A Working Demonstration of a Mesoscale Freight Model for the Chicago Region

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For presentation at Transport Chicago (Chicago, Illinois) on June 1, 2012

ABSTRACT

This paper describes the development and implementation of a supply and logistics chain model that is used for modeling freight movements in the Chicago region. The current regional travel demand model handles freight truck movements with a relatively low level of sophistication. However, freight movements are important to the transportation system as well as to the economy. This is particularly true for the Chicago area, which both generates significant freight demand and serves as a freight transportation hub for distribution channels in the greater Midwest and U.S. In 2010, the Chicago Metropolitan Agency for Planning (CMAP) commissioned the development and implementation of an advanced working demonstration model, which will later be refined using observed data. The mesoscale model is the middle layer of a proposed three layered approach where high-level commodity flows are generated by a macroscale model and detailed vehicle movements are simulated in a microscale model. The mesoscale model uses an agent-based approach to evaluate goods movement decisions by individual businesses. This model links together firms to form supply chains (shipper-receiver pairs) and apportions to them the macroscale commodity flows using disaggregate level choice models, thereby generating agent-based shipments with path information that can be input into the microscale model. This model is informed by earlier frameworks, is the first implementation of its kind at an metropolitan planning agency (MPO) in the U.S., and generates a wide variety of valuable insights into regional freight transportation patterns. This paper describes the fully functional mesoscale model and discusses its potential application capabilities.

1. MODELING FRAMEWORK

This paper describes the development and implementation of a powerful and innovative prototype model of freight movements that has been prepared for the Chicago Metropolitan Agency for Planning (CMAP). The model can be applied in analyzing a variety of important goods movement decisions that are made by individual businesses. The objective of the model at this stage of development is to provide CMAP with a working demonstration of a theoretically robust framework. Calibration of the model parameters will take place in the next stage of development. This section frames the current work in the context of related previous efforts and describes their similarities and differences.

A Firm-Based Focus on Commodity Moves

Advanced regional or statewide freight models that have been implemented so far in the U.S. primarily have focused on truck tours. Truck vehicle touring models in Ohio *(1)* and Calgary *(2)* do not address the logistics handling of commodity flows. Furthermore, these models represent the perspective of carriers (i.e., they analyze the demand for trucks) rather than the underlying economic demand for the commodity itself (as this framework does). The Oregon statewide freight model *(3)* addresses logistics handling, but it replicates observed outcomes rather than explanatory models with a behavioral basis.

In contrast, the prototype mesoscale model examines commercial vehicle movements from the economic perspective of individual businesses that produce or consume goods. Choices that impact transportation and logistics use, including supplier selection and path selection, are modeled at the disaggregate level.

The Three-Layered Approach to Freight Modeling

The working demonstration model – also called the prototype mesoscale model – is the middle layer of a three-layered analytical framework. The mesoscale model will bridge the proposed macroscale and microscale models (when they are developed and implemented) as follows:

- The proposed macroscale model will use economic modeling tools to generate high-level commodity flow data that are similar to the Federal Highway Authority's Freight Analysis Framework 3 (FAF3) data.
- The mesoscale model breaks down the high-level commodity flows into a table of shipments between individual businesses using an agent based analysis and disaggregate choice modeling.
- The proposed microscale model, which will use outputs from the mesoscale model, will provide a way to examine detailed freight vehicle movements in a microsimulation environment.

This innovative multilayered framework of analytical tools is informed by earlier modeling frameworks that have been proposed and, in some instances, implemented fully or in part. These efforts include the SMILE *(4)* transport and logistics model from the Netherlands, the Los Angeles County Metropolitan Transportation Authority framework *(5)*, and the Aggregate-Disaggregate-Aggregate (ADA) framework *(6, 7)*. These frameworks view the goods movement cycle in three fundamental steps: analyzing goods production and distribution based on economic trade relationships between freight producers and consumers; evaluating logistics decisions that are made in transporting the goods between producers and consumers; and assigning the resulting vehicles to a transportation network.

