Characteristics of Effective Freight Models

Mark A. Turnquist
School of Civil & Environmental Engineering
Cornell University
Ithaca, NY 14853
mat14@cornell.edu

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Preface

The conference organizers suggested that the topic of this paper should be “What makes a freight model ‘good’?”, but a slightly less presumptuous title has been chosen. The paper describes characteristics that this author believes are important in making freight models effective – that is, useful for specific intended purposes – but it stops short of asserting that all “good” models must possess all of these characteristics.

These thoughts regarding characteristics of effective models are based on personal experience from more than 30 years of building models for use in a relatively wide variety of freight contexts, and for a variety of users – shippers, carriers and public agencies. This experience is supported by both theory and common sense, but nevertheless what this paper has to say is from personal experience, and this may differ in some respects from the experiences of other modelers and model users.

Most of the experience on which this paper is based is not in freight demand forecasting, even though that is the primary focus of this conference. Some of the work that forms the personal experience base (for example, synthesizing truck origin-destination tables from link counts and other available count data) might fall into the demand forecasting category, but mostly the experience is in other aspects of freight systems – carrier operations, distribution system design, specialized operations for highly hazardous cargoes (e.g., nuclear materials), etc. Thus, the perspective in this paper is not what makes an effective freight demand model, but rather what are the important characteristics of models of freight systems. This perspective also has value for freight demand modeling, but many of the examples cited here are from models that are not focused on demand forecasting.

Modeling as an Art

Most transportation system modelers come from a scientific/engineering background. We are taught from the beginning of our technical education that models (especially mathematical models) are the appropriate way to express our understanding of “the way the world works.” This is very important and useful, but as we build models, especially of social and economic systems, we must also recognize modeling as an art.
Georgia O’Keeffe, the very well-known 20th century American painter, once commented that “Nothing is less real than realism. Details are confusing. It is only by selection, by elimination, by emphasis, that we get at the real meaning of things.” [1] She was talking about an approach to painting, but she could just as well have been talking about building mathematical models of transportation systems. We do not get to effective models by including every detail of every action that occurs in the freight transportation system every day. Effective modeling forces us to be selective in what we include, to eliminate unimportant details, to emphasize important relationships. In this way, we can “get to the real meaning of things.”

With this philosophical base as a starting point, this paper postulates four main characteristics that are important for effective modeling. These characteristics apply more broadly than just to modeling freight systems, but the present interest is there, so the subsequent discussion is grounded in that context. The four characteristics are:

1) An effective model is focused on producing an output someone wants, and knows how to use.
2) An effective model includes the important variables that describe how the system works, and represents their interactions clearly and correctly.
3) An effective model operates in a way that is verifiable and understandable.
4) An effective model is based on data that can be provided, so that it can be calibrated and tested.

These ideas probably do not seem earth-shattering, and in fact, perhaps they seem self-evident. If this is true, then the task of this paper is already half accomplished. It doesn’t have to convince you as a reader that some “bizarre” concept is true; it only has to persuade you that failure to pay attention to these straightforward ideas is quite common, and often leads to model (and modeling project) failures. In the following four sections, these ideas are discussed in greater detail in the context of freight transportation system models.

**Produce an Output Someone Wants and Knows How to Use**

In the late 1970’s, the author was part of a project team that estimated short run total cost functions for railroads. The team experimented with using some new techniques for combining engineering and econometric analysis and produced a set of models with statistically estimated parameters for predicting railroad costs. The results of the analyses were published in well-regarded economics journals [2, 3], and over the next ten years or so those papers were cited relatively frequently in other academic papers, but as far as this author is aware, no railroad manager ever used those models directly.

Thus, there is a legitimate question: Was that an effective modeling effort? The answer, of course, depends on who the “someone” is whose desires for model output are being met. From an academic perspective, other researchers could (and did) use the model output, so the question might well be answered in the affirmative. From the perspective
that is central to this conference (understanding how to transfer the state-of-the-art effectively into practice) however, it is not clear that any practitioner wanted what the project produced, or knew how to use it.

Freight models may be built with several very different ideas in mind about who will use the results, and aiming different types of modeling efforts at different users is a perfectly valid exercise. If a particular modeling effort is aimed at practitioners, it is important to understand who those practitioners are, and to know that they will understand how to use what is being produced. Often, the “user” is an organization, and the ability to use a model is subject to the culture and knowledge within that organization. This can be a major challenge.

