IV.G

Supply Chain Management and Logistics

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CHAPTER 76
Logistics Systems Modeling

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1. OVERVIEW 2007

2. INTRODUCTION TO LOGISTICS MANAGEMENT 2007

3. LOGISTICS MODELS 2008

3.1. Logistics Network Design and Configuration 2008

3.2. Supply Chain Planning 2009

3.3. Transportation Planning 2011

4. DECISION SUPPORT SYSTEMS 2011

4.1. Input Data 2012

4.2. Analytical Tools 2013

4.3. Presentation Tools 2015

4.3.1. Geographic Information Systems 2016

4.3.2. Integrating Algorithms and GIS 2018

5. THE IMPACT OF DECISION SUPPORT SYSTEMS ON LOGISTICS MANAGEMENT 2018

REFERENCES 2019

1. OVERVIEW

Information technology is a critical enabler of effective logistics strategies. Indeed, much of the current interest in logistics and supply chain management is motivated by the opportunities that appeared due to the abundance of data and the savings that can be achieved by sophisticated analysis of these data. Thus, in this chapter we focus on models and decision support systems for logistics management that take advantage of the opportunities provided by information technology and allow companies to reduce costs and increase service levels. In particular, we review models and decision support systems for strategic, tactical, and operational decisions and look at the impact of new technology, such as the Internet, on the way decision support systems are used in practice.

2. INTRODUCTION TO LOGISTICS MANAGEMENT

Fierce competition in today's global markets, the introduction of products with short life cycles, and the heightened expectations of customers have forced manufacturing enterprises to invest in and focus attention on their logistics systems. This, together with changes in communications and transportation technologies, such as the Internet, mobile communication, and overnight delivery, has motivated continuous evolution of the management of logistics systems.

In these systems, items are produced at one or more factories, shipped to warehouses for intermediate storage, and then shipped to retailers or customers. Consequently, to reduce cost and improve service levels, logistics strategies must take into account the interactions of the various levels in the logistics network. This network consists of suppliers, manufacturing centers, warehouses, distribution centers, and retail outlets as well as raw materials, work-in-process inventory, and finished products that flow between the facilities.

The goal of this chapter is to present the state of the art in the modeling, analysis, planning, and control of logistics systems, so-called logistics management. But what exactly is logistics management? According to the Council of Logistics Management, a non-for-profit organization of logistics educator and professionals, it is:

> the process of planning, implementing and controlling the efficient, cost effective flow and storage of raw materials, in-process inventory, finished goods, and related information from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements.

This definition leads to several observations. First, logistics management takes into consideration every facility that has an impact on cost and plays a role in making the product conform to customer requirements, from supplier and manufacturing facilities through warehouses and distribution centers to retailers and stores. Second, the goal in logistics management is to be efficient and cost effective across the entire system; the objective is to minimize system-wide costs, from transportation and distribution to inventory of raw material, work-in-process, and finished goods. Thus, the emphasis is not on simply minimizing transportation cost or reducing inventories, but rather on a systems approach. Finally, because logistics management evolves around planning, implementing, and controlling the logistics network, it encompasses many of the firm's activities, from the strategic level through the tactical to the operational level.

Indeed, following Hax and Candea's (1984) treatment of production-inventory systems, logistical decisions are typically classified in the following way.

- The *strategic level* deals with decisions that have a long-lasting effect on the firm. This includes decisions regarding the number, location, and capacities of warehouses and manufacturing plants or the flow of material through the logistics network.
- The *tactical level* typically includes decisions that are updated anywhere between once every quarter and once every year. This includes purchasing and production decisions, inventory policies, and transportation strategies, including the frequency with which customers are visited.
- The *operational level* refers to day-to-day decisions such as scheduling, routing, and loading trucks.

In the next section we provide examples of three logistics models that span the three levels of decisions described above. In Section 4 we describe the key components of decision support systems (DSS) for logistics management. Finally, in Section 5 we describe the advantages and impact of using DSS on logistics management.

