Optimization Models of Container Shipments in North America: Spatial Competition and Projections (Methodology)

Towards a Global Forecast of Container Flows
Container Model and Analysis:
Longer Term Analysis for Infrastructure Demands and Risks

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Task 7: Model development design document (what can be done)

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1. Introduction

The Institute for Water Resources's (IWR) Navigation Economic Technologies (NETS) Research program has developed a global spatial equilibrium model for the forecasting of grains.[1] This analytical approach to forecasting projects supplies and demands by region and transfers excess supplies to the excess demand regions by the least cost route. The model can also be used to evaluate comparative statics to assess how changes in infrastructure impacts the equilibrium shipments during the projection period. This is important in that any infrastructural project takes time. Thus, analysis should seek to evaluate how the equilibrium changes during a relevant projection period. The objective of this research is to evaluate the applicability of this approach to the forecasting of container cargoes.

This report describes alternative modeling approaches and provides advantages and disadvantages of each. Specifically, it addresses Task 7 of the overall study:

Task 7: *Model development design document (what can be done?)*[2]

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[1] This is available at Wilson, DeVuyst, Taylor, Dahl, and Koo (2006) and summarized in Wilson, DeVuyst, Taylor, Dahl and Koo, 2007. Additional papers from that study include are in Wilson, Koo, Taylor and Dahl (2008a and 2008b) and several articles under review including DeVuyst, Wilson and Dahl (2008) and Wilson, Dahl, Taylor and Koo (2008) which are available from the authors.

[2] Other tasks include the following, and are available in accompanying reports: Task 2 Describes historical movements in world container trade; Task 3 Analyzes historical movements in US container markets including an econometric analysis of container demands; Task 4 Rail rate analysis of container shipments; Task 5 Ocean rate analysis of container shipments; Task 6 is included in this report; and Task 7 An evaluation of alternatives for spatial modeling of container shipments.

Reports on each of these topics are available from the authors and IWR and are titled:

Report 1:	Review of Previous Studies on Container Shipping: Infrastructure, Projections and Constraints
Report 2:	Analysis of Container Flows: World Trade, US Waterborne Commerce and Rail

The paper is organized as follows. Section 2 provides a summary of the salient features of the container marker. Section 3 describes the features of the world grain model and assesses the extent that it could be used for modeling containers. Section 4 provides details on two alternative approaches for modeling container shipments. Section 5 discusses some of the outstanding issues and makes an analogy to the world grain model. Section 6 provides details of the steps necessary to complete a spatial optimization model for containers and Section 7 identifies areas of concern as well as opportunities for modeling world container flows.

2. Salient Features of the Container Market Important to the ACE

This section provides a brief summary of some of the salient features of the container market that are relevant and provide motivation to the need for developing a spatial optimization model. Most of the material here is taken from companion reports listed in note 2 above.

Trade in containers is probably one of the most radical changes in world commerce. This is an industry that has been evolving for many years. However, the pace of growth has likely accelerated in the past decade:

Shipments In North American Markets
Report 3: Container Demand In North American Markets: A Cross-Sectional Spatial Autocorrelation Analysis
Report 4: Container Shipping: Rail and Ocean Shipping Rates
Report 5: Optimization Models of Container Shipments in North America: Spatial Competition and Projections (Methodology)

- The annual growth rate in global container trade is about 10% per year and seems relatively steady;
- Asia is by far the largest importer and exporter of containers, followed by Europe and then "Other" and North America;
- Amongst the trade lanes, the fasted growing trade is FarEast to Europe, followed by Transpacific. Growth in the Transatlantic shipments is relatively slow
- North America imports more containers than it exports, and this gap is widening over time. Asia is by far the largest source of imports for North America.
- Within North America, the ports with the greatest growth are in Mexico, then, Canada and then the United States.
- An important trend has been the escalation of containerized shipments. For most commodities, there has ben a trend toward an increasing share of trade being shifted to containerized shipments.

Container shipments within the United States have also increased rapidly over the past decade. Results of the US container flow analysis of interest are:

- Of 179 BEAs in the US, only 90 receive container shipments;
- The largest container markets in 2005 are Chicago, Los Angeles which by far dominates the market, followed by Seattle, Dallas, Memphis and then numerous others;
- Trailers comprise about 10% of the market, and their share has been decreasing relative to containers;
- Both Chicago and Los Angeles have more than doubled in the past decade;

- Shipments from ports in each of Canada and Mexico have increased substantially in the past decade, with most terminating in Chicago and Detroit;
- There have been substantial changes in growth among shipments within the United States during the past decade. Houston is the fastest growing market, followed by Chorpus Christi, Dallas and Savannah.

Shipping costs are of great importance to container shipments. A detailed analysis of rail shipping rates indicated that:

- There have been some subtle shifts in rail container rates over the past decade. Most important is probably the realignment of the eastbound vs. westbound rates with the former increasing and the latter decreasing;
- Container rates have been relatively stable, and until the past two years, have not increased;
- Rates were relatively similar amongst west coast origins to the Midwest shipping points;
- Container rates are less than trailer rates, and the differential appears to be increasing.
- From British Columbia, the destinations with the lowest rates are Chicago, Minneapolis, Memphis and New Orleans. The others are relatively higher in cost.
- In comparison from US origins, rates from British Columbia to Chicago and Memphis exceed those from Los Angeles and Seattle; those to Minneapolis from British Columbia are less than Los Angeles, but exceed those from Seattle.

- Rate functions were estimated using econometric procedures. Results indicate:
    - Relatively good relationships, in general, and relative to similar models on grain;
    - Rates were positively impacted by distance, loaded, and ton/feu;
    - Fuel costs had mixed results and suggest that these are not fully captured in shipping rates, at least to those reported to the STB;
    - The dummy variables for railroad, origin and destination were very significant. These suggest there are highly idiosyncratic effects of these groups of variables on the underlying rate;
    - Finally, the effect of year was significant and generally suggests improvement in productivity over time.