The Mesoscale Layer: An Overview

Elements of the middle layer of this framework have been implemented at varying levels of detail (for example, in the SAMGODS model *(8)* and in the Freight Activity Microsimulation Estimator *(9)* (FAME) model). The CMAP mesoscale model adapts concepts from these models. Elements of the FAME implementation, notably the supplier selection formulation, and the path selection formulation from the ADA model were adapted for use in the mesocale model.

The mesoscale model analyzes regional commodity flow data at the level of individual businesses. This involves the following principal steps. First, firms that produce or consume commodities are identified (Firm Generation). Second, trade linkages between individual businesses are formed through applying choice models at the individual business level (Supplier Selection). The resulting supply chains generate the need for physical transport of commodities between suppliers and buyers. Third, during Flow Apportionment, high-level commodity flows between regions are disaggregated into total annual shipment volumes between suppliers and buyers. Finally, in Path Selection, the selection of transport and logistics paths that are used for transporting individual shipments from supplier to buyer is modeled.

The path selection model is comprehensive and is applied for individual shipper-receiver pairs. The path selection formulation uses the robust formulation of path-based transport and logistics costs that was used in the ADA framework. This formulation allows decision makers to make tradeoffs between a number of competing costs such as transportation costs and inventory costs. The formulation includes costs related to transportation, inventory, ordering, loss and damage, and stock out. This formulation can be traced back through several decades of research and includes contributions such as Roberts et al *(10)*, Winston *(11)*, and Arrow et al. *(12)* as described by Regan and Garrido *(13)*. The path selection model has been implemented in the

Mesoscale model using heuristically determined coefficients for the prototype stage of development. The next stage of model development involved calibrating these and other model parameters.

In summary, the prototype mesoscale freight model provides a powerful and innovative framework for analyzing freight movements to, from, and within the Chicago region. Following an anticipated data collection and calibration effort, the model is expected to be used by CMAP to address a variety of freight-related questions that cannot be adequately addressed by conventional modeling tools. This is because conventional models typically evaluate travel behavior at an aggregate level and generate trips only for the truck mode. For example, a typical freight travel demand model may generate truck trips based on total employment in broad industry sectors and distribute truck trips between zones based on travel time. In contrast, the mesoscale framework:

- Models the goods movement decisions of the individual business using detailed six-digit North American Industry Classification System (NAICS) industry classes to inform decision-making in the model stream;
- Evaluates transportation decisions in a holistic approach based on trade-offs among numerous factors (including travel time, distance, mode, logistics related handling, and inventory costs) that are evaluated simultaneously; and
- Includes truck, rail, water, and air modes and handling facilities within logistics paths.

The remainder of the paper is organized as follows. Section 2 provides a brief overview of data inputs to the mesoscale model framework. Section 3 further elaborates on key elements of the modeling framework. Section 4 presents the flow of the model. Section 5 describes potential applications. Section 6 summarizes the effort and discusses next steps.

2. DATA NEEDS

This section describes key data inputs of the model. First, data from readily available sources are briefly documented. Second, the network and related elements that were developed specifically for this project are described.

In lieu of data from the anticipated macroscale model, data from the Freight Analysis Framework 3 (FAF3) comprise the commodity flow input data to the mesoscale prototype. County Business Patterns (CBP) employment data and supplementary placeholder data are used to synthesize individual firms. The Bureau of Economic Analysis' Input-Output Make and Use table is used to generate correspondences between industry types and commodities.

The mesoscale model includes moves by truck, rail (carload and intermodal), water, and air. The mesoscale zone system is comprised of township-sized zones in the inner CMAP counties, county-sized zones on the fringes of the CMAP region, and FAF3 zones elsewhere (including eight foreign zones). The national network consists of a rudimentary ground transportation network containing major interstates and rail lines radial to the Chicago region (**Figure 1**) plus a sketch level Great Lakes water network. The regional truck network is relatively detailed.