3. LOGISTICS MODELS

3.1. Logistics Network Design and Configuration

The logistics network consists of suppliers, warehouses, distribution centers, and retail outlets as well as raw materials, work-in-process inventory and finished products that flow between the facilities. In this section we present some of the issues involved in the design and configuration of a logistics network.

Network configuration may involve issues relating to plant, warehouse, and retailer location. As explained earlier, these are strategic decisions since they have a long-lasting effect on the firm. Specifically, in a typical logistics network model, we concentrate on the following key strategic decisions:

1. Determine the appropriate number of warehouses.
2. Determine the location of each warehouse.
3. Determine the size of each warehouse.
4. Allocate space for products in each warehouse.
5. Determine which products customers will receive from each warehouse.

We therefore assume that plant and retailer locations will not be changed. The objective is to design or reconfigure the logistics network so as to minimize annual system-wide costs including production and purchasing costs, inventory holding costs, facility costs (storage, handling and fixed costs), and transportation costs, subject to a variety of service-level requirements.

In this setting, the trade-offs are clear. Increasing the number of warehouses typically yields:

- An improvement in service level due to the reduction in average travel time to the customers
- An increase in inventory costs due to increased safety stocks required to protect each warehouse against uncertainties in customer demand
- An increase in overhead and set-up costs,
- A reduction in outbound transportation costs, i.e., transportation costs from the warehouses to the customers,

- an increase in inbound transportation costs, i.e., transportation costs from the suppliers and/or manufacturers to the warehouses.

In essence, the firm must balance the costs of opening new warehouses with the advantages of being close to the customer. Thus, warehouse location decisions are crucial determinants of whether or not the supply chain is an efficient channel for the distribution of the products. This task requires specialized solvers since it is a complex problem involving large data sets. That is, manual or spreadsheet analysis is not practical to solve most real-life problems. For example, in a simple site-selection problem requiring the identification of 5 optimal warehouse locations from a set of 25 potential sites, 50,000 different combinations must be considered. This is far too many to analyze with a spreadsheet. As Figure 1 demonstrates, the number of combinations grows exponentially as potential sites are added to the analysis.

Figure 2 and Figure 3 present two typical DSS screens that the user would see at different stages of the optimization. The first screen represents the network prior to optimization and the second represents the optimized network.

3.2. Supply Chain Planning

These planning tools determine the appropriate production, transportation, and inventory policies for a set of manufacturing plants, warehouses and retailers. Specifically, given manufacturing, warehouse and retailer locations, production, inventory and transportation costs and capacities, and demand forecasts for each retail outlet, the objective is to determine policies that achieve high levels of customer service with minimal cost.

In this case, we typically refer to three types of models:

1. *Production planning models:* efficient allocation of manufacturing resources over a period of several months to meet demand
2. *Distribution planning models:* efficient allocation of logistics resources over a period of several months to meet demand
3. *Demand planning models:* determine accurate forecasts based on historical data, understanding of customers' buying pattern, economic conditions, etc.

Evidently, these models and decisions are not independent. For instance, the production planning model relies on the quality of the data generated from the demand planning phase. It also depends