Ocean shipping costs and technology are also changing. An empirical model was developed to analyze ocean shipping costs. Results indicate that rates were positively impacted by fuel costs, distance and charter rates, but negatively impacted by vessel size. In comparing rates among North American ports, the results indicated:

- Amongst the US west cost ports, the lowest shipping cost is to Seattle at $202/TEU, followed by Tacoma and then, Oakland and Los Angeles at $226/TEU;
- Shipping costs to Houston and New York are greater at $430 and $445/TEU respectively, in part due to the longer distances, and due to the Panama Canal fee;

- The Canadian west coat ports have lower shipping costs than US west coast, by about $25-40/TEU. The reason for this is strictly due to distance;
- The port of Manzanillo has a longer distance than most US west coast ports (except Los Angeles) and as a result will have a relatively higher ocean shipping cost;
- Combining these with US interior shipping costs indicates that for shipments to Chicago, the lowest cost routes are Seattle/Tacoma, followed by New York.

In addition to these points, there are a number of important underlying issues confronting the container shipping industry as it would impact any type of spatial modeling. First, as a result of the growth in demand, increase in container shipping capacity particularly in Asian ports, and the escalation in ship sizes, there is substantial strain, or perception of future strain, on capacity at most US ports. However it is unlikely the industry can grow at this pace indefinitely. At some time container shipping will begin to slow and approach maturity. When that occurs is highly uncertain. Second is that interport competition is critical. The ease of shifting ports by ocean shippers and/or railroads in response to congestion, capacity, draft and rail service relative to targeted US destination makes means that interport competition for container shipping is very intense. Related to this is that there are several new ports and projects emerging that will impact container flows. These include container ports at Prince Rupert, West Coast Mexico, and the expansion of the Panama Canal.

Third is that intermodal competition within the US is important. Anecdotal evidence suggests that though railroads dominate container shipments from ports trucks play a very critical role. Finally, in looking forward it is important that many of these variables and/or relationships are highly risky. Indeed, projections of demand have elements of risk, as do ocean shipping technologies (is vessel sizes and fuel efficiencies) and costs, fuel costs which impact each of the modes slightly differently. In addition, intra-modal competition, particularly amongst US railroads would suggest the importance of strategic behavior. Indeed the rail rate functions estimated indicated lots of idiosyncracies related to individual railroads, origins and destinations.

3. Features of the world grain model that it could be used for modeling containers shipments

The world grain model is a large scale nonlinear programming model of the world grain and oilseed trade. The spatial optimization model was built for purposes of analyzing prospective changes in grain shipments as a result of exogenous changes in factors impacting world grain trade and other competitive factors. In addition, it was used to generate forecasts over the next 50 years and evaluate infrastructural changes within the projection period.

The model has the objective of minimizing costs of world grain trade, subject to meeting demands at importing countries and regions, available supplies and production potential in each of the exporting countries and regions, and currently available shipping costs and technologies. Costs included are production costs for each grain in each exporting region and country, interior shipping and handling costs and ocean shipping costs. The model was respecified as a stochastic optimization model for purposes of evaluating impacts of critical uncertain variables and to derive the distributions about the forecasts. Important uncertain variables are error terms in the consumption functions, production forecasts and modal rates. Distributions about these variables were derived and integrated into the stochastic simulations.

3.1 Model Details: There are a number of important details of the mode. These are described below.

Model Components: One of the major components of the model is consumption. For each country and/or region, consumption functions were estimated. For the projection period, estimates of consumption were generated based on incomes, population and the change in income elasticity as countries mature. Consumption functions were generated for each country and grain. Import demand was defined as consumption less production. The model comprises producing and consuming regions. In addition, each importing and exporting country was defined by one port area which was the dominant port.

Costs Included: The model is a cost minimization model and the costs included are: 1) production costs for each grain at each origin; 2) modal shipping costs for shipping amongst each of the nodes in the mode. These included matrixes for rail, truck, barges (including barge rates and delay costs) and ocean shipping for international trade; 3) handling costs for exporting; and 4) production and export subsidies, and import tariffs.

Model restrictions: The model was solved subject to a number of restrictions. There are two of importance. One is the land area in each production region. The second are modal capacity restrictions applied to rail and barge. Rail restrictions were system capacity and barge restrictions took the form of delay costs.

Competition and route allocations: The model allows for detailed logistical flows, as well as determining production and land allocation decisions in US and offshore markets. The model could be used to evaluate the impacts of changes in shipping infrastructure on cropping patterns domestically and internationally, as well as trade flows. It could also be used to analyze the impacts of changes in shipping infrastructure (barge system expansions) on intermodal, interport and inter-Reach allocation of shipments. Most important from an IWR perspective is the impact of changes in infrastructure on interport, inter-modal and inter-Reach competition.

3.2 Logic to Forecasting and Assessing Impacts of Infrastructural Changes : The model was used to make forecasts and to simultaneously allow for changes in infrastructure. First a base case set of results was derived and calibrated to recent flows. Then, the model was used to make projections based on the following logic:

- Demand for grains is projected for each country and region based on income and population projections;
- Yield and production costs for each production region are projected;
- Production potential is determined in each country/region subject to the area restriction;
- Modal rates were derived for the period 2000-2004 and it was assumed that their spatial relationship was the same during the projection period.

- Ocean shipping costs were projected based on oil, trend etc.

Using these, the model was solved for each year in the projection horizon which was defined in 10-year increments for 50 years.

