flows to the US multimodal transportation network. Tier 3 will use these mode and route specific forecasts to optimize investments in

navigable waterways and seaports including the operational and maintenance costs associated with such structures as locks and harbors.

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

The ability to pass modeling results both up and down from one tier to another is likely to be an important feature of the methodology. This includes the ability to refine commodity flow and cost estimates and to assess the effects of a wide range of variables on these estimates, by bringing information into the process at different levels of spatial and temporal specificity. For example, the effects of global changes in the demand for grain exports would come in at Tier 1. The effects of different lock maintenance and expansion plans would come in at Tier 3. And the effects of changes in mode and route specific transportation times on the patterns of commodity flows is a Tier 2 issue. The work described below is focused on Tier 2 modeling. Given a set of broad regional and commodity specific demands and supplies and a multimodal transportation network, the purpose of the RRM is to:

- develop a base year set of origin, destination, commodity and mode specific (O-D-C-M) specific annual traffic flows;
- carry out a congestion sensitive and commodity specific assignment of these traffic flows to the appropriate sections of the nation's multimodal transportation network;
- derive a set of O-D-C-M specific costs of movement associated with these assigned flows; and
- estimate the effects of significant changes in commodity production, consumption and network conditions (network capacity, carrier rates, shipper costs) on the regional pattern of commodity flows across modes and routes, and eventually also on the pattern of flows between sources and markets.

A DATA DRIVEN MODEL STRUCTURE

An important basis for much USACE 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. An underlying objective of the approach described below is to be able to produce a set of freight movements that match to the extent feasible the various "official" government sources of data reporting on them. To accomplish this task the model structure has been adapted to reflect the nature and quality of the available information. Figure 2 shows the data sources being used to calibrate the RRM prototype, and how each feeds into the RRM codes for simulating mode, route and, eventually, market (i.e. shipment destination) choice. A number of sub-models make up the RRM: a truck movements model, an iterative water and rail line-haul traffic assignment and mode split model, and a series of mode specific transportation rate models. The rest of the paper describes these data and sub-models, providing examples of selected model outputs. A summary section highlights some important data needs. For more information on the NETS philosophy on model development, see USACE [2].

INSERT: Figure 2. Structure of the Regional Routing Model Emphasizing Data Sources

CONSTRUCTION OF THE BASE YEAR COMMODITY FLOW MATRICES

To model US commodity flows a county-to-county database was created for all water and rail movements. Barge movements were aggregated from dock-to-dock data supplied by the Tennessee Valley Authority, who process this data regularly from the US Army Corps of Engineers [21]. A combination of computer programming (a linear interpolation code) and manual editing was used to assign latitudes and longitudes to these riverside dock locations which were subsequently assigned to US counties. Annual rail movements were similarly aggregated to inter-county annual flow totals based on the information reported in the 2002 Surface Transportation Board's Annual Carload Waybill Sample [22]. Waybill as well as waterborne commerce commodity flows were re-coded into a set of county-based commodity flows based on the Waterborne Commerce Statistics Center principal commodity classes, with an additional breakdown of grains into corn, wheat, soybeans and other grains for the purposes of model testing. The resulting 14 commodity classes are:

1 Coal (and coal coke)
2 Petroleum and petroleum products
3 Chemicals and related products
4 Crude materials, inedible except fuels
5 Primary manufactured goods
6 Food and farm products - except grains
7 All manufactured equipment, machinery and products
8 Waste and scrap nec
9 Unknown and not elsewhere classified
10 Units - vehicles and passengers (WCSC class 00)
11 Other grains
12 Wheat
13 Corn
14 Soybeans

Note that these flows represent "within-mode" matrices only. The true origination county, and also the final destination county for these shipments is not generally reported, with many shipments requiring a truck haul (sometimes called a truck dray) across one or more county lines as part of the delivery process. This is an important consideration given the relative expense involved in moving commodities long distances by truck. The only data source on true freight originations and destinations at the national level is the US Commodity Flow Surveys [23], and these surveys have significant holes in them while providing little by way of geographic detail below the State level. Truck movement data is even more limited in its geographic detail at either the fully national or broad regional level, requiring that we model it from the raw materials of industry/commodity production and consumption and variously limited sources of data on truck trip lengths or costs of transport (see Southworth [24]).

A method is therefore required for not only simulating truck movements but also for linking counties that use trucks to access rail and water loading sites in other counties. This is accomplished by the Truck Movements Model shown in Figure 2.

TRUCK MOVEMENTS MODEL

To create a set of base year annual truck movements the RRM currently simulates truck activity as a separate choice between direct trucking to final consumption (termed "truck-only" movements) versus rail- and waterway-serving truck shipments. That is, truck shipments are simulated to move either directly from producing county to final consumption or as hauls from a producing county to rail or waterway loading docks in nearby counties.