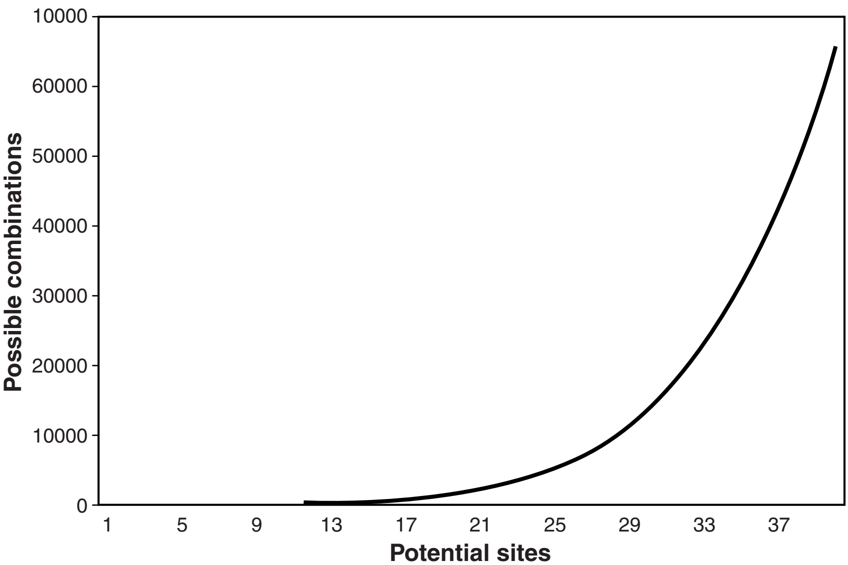

Figure 1 Number of Combinations when Locating Five Facilities in a Given Number of Potential Sites.

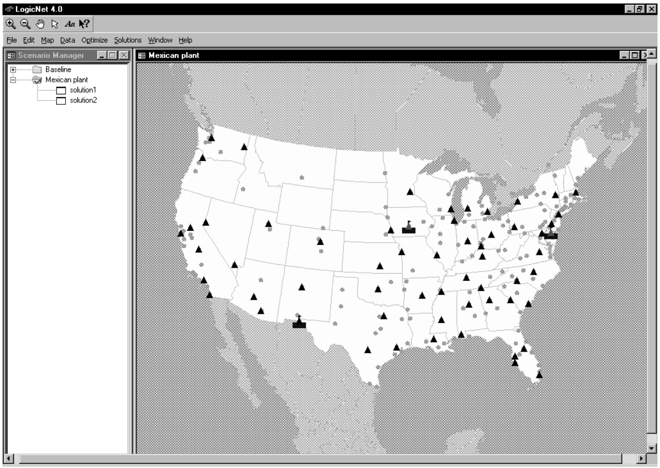

Figure 2 The DSS Screen Representing Data Prior to Optimization.

on the distribution plan since the mode of shipping, inventory plans, and deployment schedule will effect the manufacturing requirements. In addition, in many situations, there is a need to find the optimal trade-off between production timing and inventory levels. Specifically, is it more cost effective to store inventory than to work overtime in the manufacturing plants? A new breed of supply chain coordination DSS is now in the market that optimizes production, inventory, and transportation decisions by taking into account the entire supply chain.

Another key challenge at the tactical level is to take into account the dynamics of the supply chain. Indeed, in recent years many suppliers and retailers have observed that while customer demand for specific products does not vary much, inventory and back-order levels fluctuate considerably across their supply chain. For instance, examining the demand for Pampers disposal diapers, executives at Procter & Gamble noticed an interesting phenomenon. As expected, retail sales of the product were fairly uniform; there is no particular day or month in which the demand is significantly smaller or larger than any other. However, the distributors placed orders to the factory that fluctuated much more than retail sales. In addition, P&G's orders to its suppliers fluctuated even more. This increase in variability as we travel up in the supply chain is referred to as the Bullwhip effect. For more on this effect, see Simchi-Levi et al. (1999).

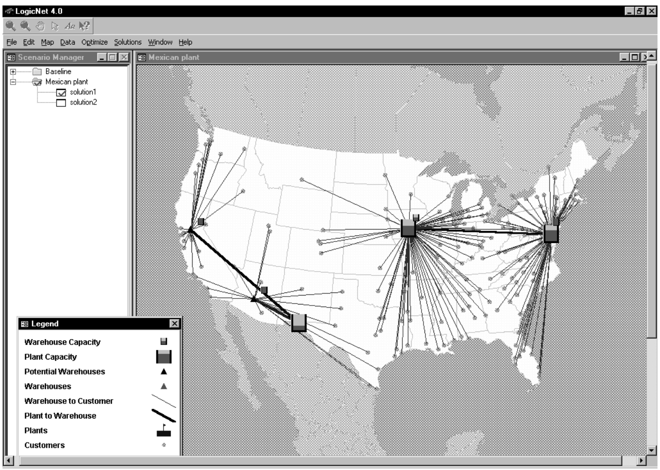

Figure 3 The DSS Screen Representing the Optimized Logistics Network.