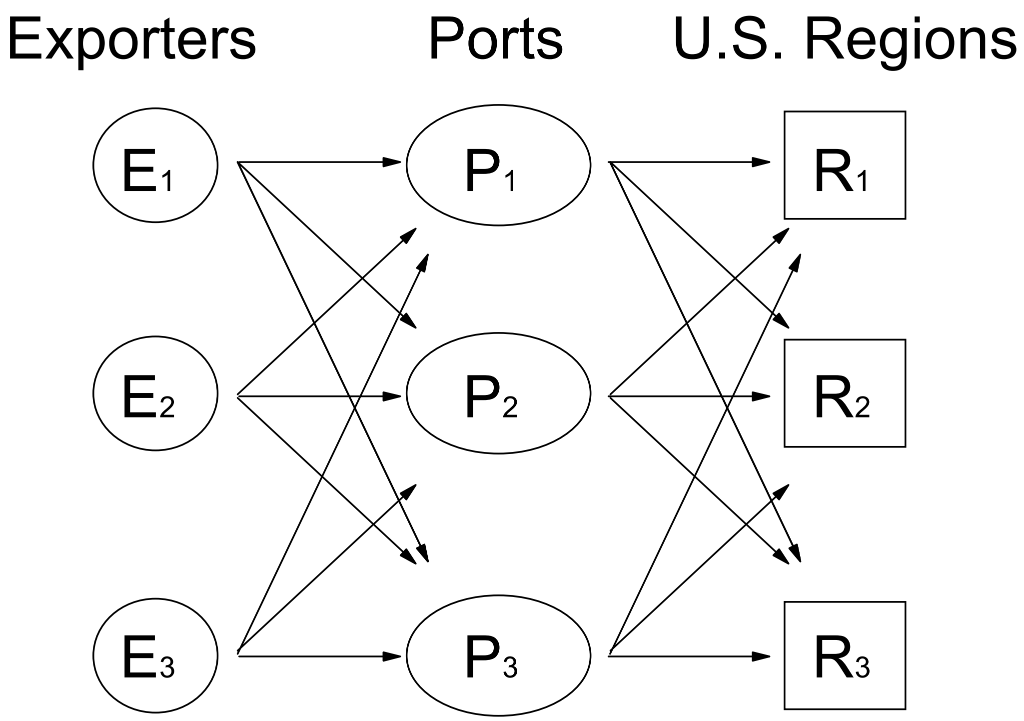
The model was also used to assess impacts of changes in barge system infrastructure. This required detailed calibration of the model relative to current flows as reflected in the base case. There were three aspects of this analysis of importance. One is that the ACE had already conducted analysis to determine delay costs for individual barge Reaches. These, when combined with the barge rate functions allowed definition of capacity on each reach. Then, through investment, the ACE could assess how this constraint would change. Second, these projects would all take 10-15 years or more and thus, any change in equilibrium had to be done during a projection period. Finally, the analysis was conducted assuming each project was made simultaneously. This is important in that there is substantial inter-reach competition. However, it is important that the results would differ if the model were to be used for evaluating expansions on individual reaches, as opposed to expanding each reach simultaneously.

4. Alternatives for Modeling Transshipment of Containers

Previous modeling efforts have often focused on 1) improved efficiency at, typically, one point in the transshipment system–such as port layout or operating procedures, while probably ignoring potential impacts on competing ports; 2) one commodity (and occasionally multiple commodities); and/or 3) are short-term focused and evaluate impacts of decisions as if they are made immediately or concurrently. We suggest alternatives to these approaches. Rather than modeling individual or even multiple commodities, we explicitly recognize that the supply and demand for container shipments are a market of its own, *regardless of the contents of the containers*.

We pose below two alternatives, each of which could be applied to analyze competition, makes projections and analyze changes in infrastructure in the case of container shipping. One uses a more traditional approach and applies cost minimization methodologies to a model with constraints. The other is a spatial price equilibrium model and is more comprehensive and can capture risk more readily. In either case, it is possible to extract from the analytical solution measures that would be relevant to the ACE-IWR in evaluating projects. A result of the cost minimization model would be a "shadow price" which could be generated for all constraints in the model. Those of greatest interest would be on port capacity. In the spatial price equilibrium model, we can define and derive a change in welfare associated with expanding ports. Comparison of either of these among ports would allow an objective means of prioritizing projects.

4.1 Cost-minimization model First we consider a transshipment model which would be most closely related to the grain model.   The objective is cost minimization to satisfy container transport demand to various U.S. regions. Graphically, this can be represented as in the figure below.



Container exports, $E_{i,}$ are shipped by ocean transport to ports at a cost. Different size ships can be included, each with different cost and capacity demands. These are shipped to ports (P_j) servicing the United States, including those in Mexico and Canada. In addition, alternative configurations including proposed "load centering" models could be included, relative to the incumbent system. Each port would have a cost, an annual capacity and constraints for transshipping, outbound logistics and draft, which would ultimately impact the ship size that could serve that port.

From the ports, containers move via rail, truck or smaller ocean vessels to satisfy final demands at U.S. Regions (R_k). Demands for containers can be estimated using spatial econometric methods (as has been done in Wilson and Sarmiento). Each movement of containers, denoted via arrows in the figure, has cost O_{ij} for movements from exporters to ports and C_{jkm} for movements from ports to regions where subscript i, j, and k denote origins and destinations and subscript m denotes mode of transport from ports to U.S. regions. These modes (m) are rail, truck and ocean vessels.

The traditional transshipment model can be extended to explicitly consider container backhauls, a crucial feature of the logistics in this industry. Containers sent to a region R_k are sent back through the transport channels to a port for export. Most often the containers are full when moving from the U.S. to another country (or exporter E_i in the figure), or a portion could be defined as loaded. Backhauls themselves represent a supply-demand system that is fully integrated with the system described above with costs for shipping each of loaded and non-loaded containers (Wilson and Dahl show these costs to depend on whether the container is loaded). In equilibrium, backhauls must equal the number of containers coming into a region R and containers leaving an export E must equal the number of backhauls to E. Further, intra-U.S. transport/backhaul of containers are intricately linked. So, backhauls introduce significant model challenges. We suggest that demand functions be estimated for backhauls from U.S. regions to "exporters." Graphically, in the figure, each arrow becomes two headed, pointing from the "destination" back to the "origin."

The objective of this transshipment model is to minimize total cost of satisfying demand for transport of containers to U.S. regions plus total cost of satisfying demand for backhaul of containers to exporters. Mathematically,

(1)
$$\max_{Q_{ijkm},\, B_{ijkm}} \quad \sum_{ijkm} Q_{ijkm} \times (O_{ij} + C_{jkm}) + \sum_{ijkm} B_{ijkm} \times (O_{ij} + C_{jkm}) .$$

where Q_{ijkm} is the total quantity of container transport from exporter *i* through port *j* to region *k* via mode *m* and B_{ijkm} is the total quantity of backhauls from region *k* to port *j* via mode *m* to exporter *i*.

Constraints are imposed on (1). Demands must be satisfied for each region. Or,

(2)
$$\sum_{ijm} Q_{ijkm} \geq \overline{Q}_k \quad \forall\, k$$

where $\overline{Q_k}$ are point estimates of the container transport demands to region *k*. Backhaul demands must be satisfied for each exporter. Or,

(3)
$$\sum_{jkm} B_{ijkm} \geq \overline{B_i} \,\forall\, i$$

where $\overline{B_i}$ are backhaul demands at exporter *i*. Port capacities are imposed as

(4)
$$\sum_{ikm} (Q_{ijkm} + B_{ijkm}) \leq \overline{P_j} \quad \forall\, j$$

where $\overline{P_j}$ are port capacities at port P_j. (We assume in this representation that port capacity constraints are additive in TEUs from transport and backhauls. The relationship may be more complex, even symmetric in nature. Further analysis is necessary to determine the nature of port capacity constraints.)