County annual production and consumption totals come from the Economic Research Service (ERS) within the US Department of Agriculture (USDA) who used its inter-regional input-output model [5] to develop data for the project. To do this the commodity make-up of each industry within a county has to be defined. Then a commodity-to-industry conversion table is used that reports the amount of a commodity (e.g. wheat) required to produce a unit of output for each of the county's industries (e.g. flour milling). Converting and summing over all industry specific needs in the county then gives the aggregate, annual demand for the commodity. For RRM purposes this meant converting from dollar valued industrial demands to tons of raw produce consumed. For county production purposes this meant converting from bushels of grain or numbers of units (e.g. apples, broilers) into tons shipped. Where production totals are involved (see Figure 2) this also means estimating any reductions in tons shipped due to on farm consumption, currently a necessarily approximate value given existing data sources.

A quasi-constrained spatial interaction model is then used to allocate truck shipments from county of production, i, to county of destination, k as (see de Vries, Nijkamp and Rietveld [25], for example):

$$T(i,k) = A(i)^{1-\alpha} P(i) * B(k)^{1-\gamma} * D(k) * \exp(-\beta * c(i,k)) \quad (1)$$

for P(i) = volume of grain produced in county i, D(k) = demand in county k (= the sum of consumption of grain in county k's industries plus the volume of grain loaded on rail or barge in county k), c(i,k) = the cost of trucking a ton from i to k, and where α , β, and γ are model parameters to be estimated. Here β = the sensitivity of destination choice to extra transport cost, and α and γ allow the resulting T(i,k) estimates to sum more or less closely to the input P(i) and D(k) totals, by way two sets of trip end balancing factors A(i) and B(k):

$$A(i) = [\ \textstyle\sum_k B(k)^{1-\gamma} * D(k) * \exp(-\beta * c(i,k))\ ]^{-1} \quad (2)$$

$$B(k) = [\ \textstyle\sum_i A(i)^{1-\alpha} * P(i) * \exp(-\beta * c(i,k))\ ]^{-1} \quad (3)$$

Grain truck rates are initially based on the work of Wilson et al [26, page 50]:

$$\text{truck rate} = 4.12 - 0.472 * \ln(\text{miles}) \quad (4)$$

where the truck rate is in dollars per loaded truck mile, and ln( ) = the natural logarithm of.

Alternative and more elaborate truck rate models, such as the grain transport costing model developed by Berwick and Faroog [27] are also being experimented with. In this manner we are

attempting to identify the base year multi-county hinterlands associated with water and rail loading centers under different assumptions about truck haulage distances and truck per ton shipping rates. This is something of a challenge at the present time as statistically robust sources of data on truck volumes, rates and their distances remains limited. Truck shipment tonnages are currently estimated, therefore, by allowing the analyst to select both an average and a maximum trucking distance for the commodity of interest based on any national or locally reported data sources. Average truck trip distances reported by commodity class in the US Commodity Flow Surveys [23] served as a starting point for interaction model calibration, but statistically robust data on the distances associated with the truck haulage portions of intermodal trips remains a weak area in current federal and state freight data. Testing the sensitivity of model results to both average and maximum allowed truck hauls is therefore a good idea.

Linking these truck flows to the rail and waterway line haul tonnages then gives the estimated tons shipped from production county i via a rail or barge loading at county k to a rail or barge destination county in j, P(ikj), as:

$$T(ikj) = T(k,j)*P(i/k) \quad (5)$$

for T(k,j) = tons shipped from rail and/or water loading county j to destination county k and P(i/k) = the probability of selecting county i as a source for loading freight at county k. In this manner the resulting truck flow estimates remain consistent with both the annual county production and consumption totals and also with reported annual rail and waterway loadings for that year. Combining the results of the truck haul costing model with those from the line-haul rail or waterway costing models (see below) then provides a means of comparing truck-rail versus truck-waterway shipping costs from county of production to final offloading county.

CONGESTED MULTI-COMMODITY NETWORK ASSIGNMENT

Representation of the U.S Multimodal Transportation Network

For assignment of freight to the U.S. transportation network all commodities are being flowed over an updated version of Oak Ridge National Laboratory's (ORNL) multimodal freight transportation network model [16]. This network 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. 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 USACE definitions.

Counties and seaports are connected to this network via a series of mode specific access/egress links. Each county and seaport 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 network's various physical and logistical characteristics, including any traffic flows and costs estimated by the RRM. These networks are also connected to a trans-global deep sea network that allows flows to be flowed through U.S. seaports and the St.

Lawrence Seaway to foreign seaports. 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 (Figure 3). As described in the next two sections of the paper, a valuable benefit of the current project will be the addition of shipper cost-based impedances (i.e. generalized costs of movement) 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.

INSERT: Figure 3. Network Representation of Intermodal Terminals and Transfers

Multi-Commodity Route Assignment

Rail and waterway transit times and distances are generated during the traffic assignment phase of the RRM. Rail commodity movements are simulated across the entire U.S. network, as are waterway movements. Flows are simulated at a county-to-county level, and flows external to the region of interest can be aggregated to states or other macro-economic regions for analysis or mapping purposes. Truck movements are currently outside this assignment stage, being limited to those flows occurring within the specific river system of interest, where they are also modeled at the county-to-county level.