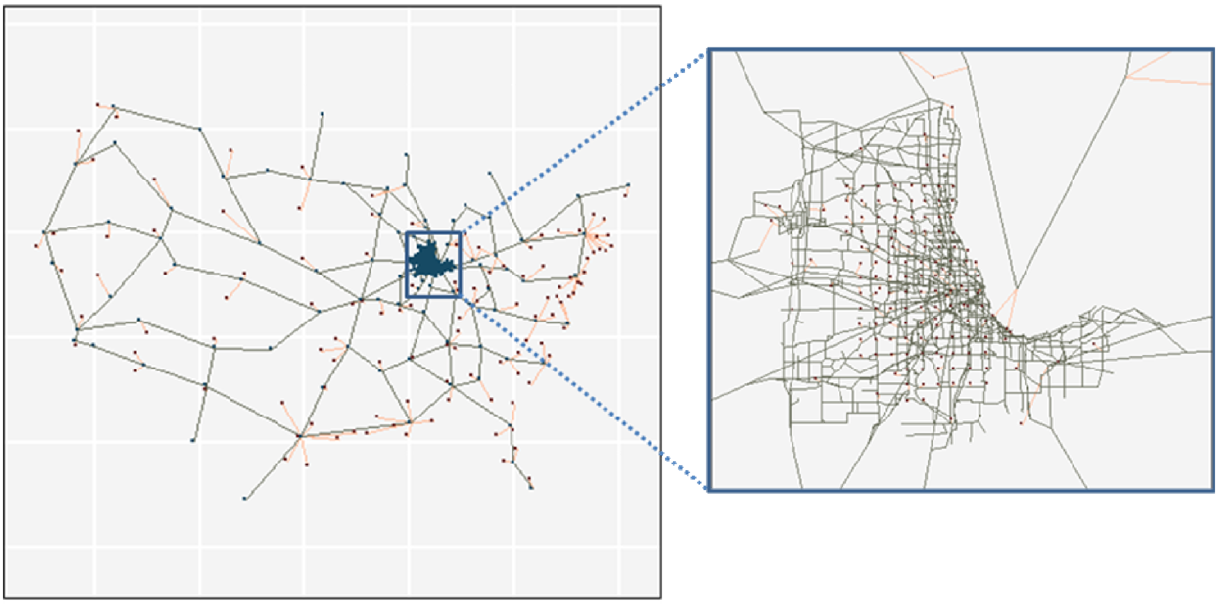

FIGURE 1 National “stick” network and detailed regional network.

Logistics nodes that represent intermediate handling facilities also were created for the prototype. These logistics nodes represent intermodal facilities such as airports, water ports, and rail intermodal yards as well as locations where other types of handling such as break-bulk handling or distribution/consolidation occur.

3. POTENTIAL APPLICATIONS AND LIMITATIONS

This section discusses examples of application capabilities of the model. Limitations of the model are also discussed.

Modeling of Policy and Project Alternatives

The mesoscale freight model framework provides a powerful and flexible framework for goods movement analysis in the Chicago region. The macroscale and microscale models, when developed, will generate additional analytical capability.

This model generates a wealth of practical information that can be used to evaluate freight related issues in the region. For example, information on mode, vehicle type, locations of intermediate handling stops, and shipment size and frequency is captured for every leg of the path that is used by each shipper-receiver pair. This information can be used for interesting analyses such as estimating the potential demand for a new cargo airport. This and other applications are discussed later.

Like other agent-based models, the mesoscale model is most powerful for analyzing the collective impact of individual choices across the modeled agents. For example, following data collection and a subsequent model calibration effort, the fully implemented model can be used to estimate mode choice under different fuel price or congestion scenarios. **Table 1** describes some examples of potential model applications and lists the types of choices being made in the model as well as suggested ways of analyzing the data. These examples include more traditional analyses such as mode choice and VMT as well as more innovative types of analysis such as evaluation of industry trading partners or a comparative analysis of the attractiveness of different logistics facilities.