Last year a team from General Motors, of which the author was a part, was awarded the Franz Edelman Prize for Achievement in the Management Sciences. The focus of this effort was an integrated suite of models for identifying bottlenecks in production lines at GM, so that changes could be made to increase throughput [4]. Over an 18-year period, the tools from this modeling effort have become ingrained in GM’s culture, and have produced documented cost savings in excess of $2 billion. A small group of original model builders (including the author) started this effort in the late 1980’s, but the real heroes of this story are the people who first convinced managers in a few plants to implement changes based on the model analyses. They created an internal corporate consulting group to help other plants adopt the models and change processes, and have quite literally changed the way GM managers think about production bottlenecks. This group inside GM has eventually trained more than 4,500 GM employees from around the world in the practical use of the tools.

The team that started this work foresaw very little of the eventual success. At the beginning, plant production managers and line designers in GM had some simulation tools available, but these models were difficult to calibrate and use, and as a result they were mostly ignored – especially by the people “on the firing line” in the plants. We decided to approach the problem from a different perspective, to focus particularly on potential users in the plants, and to build models that could be supported by data the plant production people could understand how to collect for themselves. It took awhile for this process to be successful; GM is a huge organization and any change takes time and persistence, but eventually the focus on making sure the users could really use the models we were producing paid off in a dramatic way.

**Including the Important Variables and Interactions**

The freight system is complex. There are many actors and modal options, a huge range of commodities being transported, and shipper-receiver locations that span the globe. It is difficult to describe concisely what elements of this complex system are most important, but one of the best short summaries available is Chapter 2 of NCHRP Report 388 [5]. While this report was published nearly ten years ago, and was written somewhat before
that, its description of the key elements of the freight system and the role of public sector planning is still highly relevant and well worth reading.

In a very aggregate sense, one of the things that is extremely important in focusing modeling efforts in freight is the change over the last 20 years in transportation and inventory costs as a percentage of national gross domestic product (GDP). This is illustrated in Figure 1, with observations at five-year intervals, except for the last. The last observation is for 2004 because the 2005 values are not yet published. Considering transportation and inventory costs together is important because their combination makes up the total logistics cost in the economy.

![Figure 1. Freight transportation and inventory costs as a percentage of US GDP. (Sources: [6] and [7])](image)

There are at least three vital pieces of aggregate information about the US logistics system discernable from Figure 1:

1) Logistics has gotten much more efficient over the last 20 years, so that logistics costs (in actual dollars) have increased much more slowly than the economy as a whole has grown, and measured as a percentage of GDP, logistics costs have decreased about 30% since 1985.

2) Inventory costs (as a percent of GDP) have decreased much faster than transportation costs over the same period.

3) Transportation costs (as a percent of GDP) have decreased more since 2000 than they did over the previous 15 years, despite the run-up in fuel costs that was quite noticeable in 2004 (and has continued with a vengeance since then).

These three observations lead to a core set of ideas about how shippers and carriers operate, and those ideas need to be incorporated into effective freight models. The first of these ideas is that shippers increasingly focus on total logistics costs (transportation plus
inventory), not just transportation costs, when they make decisions about how to ship materials across the supply chain. Paying more for faster, more reliable, transportation is a key means to reduce inventory requirements, and this has happened in a dramatic way over the last 20 years. This is a primary reason why inventory costs have fallen faster than transportation costs. This has obvious important implications for freight demand modeling, especially with respect to mode shares.

A second core idea is that the inventory-transportation cost evaluation is not done in isolation, but has significant related implications for location decisions and service quality as firms design their supply networks and product distribution networks. For example, Bowman [8] describes the efforts of Best Buy (a large consumer electronics retailer) to reconfigure their distribution center (DC) system, emphasizing customer responsiveness. The desire to provide faster delivery of products to customers, using smaller more frequent shipments, means that outbound transportation costs from the DC’s are relatively high. This creates an incentive to locate DC’s near major customers.

An integrated analysis of distribution system design, like that in [9], includes location decisions, inventory costs, transportation costs, and service quality measures in an overall assessment of how a firm might best distribute its products. For example, Figure 2 illustrates a set of tradeoff possibilities between total logistics costs (including inventory, transportation and facility costs) and “200-mile coverage” (i.e., the percent of total final demand within 200 miles of a DC) for a US automotive manufacturer. Increasing service quality (as measured by increasing coverage) is achievable at increasing total cost, and the marginal rate of cost increase is also increasing.

![Figure 2. Tradeoffs of total cost vs. service quality (% coverage at 200 miles) for DC locations. (Source: [9])](image)
Figure 3 shows the solution for 29 DC’s in this case. As indicated in Figure 2, this solution has an annual cost of $672 million (about 5% above the minimum cost solution), and covers 94% of demand within 200 miles (allowing overnight delivery to be realistic).