The final constraints require conservation of containers, so that the number of containers sent to a region equals the number that are backhauled from the region. Or,

$$\sum_{ijm} Q_{ijkm} = \sum_{ijm} B_{ijkm} \quad \forall\, k. \tag{5}$$

Also, the total number of containers backhauled to an exporter must equal the number shipped out. Or,

$$\sum_{jkm} Q_{ijkm} = \sum_{jkm} B_{ijkm} \quad \forall\, i. \tag{6}$$

Transport costs can be incorporated using one of two approaches, each of which has already been developed as shown in the companion report by Wilson and Dahl 2008d. The basic approach is to use matrices of costs for movements between any origin-destination pair. This approach assumes constant margin costs for container transport.

The second approach is to use estimated marginal cost functions (i.e., inverse supply equations) for each mode of transport for each origin-destination pair (like the barge rate functions in the grain model). Competition between both ports and modes of transport is then explicitly modeled, in addition to increasing marginal costs. Data needs are more expansive. In addition to demand at each U.S. region (R_k), supply functions for transport by mode (m) and potentially origin-destination pair must be estimated. Further, the relationship between marginal costs, transport and backhauls must be determined. The resulting optimization is nonlinear. The model is still a convex program, so solution is guaranteed but can require more solver time. The value of increasing port capacity is modeled by shift supply curves outward for a port(s). Simulation modeling or extrapolation will likely be used to determine how supply curves (or marginal costs) shift due to increased capacity.

In either case, a crucial parameter that would be determined analytically is the shadow price. For each constraint in the system, a shadow price can be derived. The shadow value of a capacity constraint is equal to the reduction in total costs from increasing that port's capacity by one TEU. So, it possible to determine the marginal value of increases of each port's capacity. The shadow price essentially derives the value of cost savings associated with moving from one equilibrium to another, as a result of relaxing the constraint. The intention here would be to derive this for constraints related to port handing or draft capacity. However, shadow prices of other constraints could be evaluated similarly. From the ACE-IWR perspective, these are critical in that they could be used to evaluate the value of projects that would relax the constraint. Evaluation of shadow prices amongst port projects would yield useful, objective and similarly derived results, that would allow determination of priorities among projects. Simply, projects could be compared by the shadow price.

A weakness of the cost-minimization model is that it ignores two salient realities. One, the demand (i.e., the right-hand sides of constraints given in 2) in each region is not deterministic. While point estimates can be used, there are distributions around those point estimates. The model above can be modified to consider the uncertainties in the right-sides of the model constraints via chance-constrained programming. Wilson et al. employed chance-constrained programming to model grain traffic on the upper Mississippi River system. It is, however, desirable to linearize the constraints to given solver difficulties with nonlinear constraints. Wilson et al. used Chebychev's Inequality to place conservative confidence intervals on demands and were then able to linearize their constraints. Chance-constraint programming becomes problematic when right-hand side variables are correlated as it is necessary to analytically derive cumulative joint probability functions (cdfs). Few joint densities are amenable to analytical derivation of their cdfs. Given the integration of economic activity across U.S. demand regions (with arbitrarily defined borders), it is a certainty that demands across U.S. regions are highly correlated. So, it may not be possible to formulate chance-constrained programming models to adequately reflect these correlated demands.

The second issue relates to port capacities which are not necessarily fixed. Instead marginal cost functions can be increasingly steep as throughput increases (similar to the delay curves in Wilson et al.). Eventually, the marginal cost functions may become asymptotic (i.e., nearly vertical). Given difficulties in estimating asymptotic functions, as we never observe the throughput that generates the asymptotic portion of the marginal cost function, it is convenient to model port capacity as fixed. That, however, ignores the possibility of allowing port traffic to increase, when economically feasible, beyond previously observed levels–albeit at very high marginal costs. The difficulty of estimating asymptotic functions can likely be overcome by simulation modeling, as was done for the Wilson et al. model.

In summary, the transshipment model using a cost-minimization objective has relatively low data needs (in contrast to other approaches). The method has shortcomings some of which can be addressed with additional modeling efforts–such as introducing chance constraints. Other shortcomings, such as the inability to address correlated demands, are potentially fatal to this modeling approach.

4.2 Spatial price equilibrium model A second and more elaborate method for modeling container transshipment is to use a spatial price equilibrium model. A spatial price equilibrium model is a partial equilibrium model that explicitly considers the effects of distances on prices. Transportation margins are incorporated into the analyses and reflected by prices. In the case of container transshipment, transshipment modes (rail, truck and ocean vessel) are assumed to have marginal cost functions (i.e., inverse supply functions) for transporting/backhauling containers between exporters, ports and consuming regions. Combined with transport/backhaul demand equations and transportation costs, a partial equilibrium model can be formulated to maximize total producer and consumer welfare.

Mathematically:

$$(7)\quad \max_{Q_{ijkm},\, B_{ijkm}} \sum_k \int D_k^{-1}(Q_k)dQ_k \quad + \quad \sum_i \int H_i^{-1}(B_i)dB_i \quad - \quad \sum_m \iint S_m^{-1}(Q_m, B_m)dQ_m dB_m$$

where $Q_k = \sum_{ijm} Q_{ijkm} \quad \forall k$ is the total quantity of container transport to region *k*;

$D_k^{-1}(\cdot)$ is the inverse of container transport demand to region *k*; $B_i = \sum_{jkm} B_{ijkm} \quad \forall\, i$ is the total quantity of container backhaul to exporter *i*; $H_i^{-1}(\cdot)$ is the inverse of container backhaul demand to exporter *i*; $S_m^{-1} = S_m^{-1}(Q_{ijkm}, B_{ijkm}) \forall\, m$ is the inverse supply equation for container transported by mode *m* and is a function of container transport/backhaul.[3] Demand satisfaction constraints (2) and (3) are no longer applicable. However, the port capacity constraints (4) and container conservation constraints (5) and (6) are still necessary.