At the outset two options were considered for assigning flows to the US transportation network: a) a simultaneous assignment of O-D-C flows to modes and routes, and b) a sequential assignment of flows to modes and routes. The recent literature on this topic recognizes pros and cons to both approaches [20]. Initial work on the project has adopted the sequential approach for ease of implementation, allowing separate calibration of the rail and waterway network flows. Subsequent modeling will look at assigning rail, waterway and also truck flows simultaneously, out of specially constructed county centroids that can be used to influence the initial assignment of flows to modes based on non-network cost factors. In either case an ideal solution for economic analysis purposes is seen as an implementation of a Wardrop-style equilibrium traffic assignment in which shippers have their goods delivered by the mode/route alternative that minimizes their costs, subject to the movements of everyone else shipping over the same network.

Currently an incremental assignment that loads each commodity class in sequence is being used to balance flows across alternative, principally rail routes. Iteratively linking this assignment with a mode choice routine then approximates the desired multi-route, multi-modal equilibrium solution, while allowing detailed tracking of specific O-D-C movements over the respective modal networks. While such O-D-C flow to route assignments are not unique (nor would they be if a fully equilibrated assignment were carried out), this tracking capability is seen as important to prototype development, allowing the analyst to examine the implications of model inputs in considerable detail. Specifically, the assignment routine retains the details of which commodities flow over which links in the network, by commodity class, by region of origin and by region of destination: a time consuming computational task that involves a good deal of back-tracing of paths data (and one that can be suppressed for scenario generation).

Both rail and waterway link cost functions measure in-transit time delays on the basis of annual kilotons transported, for which purpose a variety of rail and waterway congestion functions are

being tried. For waterways this means measuring the build-up of multi-barge tow traffic at "lock links". Monthly data from USACE's Lock Performance Monitoring System [21] are used here to estimate approximate lock transit times as a function of annual kilotons locked, with direction-specific average tow speeds being used for non-lock links. Figure 4 shows the sort of link congestion function currently in use.

INSERT: Figure 4. Example Lock Link Congestion Functions

Rail congestion functions are proving somewhat more difficult to develop, requiring information on the costs of railroad interlining and terminal delay times as well as representative line haul speeds by different classes of traffic (e.g. containerized versus non-containerized cargo). Initial assignments are using quadratic delay functions based on past experience with routing shipments over the network for the 1993, 1997 and 2002 US Commodity Flow Surveys [16], employing the idea of a nominal rail capacity that is based on the class of track and the reported density of line utilization. The ability to select and weight specific routes is here less of an issue than the ability to validate the effects of congestion on the resulting transit times.

TRUCK-WATER VERSUS TRUCK-RAIL MODE CHOICE MODEL

RRM modal split is handled by a logit model that is designed to assess the sensitivity of mode choice to differences in modal costs. It operates at the O-D-C level, i.e.

$$X_{ij}^{mg} = X_{ij}^{mg} * [\exp-(cij^{mg})/ \sum_{m} \exp- (cij^{mg})] \tag{6}$$

where X_{ij}^{mg} = annual tons of commodity g shipped from origin county i to destination county j by mode m, and c_{ij}^{mg} = the generalized cost of transportation of the form [30,31]:

$$c_{ij}^{mg} = \theta_0 + \theta_1 \; r_{ij}^{mg} + \theta_2 \, t_{ij}^{mg} \tag{7}$$

for r_{ij}^{mg} = the dollar valued freight rate for moving g from i-to-j by mode m, and t_{ij}^{mg} = the network assignment model estimated (i.e. congested) transit time associated with such a movement; and where θ_0, θ_1 and θ_2 are empirically derived model parameters.

Good examples of the sort of statistical rail rate models that can be built to support equation (7) are reported by Fuller et al [28], and by Bizman et al [29]. For the purposes of prototyping grain specific rail rate models were generated from shipment level data in the 2002 US railcar waybills. These equations take the general form:

$$\text{rail rate (\$/ton)} = \alpha 0 + \alpha 1(\text{Miles}) - \alpha 2\,(\text{Carloads/Shipment}) - \alpha 3(\text{Tons/Carload}) \tag{8}$$

Adjusted R^2 values are in the range 0.5 to 0.6. Other attributes, such as the specific railroads involved and the season shipped can be added (based on examples in the literature) to improve model fits.

Detailed waterway rate modeling has been ongoing at the Tennessee Valley Authority now for a number of years, and the longer term aim is to use this work directly in the RRM, simple distance based waterway rates. For initial model testing simple distance based waterway shipper rates, in dollars per O-D-C ton shipped are being used.