TABLE 1 Examples of Potential Model Applications

Description of Analysis	Choices	Suggested Level of Analysis
Mode choice	Truckload, less-than-truckload, rail carload, rail IMX, air, water	Summarize by commodity type, distance, county, or other relatively broad category for modes used in logistics paths.
Type of logistics facility used	Rail terminal/intermodal yard, truck terminal, water port, airport	Compare tons of freight passing through different types of facilities
Location of selected facility	Variable	Compare tons of freight passing through specific facilities
Supply chain analysis	Supplier selection	Evaluate trading partners by type of industry, distance, and business size
Vehicle-miles traveled (VMT)	Path selection	Summarize by commodity type, mode, county, or other relatively broad category
Ton-miles traveled	Supplier selection	Summarize at county level
Freight volumes by rail line at regional entry/exit points	Class I railroads	Summarize by carrier, external region, and other broad categories
Freight volumes by interstate at regional entry/exit points	Interstate highways	Summarize by highway

The results can be examined at various levels of aggregation depending on the intended analytical objective. For example, in order to evaluate the demand for a proposed new airport, the number of businesses that are forecast to use existing airports versus a proposed new airport can be summarized across different levels of geography such as the entire region or by county.

Following the anticipated data collection, calibration, and validation effort, the mesoscale model also can be used to quantitatively evaluate many of the specific freight-related recommendations that were made in CMAP's 2010 Regional Freight System Planning Recommendations Study. For the study, recommendations in the broad categories of infrastructure, policy, and operations were only qualitatively evaluated based on system performance measures of accessibility, economic development, mobility and safety. This model provides a valuable analytical tool for evaluating the impacts of many of these scenarios in a more rigorous fashion.

Limitations

While this model development effort has resulted in a very promising prototype, it is still just a working demonstration and currently has the following limitations:

- First, because the macroscale model has not yet been developed, through trips (External-to-External) are not currently included in the model. This is an important source of freight traffic in the Chicago region;

- Second, a more detailed regional transport and logistics network is needed to understand logistics-related travel throughout the regional network; and
- Third, the choice models and much of the data use placeholder values. Since the model framework is very thorough, it will need and benefit from an equally thorough calibration and validation process.

4. SUMMARY AND NEXT STEPS

This paper documents a working demonstration of an advanced mesoscale freight model that has been developed and implemented for the Chicago region. The primary objective of the model is to evaluate high level commodity flows at a level of detail that is suitable for regional analysis. Choice models are invoked at the disaggregate level to evaluate the formation of business partnerships and the selection of transport and logistics paths. Transport and logistics paths are represented in a comprehensive fashion using a formulation that accounts for the simultaneous impact of each cost component on total cost on an annualized basis. Annual shipments are summarized across supply chains using the regional zone system and can be used for regional travel demand model assignments or microsimulation assignments.

The working demonstration of the mesoscale model builds upon earlier frameworks but appears to be the most complete and fully functioning implementation of this kind of model to date in the U.S. Furthermore, this effort provides several important enhancements over earlier frameworks, including:

- The inclusion of wholesale firms;
- A location model that assigns each business to a specific zone in the region; and
- A methodology that allows demand for specific logistics nodes and path types to be evaluated.

The next step of the mesoscale model development involves data collection, calibration, and validation. Model refinements are expected to occur during this process.

ACKNOWLEDGEMENTS

The authors would like to thank Kouros Mohammadian, Kazuya Kawamura, and Joshua Auld for their assistance in developing this model. Furthermore, the authors are grateful to Kermit Wies and other staff of the Chicago Metropolitan Agency for Planning (CMAP) for helping guide the development of this highly innovative and practical modeling tool.

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