The value of increased port capacity is measured by the change in the objective function (7). The model is first evaluated at existing conditions, i.e., port capacities, and total surplus found as in equation (7). Then, an individual port's capacity or a combination of port capacities are increased. The model re-evaluated to find the post-expansion total surplus. The difference in surplus (post-expansion minus ex ante) is the value of port expansion as illustrated in the figure below. By expanding capacity, the supply function shifts rightwards (as in the delay curves in the world grain model), which reduces prices and/or increases capacity. The impact is the shaded area which is the value of the increase in welfare associated with the project. This would be the approximate equivalent of the shadow price derived in the cost minimization model, and could be applied similarly.

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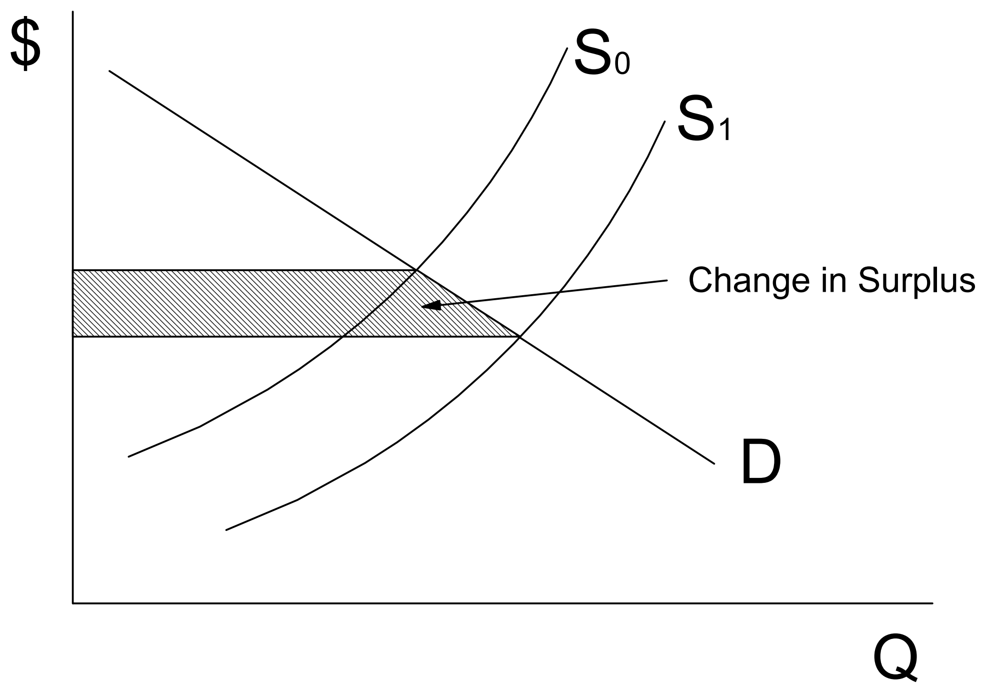
[3] The supply equations potentially vary by origin-destination pair. Further, supply equations may differ for backhauls. For brevity, we present notation that assumes otherwise. Empirical analyses will be necessary to determine the relationships and functional forms needed to represent these supply equations.



The advantages of this approach are that inter-port competition and competition between intra-U.S. transport/backhaul modes can be explicitly considered. There are variations on this approach to allow for imperfect competition between modes and ports.

Parameter uncertainty The basic model does not explicitly consider uncertainty of transport/backhaul demands. However, the partial equilibrium framework is amenable to incorporation of risk. Conditional (CSSA) and Unconditional Systematic Sensitivity Analyses (USSA) can be used to determine distributions of outcomes associated with counterfactual scenarios, *e.g.*, dredging of ports to alleviate capacity constraints or opening a new deep water port in Mexico. The first of these analyses, CSSA, is used to assess the impact of uncertainty in a small number of estimated parameters. For example, we could assess the impact of a 10 percent increase/decrease in demand parameter estimates. The CSSA analyses are ad hoc and not amenable to inference testing. The second of the analyses, USSA, is used to assess the impact of jointly varying a large number of estimated parameter values. DeVuyst and Preckel demonstrate how cubature and USSA can be used to accurately incorporate parameter uncertainty into general equilibrium models. Further, hypothesis (or classical inference) testing can be performed using Chebychev's Inequality.

Parameter estimates in supply and demand equations are uncertain as reflected by standard errors from econometric analyses. So, any result from a model employing parameter estimates are also uncertain. To address model uncertainty, numerous studies suggest a method of jointly varying uncertain parameter estimates, *USSA*. However, the largest challenge in addressing parameter uncertainty is the curse of dimensionality. As the number of uncertain parameters increases, the number of points in the joint distribution of the parameters increases exponentially. Wigle (1991) shows that an USSA with 18 uncertain parameters each represented by only 5 possible outcomes will have over 3 trillion model evaluations.

To deal with this problem, Harrison and Vinod suggest randomly sampling from the joint distribution of parameters. DeVuyst and Preckel (1997) further refine the approach to improve accuracy and largely mitigate the dimensionality problem. Their approach employs Gaussian cubature (GC) to "sample" from the joint distribution of parameters. Gaussian cubature more judiciously samples from parameter distributions than Monte Carlo methods by choosing points and probability weights to maintain the moments of the underlying joint parameter distribution. DeVuyst and Preckel also demonstrate the USSA via GC approach is more accurate than other sensitivity analysis methods. A further refinement (DeVuyst and Preckel, 2007) allows the selection of points and probabilities via linear programming.[4] A version of the USSA using GC has been implemented in the widely used GEMPACK model (Arndt and Pearson, 1998).