Once an acceptable set of commodity specific mode splits has been achieved these results are fed back to the RMM route assignment model and iterated to convergence (cf. Figure 2). This iterative sequence also allows for the effects on transit times due to changes in rail or waterway network capacity to be simulated. Our experiments suggest that sensible rail traffic shifts can simulated when certain rail or water links are closed or restricted to limited classes of traffic, or where the volumes of selected O-D-C freight traffic (e.g. a 10% increase in wheat flows) are arbitrarily increased: although the effects of these shifts on subsequent mode selection is likely to be less easily determined within this single tier of the 3-tier modeling process.

AN EMPIRICAL EXAMPLE

Empirical testing of the approach, still in its early stages, is based on the model's ability to use existing data sets to reproduce the flows of selected grains: corn, wheat and soybeans. Grain forecasts in NETS are based on the ten grain producing macro-economic regions shown in Figure 5[26].

INSERT: Figure 5. NETS Tier 1 Grain Producing Regions

To test the RRM truck movement model the Pacific Northwest grain producing region was divided back into its 119 counties, allowing all counties in Idaho, Oregon or Washington State the possibility of using the river as a truck-only, truck-rail or truck-water movement option. Figure 6 shows the volumes of inter-county wheat flows by water in 2002 and the results of assigning these tonnages to the nation's principal waterways. Also shown is the relative size of county wheat production for that year. (Results for rail shipments are not shown due to restrictions on STB data presentation).

INSERT: Figure 6. Wheat Production and Simulated Waterway Movements between U.S. Counties in 2002.

The truck haul travel times and freight rates coming out of this model were then added to the line haul rail or water costs within the 3-State region. The resulting truck-plus-rail versus truck-plus-waterway O-D-C specific generalized cost differences were then used to calibrate a linearized logit mode split model of the form:

$$\text{Ln}\ [\ P(w) / 1\text{-}P(w)] = \lambda_0 + \lambda_1 * [c(\text{water}) - c(\text{rail})] \qquad (9)$$

where c(water) and c(rail) are as defined in equation (7), using example results from the disaggregate mode choice model developed by Wilson and Train [30] to approximate θ_0, θ_1 and θ_2. The λ_0 and λ_1 in equation (9) are in this case simply regression model parameters that factor these shipper response-based costs to match the count-to-county mode splits reported. Figure 7 shows the regression result, which fits the data quite well. This is to be expected given the

importance of truck haulage distances and the comparatively higher per ton-mile costs of trucking grain versus moving it in barges or railcars. That is, the distance that a shipper is from a rail or water transfer terminal has a significant impact on the choice of mode used: a condition often referred to in the modeling literature and readily evident when mapping current water versus rail originations for grain as well as most other bulk commodity movements.

INSERT: Figure 7. Mode Choice Modeling of Wheat Shipments Originating in the Pacific Northwest

CONCLUSIONS

The RRM effort has set out to prototype a freight routing model for waterway analysis that is decidedly mesoscopic, focusing on county to county movements as a means of loading flows onto the transportation network. This approach seems to offer sufficient geographic detail for the purpose, especially since "routing options" where navigable rivers are concerned typically implies a modal choice between water and rail: but with the important caveat that more than one rail route (and more than one railroad) will often offer viable delivery alternatives. Adding to the mix, truck as a competitive as well as inter-modally cooperative mode has increased in stature measurably over the past three decades, and for a range of commodities that includes some that move regularly by river [23]. Yet we have comparatively limited truck movement data for the purposes of national flow modeling.

Data sources sorely in need of improvement includes data on truck distances and associated models of truck freight rates, both for truck draying to line-haul modes and as the sole mode of transport to the consuming industry. Given the scarcity and often small sample sizes generally available to freight shipper or carrier surveys we also need to develop alternative ways to bring this information into multi-regional and national flow models. As shown in this paper these flow models can draw on a variety of "administrative" data sources reporting annual and seasonal economic activity, flows and costs. What these datasets lack are the many other variables that often serve to limit or encourage the use of one mode or one route versus another – variables such as delivery time reliability and the relationship of transportation costs to compete business logistics costs. Finding ways to bring these variables into the analysis seems key to useful forecasting. Even so, the ability to match any such base year forecasts to reported flow, production, and consumption totals remains an important goal.

Finally, a set of commodity specific market (destination) choice models might also enter the iterative sequence shown in Figure 2. For completeness such an extension to the current framework will require iteration back through the Truck Movement Model as well as through the Traffic Assignment and Truck-Rail/Truck-Water Mode Choice Models. It will also require a method for capturing any truck hauls from final rail or water off-loading counties to final consumption counties if we wish to allow existing and complete O-to-D freight movement volumes to alter within this tier of the 3-tier modeling framework envisioned in Figure 1.

References

[1] FHWA (2006) Freight Analysis Framework. Technical Documentation. Federal Highway Administration, Washington D.C. 20590.