3.3. Transportation Planning

The transportation component of logistics management is evolving into a complex process where costs are optimized at every step and sophisticated DSS are utilized to achieve efficiencies.

There are a few typical types of DSS used in the transportation planning. Some examples include:

1. *Routing and scheduling:* Streamline daily delivery operations by developing least-cost routes that meet customer delivery requirements. The DSS sums multiple routing passes to determine the best daily plan that meets the specific needs of user's operation. There are many DSS geared towards routing; however, the requirements can differ based on industry and type of transportation used. For instance, garbage pickup routes are different from a soft drink distributor's direct store delivery (DSD) routes. There are also DSS that concentrate specifically on fuel efficiency, driver swaps, and other complex aspects of routing. Figure 4 shows an example of a typical routing software map display.
2. *Mode selection:* Common transportation modes include overnight package, parcel, less-than-truckload (LTL), truckload (TL), and rail carload (CL). Each mode offers different cost and service advantages and disadvantages relating to shipment size, cost, and delivery time. For instance, TL is generally cheaper and faster than LTL but requires large loads. Shipping by air is expensive but may reduce inventory costs considerably.
3. *Carrier selection:* In situations where companies must analyze and negotiate pricing bids from carriers, there are DSS that assist with this process. Inputs are shipping requirements and carrier bid responses that handle selected lanes of freight. The DSS optimally chooses the least-cost set of carriers to fulfill the shipping volumes. A number of operational constraints such as minimum carrier commitment levels, and maximum number of carriers to select can be imposed.

Transportation DSS are evolving to accommodate for real-time needs that are pushed by on-board computers and wireless communication. In addition, data interfaces with enterprise resource planning (ERP) systems are becoming more streamlined and allow optimization of transportation decisions by considering their impact on the entire logistics network. Finally, transportation DSS also have to take into account the recent proliferation of Internet transportation exchanges.

4. DECISION SUPPORT SYSTEMS

In order to select and use decision support systems effectively, it is helpful to understand the essential pieces of a properly configured decision support system. The three major components of a DSS are the input databases and parameters, the analytical tools, and the presentation mechanism:

- The input database is a form of database with the basic information needed for the decision making. This can be a PC-based database extract designed for the specific problem, a data

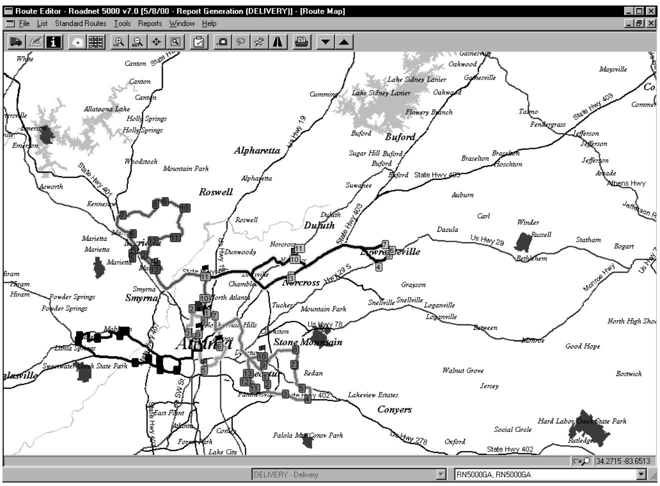

Figure 4 A Typical Routing Software Display.

warehouse with an accumulation of the company's transactions, or distributed databases accessed through a network. This database can also include certain parameters and rules such as the desired service level, hard-coded restrictions, and various other constraints.