We offer the following example of an USSA. Let demand for a good be given as a function of its own price (P_n), a cross price (P_o) and income (I):

$$D_n = b_1 + b_2 P_n + b_3 P_o + b_4 I.$$

The b_i's are estimated and have standard errors given as SE_i. We can use the mean of the parameter values (i.e., the point estimates) and the standard errors to construct a GC approximation as described above. (Typically, supply and demand equations are reported as functions of elasticities. In these formulations, uncertainty around the elasticity, as opposed to parameter estimates, is considered.) A counterfactual scenario can be analyzed, such as an increase in income I. Demand is analyzed at each point in the cubature before and after the counterfactual shock. So, a distribution of the impact of the

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[4] To illustrate the USSA method via GC, an example is offered. W

We demonstrate a Gaussian cubature. Assume $X = (X_1, X_2, ..., X_5)$ is a vector of independently distributed standard normal random variables. Let each X_i be represented by a discrete set of points x_{ij} and probabilities p_{ij} such that $E[X_i^n] = \sum_j^J x_{ij}^n \cdot p_{ij} \quad \forall\, n \leq N.$ In short, choose a set of points and probabilities from the marginal distribution of each X_i so that the moments of order N or less are preserved. If we form the lattice of points from the marginal density with J=4, the number of points in the lattice is 1024 points. The points of the lattice and associated probabilities form an approximation to the joint density of X. The number of points and probabilities J is equal to (N+1)/2 (Miller and Rice, 1983). Arbitrarily choosing N=7, then J=4. Using a result from Haber (1970), the total number of moments of order 7 or less in the joint distribution X equals 792. So, there are more points and probabilities in the joint approximate density than are needed to determine the 792 moments and cross moments of degree 7 or less.

It is this fact that DeVuyst and Preckel (1997; 2007) exploit to reduce the number of points in the joint approximate density and still preserve the moments of order 7 or less from the joint density of X. They fix the location of the points x_{ij} to their lattice locations and use LP to choose the probabilities so that the moments of the joint distribution of X are maintained. Although the example here assumes independence of the X_i's, DeVuyst and Preckel (2007) present an heuristic algorithm for the dependent case.

shock can be analyzed. From this distribution, a mean and variance of the impact can be found. Chebyshev's Inequality then allows us to test the hypothesis of no net affect of the shock.

While this example is very simplistic, it demonstrates the power of USSA via GC. In the context of modeling transport supply and demand, systems of equations would be simultaneously estimated. Supply and demand parameter estimates and their associated standard errors would be used to find a GC approximate distribution. Counterfactual scenarios, including dredging of individual ports and multiple ports and/or the opening of new deep water ports in Canada/Mexico, would be statistically analyzed. Each point in the GC requires a model evaluation. Model results are then weighted by the probability associated with the points of the GC. Means and variances of model results are then computed and results could be used to develop confidence intervals about the conclusions. Null hypotheses of no impact on total welfare from these counterfactual scenarios would be tested via Chebychev's Inequality. For example, inference testing might conclude that dredging (or, some form of port expansion) of an individual port P_j will increase total welfare (as shown in the figure above) with 80% confidence in year 2010, 85% confidence in year 2020, etc.[5]

Intertemporal Considerations In the discussion and models above, time has been ignored. It will be necessary to project the appropriate equations and parameters fifty

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[5] The USSA method is very computationally intensive. It is likely that thousands of model evaluations will be necessary. Also, the time to program and solve the LP model that determines the Gaussian cubature approximation would be considerable.

years forward. This will add to both the information/data requirements and the computational difficulties associated with the modeling. The models present above are static. Dynamic models, while explicitly considering timing, have even higher data requirements and are exponentially more difficult to program and solve.

Inputs and Outputs The table below summarizes the inputs needed for each model (cost minimization vs. spatial price equilibrium) and the outputs that would be generated.

Inputs	Cost-min.	Spatial Price
Container demand point estimates		
for U.S. regions	YES	NO
for exporters	YES	NO
Cost matrix for container transport		
by origin-destination	Maybe	NO
by intra-US mode	Maybe	NO
Marginal cost functions for container transport		
by origin-destination	Maybe	YES
by intra-US mode	Maybe	YES
by ship size	Maybe	YES
Nodal (i.e., port) capacity	YES	NO
Marginal cost functions for port throughput		
ex ante	Maybe	YES
post-dredging	Maybe	YES
Distributions of estimated parameters	NO	YES if uncertainty is considered
Gaussian quadrature approximations	NO	YES if uncertainty is considered
50-yr Forecasts of relevant parameters and functions	YES	YES

Outputs	Cost-min.	Spatial Price
Costs of container transport by		
origin-destination	YES	YES
mode	YES	YES
total	YES	YES
Surplus of container transport by		
US region	NO	YES
mode	NO	YES
exporter	NO	YES
Number of containers transported by		
origin-destination	YES	YES
mode	YES	YES
Confidence intervals on Surplus	NO	YES

5. Issues In Modeling Container Flows

There are a multitude of issues in any major modeling initiative. This section highlights some of the outstanding issues needing resolution prior to expending effort on developing a model of container flows. First we provide a container analogy to the world grain model. Then, in the section that follows we identify some outstanding issues.

5.1 Analogous Relationships for Containers to the World Grain Flow Model: This section provides perspective on issues related to modeling containers in comparison to grain. The table below points to some of the relevant similarities and differences:

Item	World Grain Model	Container Flows	Major Point for Discussion
Geographic Scope	World; US is an exporter	United States which is an importer and exporter	Should the model be of US imports, or world trade?
Equilibrium	Determined by balancing world supplies and demands	Transshipment model to evaluate shipments to N. American ports and shipments with the US	
Demand	Determined by population and income	Determined by population, income and BEA characteristics. But, quantity consumed a final demand is not clear	BEA demand is important by the spatial demands are complex
Production Costs	Source of international competition	Not available due to not knowing content of container shipments	
Modal Shipping:	Truck, barge, rail and ocean vessels	Primarily, ocean shipping and rail. Emerging increases in vessel size that impact costs, rates and draft requirements	Inclusion of more complex shipping functions is important
Port costs and constraints	Not too relevant, though included	Very important, and vary by port	
Interport Competition	Inter-reach competition was important	Interport competition is important and analogous	

5.2 Elements of Container Flows Relevant to Model Specification: We identify and discuss below major elements of the problem.

<u>Demands:</u> Two elements of demand that are important. One is US demand for containers. These vary geographically, are dependent on income and population, as well as a number

of BEA demographic characteristics, and are spatially interdependent. These can be used to make projections for future demands for containers by BEA.

There are also off-shore demands for containers. Typically, these would vary through time in response to income and population. Hence, these demands would be projected, by importing country, based on incomes and population growth.

Supplies by US Origins: Most of the foci of this study relates to containers being shipped through ports. However, a non-inconsequential amount of containers originate and terminate within the US. In a broad view, these containers compete with container shipments that are imported.