![Figure 3](image)

Figure 3. Illustration of locations for 29 DC’s. (Source: [9])

The implications of this integrated analysis of locations, inventory and transportation costs and service quality for freight demand forecasting are quite clear. If firms make these decisions in an integrated way, forecasts of origin-destination patterns for freight should also reflect this type of integrated analysis.

A third core idea is that carriers are getting better and better at optimizing their operations to reduce costs. Even in the face of shippers using higher cost services to reduce inventory costs, transportation costs have grown more slowly than GDP, and since 2000, the reduction in transportation costs has been quite dramatic. Continuing pressure from high fuel costs will likely produce more focus on optimizing operations in the future, as carriers continue to find ways to improve productivity of labor and physical assets, and reduce fuel consumption.

As shippers have decreased shipment sizes and increased frequency to provide improved service and reduce inventory, carriers have responded by getting better at combining shipments in vehicles using cross-dock operations, using vehicle routing software to optimize routes with multiple stops, and reducing empty equipment repositioning costs. This also has direct implications for freight flow forecasting, because the underlying decisions that carriers make (which create the vehicle flows in the transportation network) are becoming more complex, and forecasting models need to reflect that.
Models That Are Verifiable and Understandable

Most model users are not model builders, and they are not comfortable “slogging through” much heavy-duty mathematics or statistics. They do, however, have a clear need to be able to verify models that they are considering for use. Verification means that the model operates correctly – it is logically consistent and complete. This is different from validation, which is the process of determining whether the model is a sufficiently accurate representation of the real system it is designed to reflect. Verification is frequently done by a series of basic checks (“If ten trucks enter the system here, do they come out over there?”; “If this is an optimal location for a DC and it is moved a little, does cost go up?”; “If this parameter is set to zero, does the expected thing happen?”; etc.). Model builders need to do a careful job of model verification themselves, and also expect to spend time with potential users, going through similar exercises to build their confidence. It is also vital to be able to explain the output of the models in clear, logical terms.

This author has had recent experience with these issues in the context of national-level models of freight flows being used to test the performance of the system under stressful conditions (inability to use certain parts of the system, etc.). The model built to answer the questions being posed by the users (in this case, federal officials) is based on fairly “standard” network flow computations (i.e., conservation of flow equations at network nodes, time delays as a function of volume on links, etc.). The users may not appreciate the details of the nonlinear optimization methods being used to compute the network flow solution, but they can easily “trace” aggregate flow volumes and identify traffic diversions around portions of the network that are taken out of service in various experiments. The fact that model solutions can be explained in a straightforward way has served to increase confidence in its use.

This can be contrasted with the outcomes of some types of simulation studies. Telling a client that some specific outcome of the model “just happened” through unpredictable interaction of a collection of agents, does not tend to instill confidence that the modeler understands what is being modeled. Agent-based simulation (as well as other types of simulation) is a vital modeling tool, and as computing power continues to increase at an exponential rate, it is ever more useful. However, simulations need to be verifiable and understandable, just as other analytic models are. This means that careful attention needs to be paid to estimating probability distributions and other parameters of the simulations from observable data, to explaining the structure of the model to the user, and to reporting the outputs of the simulation in statistically valid ways.

Models Should Be Supportable by Data

The issue of estimating model parameters and probability distributions from real data is the fourth main point of this paper. For some modelers in the demand forecasting arena, especially those who focus on econometrically estimated models, this is almost the only
point. The structure of their data set (what variables have been included, how they have been measured, and from what population sample they have been drawn) defines the range of models they can consider. At the other extreme, there are modelers who believe and argue that the “structure” of the model is the only important part – parameters values can be guessed and data is (at best) of secondary importance.

The author does not subscribe to the view that model calibration is unimportant. One of the real lessons of the success at GM described in an earlier section is that organizing the data collection to support the modeling and making sure that people understand how specific model parameters are derived from the data are both vital activities.