- The data analysis usually involves embedded knowledge of the problem while also allowing the user to fine-tune certain parameters. The tools employed are operations research and artificial intelligence-based algorithms, cost calculators, simulation, flow analysis, and other embedded logic procedures. This component is the most complex because there are few off-the-shelf solvers that can deal with the huge variety of problems that companies face.
- Various database and spreadsheet presentation tools can be used to present the results of DSS analysis. Often, however, the output contains too much information, such as lists and tables, that may be too difficult for the decision maker to absorb. Therefore, various data visualization techniques are employed to enable the user to comprehend the vast quantity of output data. For example, location, routing, and sales DSS use geographic information systems (GIS) (see Section 4.3) to display complex geographic data in problems such as site location, routing and supply chain analysis. Similarly, scheduling systems use Gantt charts to display factory schedules, and simulations use animation to illustrate the relationships in the model.

All of these components are markedly affected by the planning horizon of the problem being considered. As we have seen, strategic decisions typically require long-term planning and may involve aggregation of historical data and forecasting considerations, while their analysis and presentation does not need to be particularly fast, since immediate response is not an issue. In contrast, operational decisions typically involve short-term planning, require current data, and demand fast response from the DSS.

4.1. Input Data

As in all kinds of analysis, the data used as input to the DSS is critical to the quality of the analysis. Until fairly recently, acquiring the appropriate information was in itself a complicated feat. By and large, the information-collection battle has now been won in corporate America. Extensive deployment of information systems, bar coding, point of sale, and electronic commerce have provided companies with large databases of business data. These are now often collected into huge data warehouses or smaller data marts that, along with the appropriate tools, facilitate the analysis of the data. In addition, the proliferation of networks and network access tools means that accessing various geographically distributed databases is now feasible.

Depending on the type of analysis, a DSS may require collecting information from various parts of the company. For example, supply chain network design requires both static and dynamic information from different parts of the company. The static data include plant production rates, locations of the plants, warehouses, and customers as well as warehousing costs and transportation costs, and the dynamic data involve forecasts, orders, and current deliveries. This type of information will not usually be found in one database or one department in a company.

In order to evaluate the quality of the data as well as the quality of the models built into the system it may be possible to load the current data and models into the system and see if these correspond to reality. For example, consider a truck-routing decision support system. Ultimately, the goal of such a system is to provide routes that enable the trucks to make deliveries and pickups efficiently at the required times. The model can be tested by loading the current truck routes into the system and observing whether travel times, for example, are the same as the travel times actually experienced by the truck drivers. Similarly, projected costs from the model can be compared with actual financial and accounting records. This process, typically known as model and data validation, is essential to ensure that the model and data are accurate enough. Of course, the meaning of "accurate enough" depends on the decisions being made. For more information on this issue, see Simchi-Levi et al. (1999).

In addition, the decision-planning horizon affects the detail of the data required. For strategic planning, it often makes sense to aggregate yearly data, while for short-term planning it may be best to utilize recent raw daily or weekly data. The accuracy of the solution depends on the input data, and therefore the quality of the input data will determine to some extent the tools needed for the analysis.

For instance, consider the logistics network design model discussed previously. A DSS is often used to assist in optimizing the number of warehouses required as well as their size and customer allocation to each warehouse. The DSS uses information about the distribution system to calculate the various costs related to the site selection and customer allocation. The data required for this problem involve the manufacturers, warehouses, and customers and the transportation between them. Since this is a long-term planning tool, yearly demand data and costs are typically used, but sometimes the user may need to determine how to account for seasonality. In addition, in order for this kind of DSS to be utilized successfully, the user needs to break the products into product families and specify inventory policies. This will allow calculation of the warehouse sizes and frequency of deliveries. Some of the required input data are summarized in Table 1.

It is clear that this type of data may not be readily available in the company database. Even if the data are accessible, they may not be in the required format, particularly if the DSS involves geographic display and analysis. As one might expect collecting, tabulating, and verifying the data can take some time.

4.2. Analytical Tools

Another issue that needs to be established when working with a DSS is the measures by which the various solutions will be evaluated. Reducing total cost may be a goal, but in some cases improving customer service level may be more pertinent. DSS interfaces usually allow setting these parameters and indicating the balance required by the user.