More likely we would have to narrow the focus to import demand for containers, and make assumptions about the conditionality of the domestic demands.

US as importer and exporter and Backhauls: The US is both an importer and exporter of containers, though its import growth exceeds its exports. Nevertheless, it is important that the US operates both as an importer, and as an exporter.

As a result of this issue, as well as the definition of demands for containers, consideration has to be given to flows into a port for importing into the US; as well as into a port from US origins for exporting. These would have to be conditioned somehow in an equilibrium relationship to container backhauls. While the bilateral nature of these flows is important, whether a ports' capacity is symmetric or asymmetric with the direction of flows (into vs. from US shipping points) is also important.

Non-identity of container content and production costs: An important issue is that by-and-large, the content of containers is unknown. It is for this reason that the model specified above focused only on logistical costs. As discussed elsewhere, most containers are simply referred as FAK, or freight of all kinds. However, for rail flows within the US, most containers are FAK. As a result, it is not possible to distinguish amongst shipments by content. Further, and of importance, the production cost of the item being traded cannot be discerned. It is simply not possible to make such calculations in part, and most critically, due to that the content of the container is not apparent.

The exception is data from the Waterborne Commerce which could be used to decipher the HS codes, values, etc. However, focusing on several hundred HS codes would be very costly and time consuming.

Interior Truck Flows: There is a significant portion of flows from ports to regions apparently, within about 300 miles or so of the port area. This information is available anecdotally, and is real. However, we need some more concrete verification of the extent (origins, destinations, costs, etc.) of these shipments.

Interior Rail Rates: The rail rate structure is highly idiosyncratic suggesting there are unique factors at most markets and routes which impact the reported rate level.

Ocean Shipping: This sector is critical and will have an important impact on changes in container flows. Most important is that shipping rates can be simulated, and vary by distance, fuel costs and charter rates for container ships as well as size. Further, it will be important to allow for shipping in multiple different ship sizes, each with different costs and constraints (port requirements). Ultimately, the model would choose which size vessel would serve which routes.

A major issue is that while we have fairly good estimates for ocean shipping costs for container shipments on conventional sized ships and routes, but, this is less true for larger vessels (anything that would be post-panamax and/or new-builds).

Alternative routes: There are several routes for each possible flow. Most important is that these vary by which port the shipment goes through, which is in part impacted by port constraints, and interior shipping cost differentials in conjunction with ocean shipping cost differentials. The model would chose the optimal route.

Expansion Projects: There are several notable expansion projects which are detailed elsewhere. For purposes here, those most important are the new ports at Prince Rupert and West Coast Mexico to serve the US market, expansion of Panama Canal and numerous expansions and dredging projects at US ports, amongst others. In addition to these, alternative models such as load-centering have or are being discussed.

Each of these could be posed in the model relatively easily. However, it would be necessary to determine the appropriate costs for each. These would not be easy to develop or verify, but, would be essential to understanding how these impact the equilibrium.

6 Detailed steps necessary to complete a spatial optimization model for containers

In order to facilitate a logical discussion on how to proceed, we describe below a general overview on how to proceed to further narrowing down the scope of this project.

Kick-Off Meeting to determine the appropriate scope There are numerous outstanding issues needing decisions upon prior to proceeding. While we have reviewed all the issues, other studies and conducted preliminary analysis, it is important to include a process of further making decisions about the scope of the work. This could take place in

Washington (in which case it could seek input from relevant staff at the ACE), or in Fargo. In either case, it is essential.

To kick-it off, Wilson could provide a summary of some of the salient findings from these studies and use that as a way to get feedback from the Staff at ACE-IWR.

It is anticipated that the following issues would need decisions upon:

1) Geographic scope of the model: Is the model to be of the world or North America? And, should it be a model only of imports, or for domestic as well as imported containers.

2) Product scope: Currently the anticipation is the model would ignore its content or value and the focus is strictly upon logistical costs.

3) Relevant data needed decisions upon: There are some outstanding data items needing decisions upon. These include:
   - Use of trucks in container flows: What is the best way to document this and account for it in the model;
   - Rail rates: We need to reconcile issues to using rate matrices, or functions, and how to adjust these rates for fuel costs (which are not significant in the rate functions);
   - Ocean shipping parameterization: We developed as detailed model of ocean shipping costs as can be done with current information. There are several outstanding issues which should be resolved, including: modeling costs for routes vs. point-to-point voyages; parameters for larger vessels; and appropriateness of other assumptions in costing ocean shipping; .
   - Port costs, constraints and expansion potential: Most of this data exists in some form, or, at least approximations exist. We need discussion to determine the most efficient way to get this information. There are several areas of need: 1) handling costs or tariffs;[6] 2) annual handing capacity; 3) ship capacity restrictions (including draft) 4) potential or plans for expansion including the impact on costs and/or capacity.

   In addition to these, it will be necessary to discern if there is any way to estimate or simulate the prospective change in costs associated with expanding or not.[7]

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[6] We do have data from Waterborne Commerce that could be used to infer these and/or corroborate any information that is obtained.

[7] This would be similar to the effort by ACE to simulate added delay costs in the barge system and to which were very important in the world grain model in explaining inter-reach and inter-modal competition.

4) Analytical model or steps: Two alternative models were posed above.[8] We have to decide which of these to pursue, as well as other features of the problem. Or, alternatively, we could choose to pursue both sequentially.

Following above, the normal steps would proceed approximately as below:

Data Analysis and Development: This would include data assembly in the form necessary for the chosen model. Briefly this would include:

1) defining the geographic scope of the origins and destinations
2) developing the modal rate functions and/or matrices;
3) generating demand estimates for US BEA; and comparably for offshore markets;
4) port capacities and constraints;
5) estimation of other functions as necessary
6) developing procedures for making projections.

Model Programming:

Review of Base Case Results and Discussion:

Model Revisions:

Simulations and Sensitivities:

7. Opportunities and Issues In Modeling Container Flows Using Optimization Techniques:

There are a multitude of issues of importance to the IWR that could be addressed through spatial modeling of container flows. In the kick-off meeting, several points were conveyed. One is that though the aggregate market for containers is relatively strong, it is not possible for this to persist, nor for all ports to claim comparable growth without

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[8] In addition to these, stochastic simulation optimization could be used. However, this would only be possible if the size of the problem is kept small.

considering other ports. Second, it is very important to focus on inter-port competition and the impacts of new ports and routes on port demand in the United States. This is very analogous to inter-reach competition that was critical in the world grain flow model. Taken together, the initial ideas would be to develop a model that would focus on North America, on projections, inter-port competition and on the long-run marginal costs of flows.