In the mid-1980’s, a project at a major U.S. railroad tested a new approach to empty railcar distribution. The model was based on research done with one of the author’s Ph.D. students [10]. At the time, that railroad was creating a monthly plan for redistributing empty railcars, based on average supply and demand values at various terminals over the previous month. The new model was a stochastic optimization at a daily level, using forecast data on means and variances of daily supply, demand and travel time across the network. The project participants were confident that we were about to make a “quantum leap” in capability at the railroad. As the project began, it became clear that the company had (at that time) no way of collecting and processing data on car supplies or orders to produce the daily estimates of variability that were needed for the model. A major reformulation of the model should have been done at that stage, so that it would be consistent with the level of detail the railroad’s information systems were capable of providing, but that didn’t happen. The project team decided to “solve the data problem later” and focused on getting the computer implementation of the algorithm functioning on the railroad’s mainframe system. This was a serious strategic error, and was one of the major contributing factors in the demise of the project. This unfortunate outcome did, however, have a significant personal benefit; in subsequent projects (both relating to railroad car distribution and other modeling efforts), the author has paid much more attention to where the data will come from, how we will use it, who owns it, etc. This has proven to be a valuable lesson.

The issue of supporting models with appropriate data has a particular poignancy when freight flow forecasting in the public sector is the focus. In an earlier section, particular emphasis has been placed on how shippers make decisions as the basis for understanding and modeling how freight flows (at the commodity level) occur. There is a further argument that the translation of the demand for types of shipments (by commodity, shipment size, frequency and mode) into vehicle movements on networks is the result of increasingly sophisticated optimization by carriers. A possible response from the public sector is: “Fine, but how does a state DOT or MPO make any use of these ideas without data that shippers and carriers will consider proprietary, and which is therefore unavailable to a public agency?”

This is, indeed, a very reasonable question. Much of the experience related here has been acquired by working directly with the private companies that have the data and need to make the decisions. The standard publicly available freight data sets (the Commodity
Flow Survey, the public use Rail Waybill Sample, etc.) are woefully inadequate for the type of modeling and understanding of freight flows advocated in this paper. They are sufficient to provide aggregate checks on the types of models described here, and they can offer a very “broad brush” picture of what happened a few years ago, but they provide very little basis for modeling why it happened.

This paper does not offer a “magic bullet” solution to this problem, but there is hope that a solution is possible. This hope is based on the fact that much of the work this author has done under private sector sponsorship has been allowed to be published. This includes references [2, 3, 4 and 9] as well as other papers. Ways have been found to protect the companies’ proprietary interests and still make the work available in the public domain. This gives at least some confidence that ways can be worked out to accomplish similar things on a larger scale.

Some Conclusions and a Suggested Path Forward

It is to be hoped that through the series of anecdotes and opinions (and even a little discussion of recent data) in this paper, some valuable points have been made on how to build useful freight models. As the profession moves forward and considers what kinds of models to build in the near future, and how to implement them in practice, there are a few major trends that are also important, and which are affecting the context within which freight systems operate.

The first of these is that international freight movements are growing much faster than domestic freight movements. Over the recent past, global trade has expanded at a rate that is about 2.5 times the growth rate in world GDP [11]. For the future, this means continuing growth in containerized movements, more use of complex intermodal services, and patterns of domestic origins and destinations that are increasingly focused on ports and border crossings.

A second important trend is that increasingly global sources of production and consumption are focusing larger volumes of movement through seaports and airports. If the “domestic origin” or “domestic destination” of many shipments within the U.S. are these port facilities, it creates an incentive for U.S. companies to rethink the locations of their U.S. production and distribution facilities. This, in turn, increases the importance of the integrated view of location, transportation and inventory costs, and service quality that is described earlier in this paper.

A third major trend is coordinated decision making across the supply chain. Over the last decade, firms have made considerable strides in coordinating supply chain decisions that are within the firm. The next frontier is collaboration across firms, with suppliers and customers sharing more information regarding inventory positions, production schedules, etc. As suppliers and customers find mutually beneficial opportunities to make collaborative decisions on shipment size, timing, mode, etc., there will be a direct impact on the character of freight movements.
If the ideas expressed in this paper are carried to a conclusion (although perhaps a conclusion beyond what is justified), there is a basis for considering a method of freight flow forecasting at a regional or national level that is quite different from what has typically been used in the past. This approach would start with the integrated decisions made by representative firms as they design their supply and distribution networks, including decisions on facility location, transportation and inventory levels, and service characteristics to their customer base. For specific movements in this network, a more detailed analysis of inventory and transportation costs would be done to create representative shipment sizes, frequencies and mode choices. Then on the carrier side, these shipments would be translated (at least in a statistical sense) into likely vehicle movements on an origin-destination basis.

Obviously, there are data challenges in supporting such an approach, as described in the previous section. The one-paragraph description of the approach provided here is also far short of a full model specification. It does, however, indicate a direction in which this author believes the profession should move as we seek greater understanding of freight movements and the ability to make effective transportation policy in the public sector.

References