[2] USACE (2006) NETS. Navigation Economics Technologies (NETS). Institute for Water Resoruces, US Army Corps of Engineers. Fort Belvoir, VA

[3] de Jong, G. Gunn, H., Walker, W., and Widell, J. (2004) National and International Freight Transport Models: An Overview and Ideas for Future Development. *Transport Reviews 24(1)* 103-124

[4] ME&P et al (2002) Review of Freight Modeling. Report B2 – Review of freight Models in Continental Europe and Elsewhere. Cambride , England. June 2002.

[5] 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.

[6] Jackson, R. W et al (2004) A method for constructing commodity by industry flow matrices. Research Paper 2004-5. Regional Research Institute, West Virginia University, Morgantown, WV.

[7] Liu, N.L. 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*: 23-37.

[8] 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

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

[10] 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.* Report prepared by Oak Ridge National Laboratory for the Ohio River Division, U.S. Army Corps of Engineers, Huntington, WV 25701.

[11] Tavasszi, I.A., van der Vlis, M.J.M., Ruijgrok, C.J. and van der Rest, J. (2001) Scenario analysis of transport and logistics systems with a SMILE. TNO Inro. Delft, Netherlands.

[12] 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.*

[13] 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

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

[15] 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.

[16] Southworth F., and Peterson B.E (2000) Intermodal and international freight network modeling. *Transportation Research 8C:*147-166.

[17] 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.

[18] 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.*

[19] Kim, T.J., Ham, H., and Boyce, D.E. (2002) Economic impacts of transportation network changes: implementation of a combined transportation network and input-output model. *Papers of Regional Science 81*: 223-246.

[20] MDS-Transmodal Ltd. (2003) The GB Freight Model. Document 1 Methodology. Chester, England. September, 2003.

[21] USACE (2004) U.S. Waterway Data. Institute for Water Resources, U.S. Army Corps of Engineers, Fort Belvoir, VA.

[22] 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.

[23] Census Bureau (2004) 2002 Commodity Flow Survey. Report EC02TCF-US. US Department of Commerce, Economics and Statistics Administration, Suitland, MD.

[24] Southworth, F. (2006) Filling gaps in the U.S. commodity flow picture: using the CFS with other data sources. Resource Paper. Commodity Flow Survey Conference. Transportation Research Circular E-2088: 29-46.

[25] de Vries, J.J., Nijkamp, P. and Rietveld, P. (2000) Alonso's General Theory of Movement. Tinbergen Institute Dusussin Paper T1 2000-062/3. Erasmus University, Amsterdam, Netherlands.

[26] 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.

[27] Berwick, M. and Faroog, M. (2003) Truck Costing Model for Transportation Managers. Upper Great Plains Transportation Institute. North Dakota State University.

[28] 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.

[29] Fuller, S., Yo,. T-H., Collier, D., Jamieson, J. and Harrison, R. (2001) Texas Grain Transportation Study. University of Texas and Texas A&M University. Report to the 77th Texas Legislature.

[30] 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.

[31] 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. Fort Belvoir, VA.

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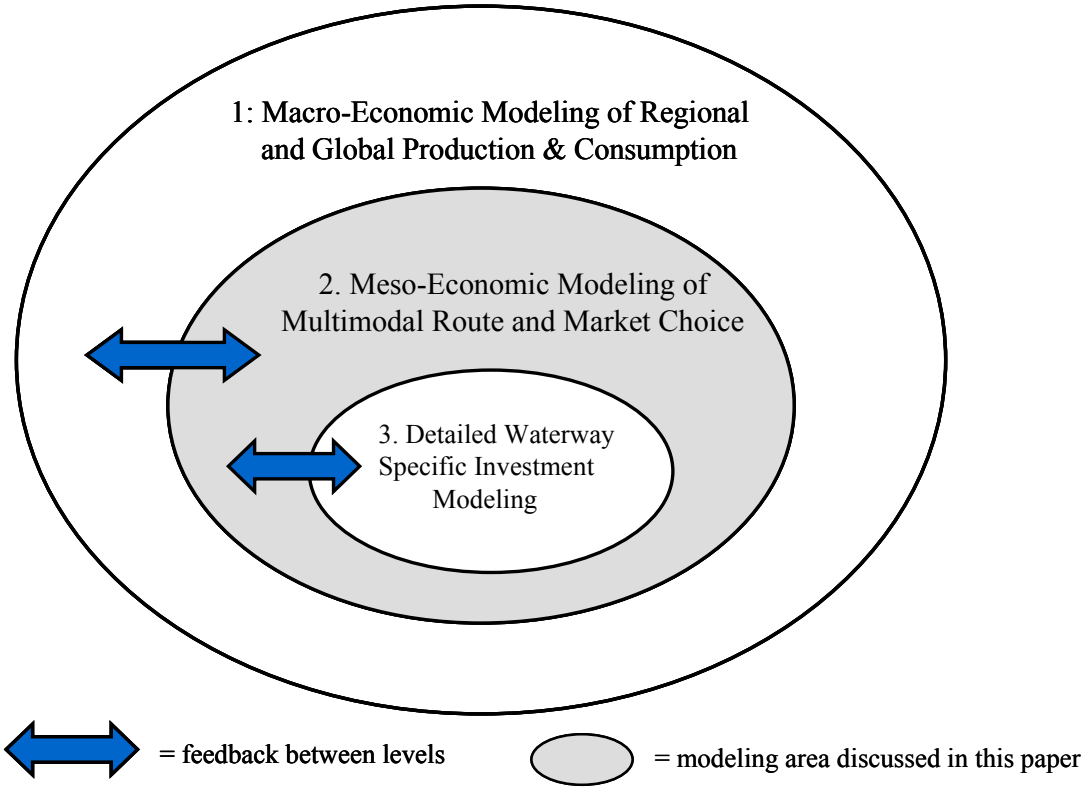