Development of a spatial optimization model would be a very useful tool that could be used in a consistent way to make projections and quantify the impacts of projects. It is fully expected that other countries or organizations are pursuing this similarly. The shadow prices as defined above would provide a useful way for the ACE-IWR to prioritize projects. The model would be similar to that of the world grain model in that it seeks to minimize costs. However, there are numerous features in the North American container market that differ from the marked modeled as the world grain model as identified above.

All of the elements necessary for a spatial optimization model are available with results of the analyses conducted in this study, or identified in this study. The exceptions are noted above. These should not be viewed as insurmountable, but do require attention and discussion.

A couple are mentioned for completeness. First, this is a rapidly growing industry. Similar growth rates cannot continue indefinitely in the future. Thus, somehow the demand projections would have to be construed to allow for a slowing of growth, or at least an evaluation of the product life cycle to define points and projections for slowed growth and maturity. Second, an important missing element is truck shipments within the United States. Anecdotally, other studies have suggested about 20-40% of container flows are outbound by truck. This is nearly impossible to verify using public data. Somehow this will have to be accommodated. More likely, this may require interviews of major ports and/or evaluation of other data that we may not be aware. Alternatively, somehow we could configure the model ignoring this component. Third, it is important that there has been an increase and shift in commodities shipped by containers (i.e., containerization as discussed in Wilson and Benson). For the most important commodity codes, there have been notable shifts from non-container to containerized shipments. Somehow this will have to be captured in the model specification.

References

Arndt, C. and K.R. Pearson, 1998. "How to Carry Out Systematic Sensitivity Analysis via Gaussian Quadrature and GEMPACK," GTAP Technical Paper No. 3, Purdue University. Available at https://www.gtap.agecon.purdue.edu/resources/download/1209.pdf. Verified 17-Dec-2007.

Bureau of Economic Analysis, Department of Commerce. http://www.bea.gov/regional/docs/econlist.cfm

Clarkson Research Service, 2007. *Container Intelligence Quarterly*, London, various issues.

DeVuyst, William W Wilson, Bruce Dahl, "Grain Shipments on the Mississippi River: Longer-Term Forecasting and Risks," to the *Logistics and Transportation Review*, Submitted Sept 13 2007, invited for 2nd round of revisions (January 2008).

DeVuyst, E.A. and P.V. Preckel, 1997. "Sensitivity Analysis Revisited: A Quadrature-Based Approach," *Journal of Policy Modeling* 19(2): 175-185.

DeVuyst, E and P.V. Preckel, 2007. "Gaussian Cubature: A Practitioner's Guide," *Mathematical and Computer Modeling* 45:787-794.

Haber, S., 1970. "Numerical Evaluation of Multiple Integrals," *SIAM Review* 12:481-526.

Miller, A.C. and T.R. Rice, 1983. "Discrete Approximations of Probability Distributions," *Management Science* 29:352-362.

Quijano, J. 2007. *The Panama Canal Expansion Program*, presentation available at Port/Intermodal/Warehouse Connection, Commonwealth Business Media Inc., 400 Windsor Corporate Center, 50 Millstone Road, Suite 200, East Windsor, NJ 08520-1

Surface Transportation Board (STB) Carload Waybill Sample, 1995-2005, ACE/TVA? Container Databank.

Wigle, R.M., 1991. "The Pagan-Shannon Approximation: Unconditional Systematic Sensitivity Analysis in Minutes," *Empirical Economics* 16: 35-49.

Wilson, William and B. Dahl, 2008a *Review of Previous Studies on Container Shipping: Infrastructure, Projections and Constraints*, ACE/IWR, NETS, forthcoming.

Wilson, William and D.Benson, 2008b *Analysis of Container Flows: World Trade, US Waterborne Commerce and Rail Shipments In North American Markets*, ACE/IWR NETS, forthcoming .

Wilson , William and C. Sarmeinto, 2008c *Container Demand In North American Markets: A Cross-Sectional Spatial Autocorrelation Analysis,* ACE/IWR, NETS, forthcoming.

Wilson, William and B. Dahl, 2008d, *Container Shipping: Rail and Ocean Shipping Rates*, ACE/IWR, NETS, forthcoming.

Wilson, William and E. DeVuyst, 2008e*, Optimization Models of Container Shipments in North America: Spatial Competition and Projections (Methodology),* ACE/IWR, NETS, forthcoming.

Wilson, William W., Eric DeVuyst, Skip Taylor, Bruce Dahl, and Won Koo, 2006 *Longer-Term Forecasting of Commodity Flows on the Mississippi River: Application to Grains and World Trade* Navigation Economic Technologies (NETS), IWR Report 006 NETS-R-12 Dec 15, 2006. available at http://www.nets.iwr.usace.army.mil/docs/LongTermForecastCommodity/06-NETS-R-12.pdf

Wilson, William, Eric DeVuyst, Richard Taylor, Bruce Dahl and Won Koo,2007 *Longer-Term Forecasting of Grain Flows and Dely Costs on the Mississippi River*, Agribusiness and Applied Economics Report No. 598, Department of Agribusiness and Applied Economics, North Dakota State University, April 2007.

Wilson, William W., Won W. Koo, Richard D. Taylor, Bruce L. Dahl, 2008a "Fundamental Factors Affecting World Grain Trade in the Next Two Decades" forthcoming executive reference book *EVOLVING EXPORT SCENARIO VOL.*-II ICFAI Research Centre, October 2007 .

Wilson, William, Won W. Koo, Richard D. Taylor, and Bruce L. Dahl. 2008b "Impacts of Ethanol Expansion on Cropping patterns and Grain Flows." *Review of Agricultural Economics*.

Wilson, W., B. Dahl, S. Taylor and W. Koo, "Delay Costs and Longer Term Projections for Grain Flows Shipped on the Mississippi River." *Journal of Transport Economics and Policy*, April 18, 2007 JTEP 2229, 2nd round of revisions under review.