Figure 1. A Nested Three-Tier Spatial-Economic Modeling Framework

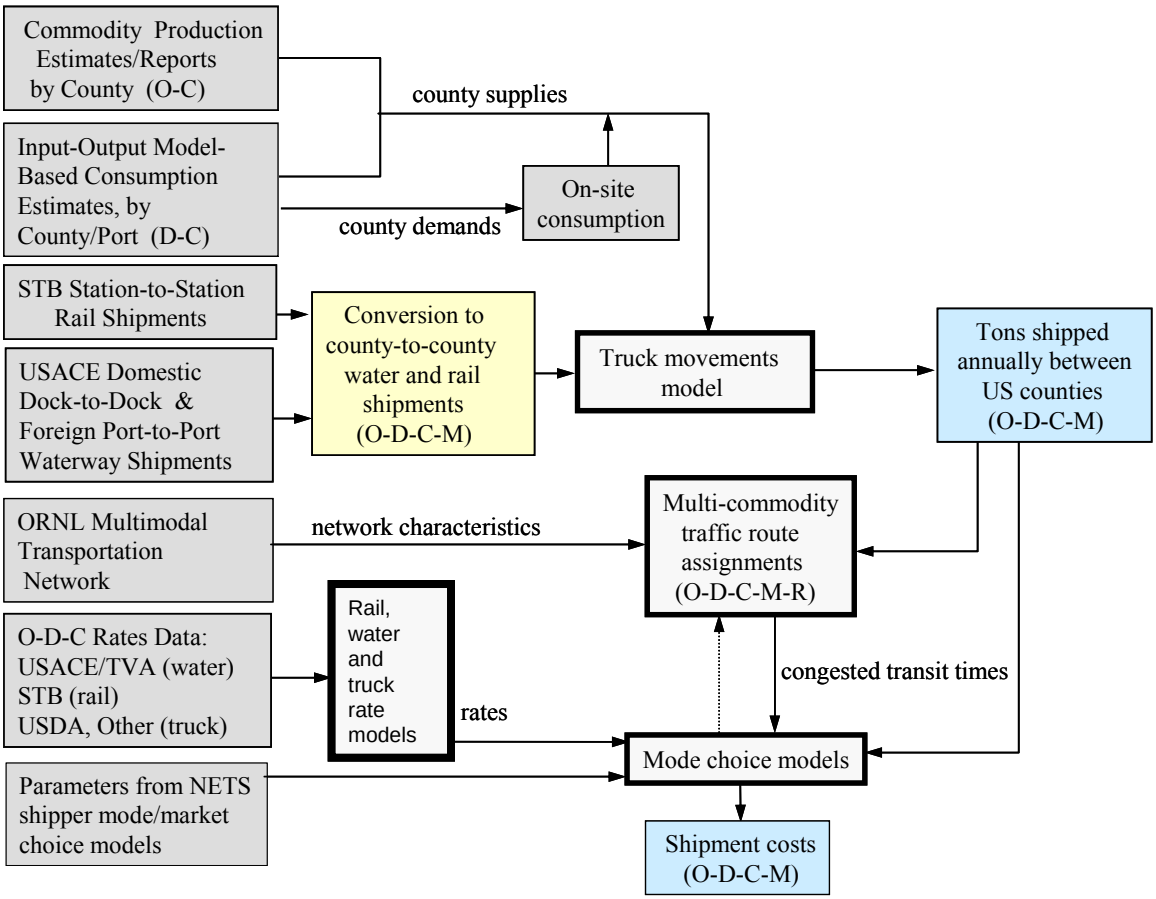


Figure 2. Structure of the Regional Routing Model Emphasizing Data Sources

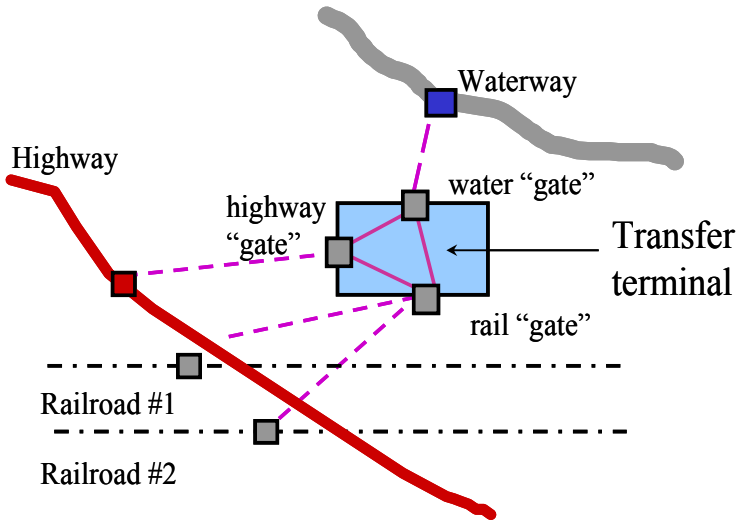


Figure 3. Network Representation of Intermodal Terminals and Transfers

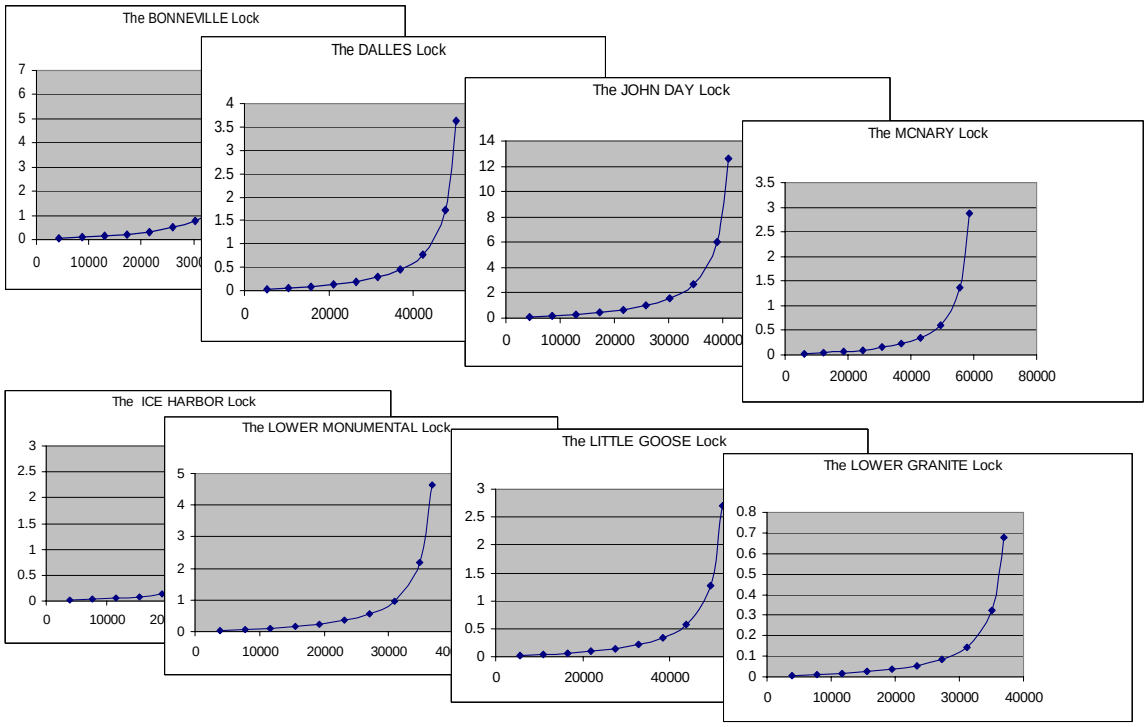


Figure 4. Example Lock Link Congestion Functions

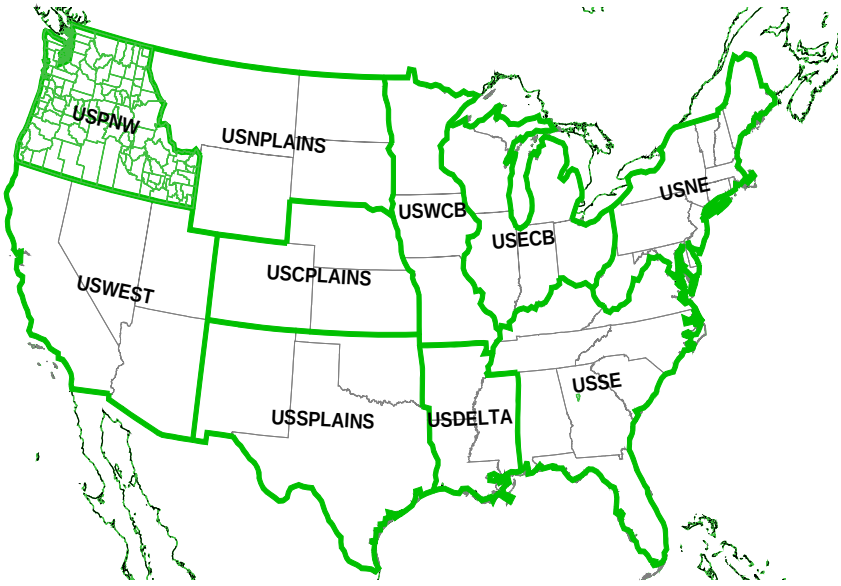


Figure 5. NETS Grain Producing Regions

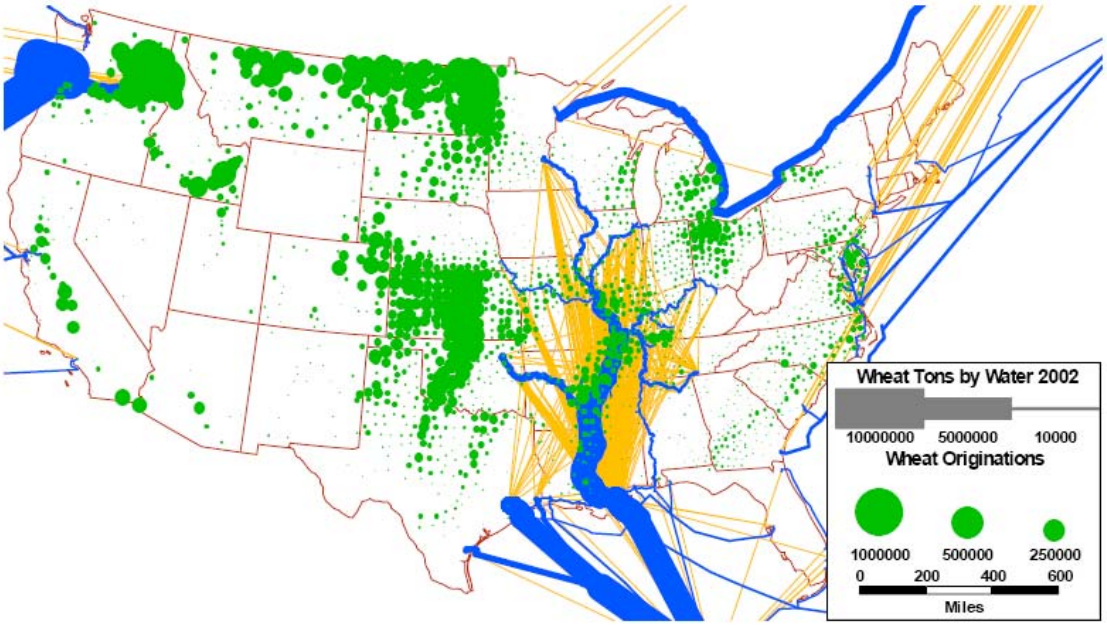
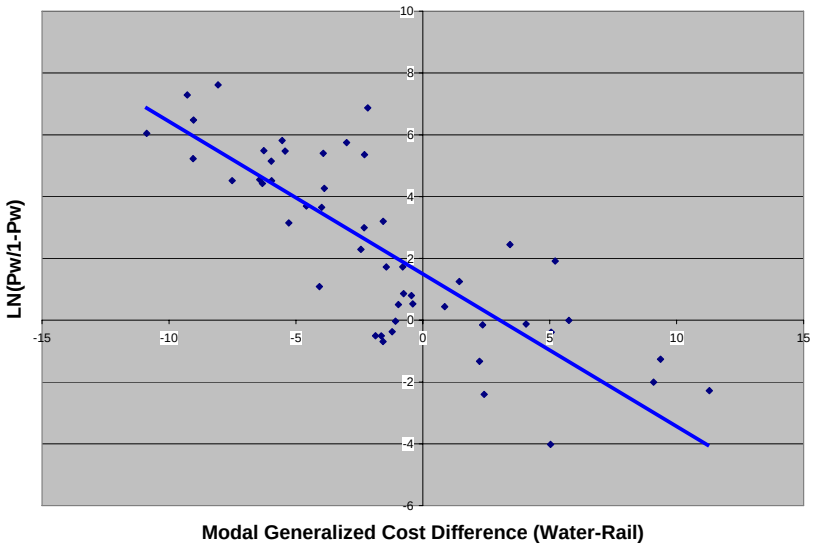


Figure 6. Wheat Production and Simulated Waterway Movements between U.S. Counties in 2002.



Pw = Probability of selecting the water mode

Regression Statistics	
Multiple R	0.807628
R Square	0.652262
Adjusted R Square	0.645018
Standard Error	1.747132
Observations	50

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	274.8293	274.8293	90.03508	1.37E-12
Residual	48	146.5185	3.052469		
Total	49	421.3479			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.574475	0.259545	6.066276	1.99E-07	1.052624	2.096326	1.052624	2.096326
CDIFF	-0.47258	0.049804	-9.48868	1.37E-12	-0.57272	-0.37244	-0.57272	-0.37244

Figure 7. Mode Choice Modeling of Wheat Shipments Originating in the Pacific Northwest