Once data has been collected, it must be analyzed and presented. Of course, depending on the DSS and the particular decision being made, there are many different ways to analyze the data. It is important for the decision makers to understand how the DSS analyzes the data, in order to assess the validity and accuracy of the DSS's recommendations. Of course, depending on the analysis, statistics can tell many different stories (see Shenk 1997 for an interesting discussion of these issues). It is up to the decision-maker to determine what analysis is most appropriate.

In what follows we examine common DSS analysis tools and techniques in general.

- *Queries:* Often, vast quantities of data make manual analysis difficult. Simply allowing decision makers to ask specific questions about the data, such as "How many clients do we service in California?" and "How many clients purchased over $3000 of a certain product by state?" often facilitates decisions.
- *Statistical analysis:* Sometimes asking questions is not sufficient. In this case, statistical techniques can sometimes be used to determine trends and patterns in the data. For example, often statistical data such as the average inventory in a warehouse, the average number of stops and length of a route, and the variability of customer demand can be useful to decision makers.
- *Data mining:* Recently, as corporate databases have become larger and more all-encompassing, new tools have been developed to look for hidden patterns, trends, and relationships in the data. Data mining, for example, produced the marketing gem that men tend to purchase beer AND diapers on Friday afternoons.
- *OLAP tools:* Online analytic processing tools provide an intuitive way to view corporate data, typically stored in data warehouses. These tools aggregate data along common business dimensions and let users navigate through the hierarchies and dimensions by drilling down, up, or across levels. OLAP tools also provide sophisticated statistical tools to analyze the data and include presentation tools as well. Mostly they are generic tools, more sophisticated than spreadsheets and easier to use than database tools, for the analysis of large amounts of data.
- *Calculators:* Simple decision support tools can facilitate specialized calculations, such as accounting costs. In many cases, more than simple calculations may not be warranted, especially if the changes are predictable and easy to evaluate. This may be the case with some product

TABLE 1 Input Data for Logistics Network Design

Component	Data
Manufacturer	location production capacity and cost transportation costs to warehouses
Warehouse	location fixed costs variable costs (labor, utilities) inventory turnover transportation costs to retailers
Retailer	location annual demand by product
Product	volume weight holding cost

types for forecasting or inventory management, while for others more sophisticated tools may be needed.

- *Simulation:* All business processes have random components. Sales may take one value or another. A machine may or may not fail. Often these random, or stochastic, elements of a problem make analyzing it very difficult. In these cases, simulation is often an effective tool to help with decisions. In simulation, a model of the process is created on a computer. Each of the random elements of the model (sales, failures, etc.) is specified with a probability distribution. When the model is run, the computer simulates carrying out the process. Each time a random event occurs, the computer uses the specified probability distribution to randomly decide what happens.

  For example, consider a simulation model of a production line. As the computer runs the model, a series of decisions is made. How long does a job take on machine one? On machine two? Does machine three break while job four is being processed on it? As the model runs, statistical data (utilization rates, completion times, etc.) are collected and analyzed. Since this is a random model, each time the model is run, the results may be different. Statistical techniques are used to determine the average outcome of the model as well as the variability of this outcome. Also, varying different input parameters allows different models and decisions to be compared. For example, different distribution systems can be compared utilizing the same simulated customer demand. Simulation is often a useful tool for understanding very complex systems that are difficult to analyze analytically.
- *Artificial intelligence:* Artificial intelligence tools may be employed in the analysis of DSS input data. These may be databases of rules collected from experts that can be applied to specific problems, or online intelligent agents. The former systems are often used to solve technical problems, such as troubleshooting a computer failure or a complex chemical procedure, while the latter are more appropriate for managing different components in the supply chain. Following Fox et al. (1993), we define an agent as a software process whose goal is to communicate and interact with other agents so that decisions effecting the entire supply chain can be made on a global level. Indeed, a number of DSS for supply chain management can be viewed as using intelligent agents to plan and execute different activities in the supply chain. These systems are characterized (see Fox et al. 1993) by the following interrelated issues:

- The activities allocated to each intelligent agent (i.e., software processor)
- The level and nature of interactions between the different agents
- The level of knowledge embedded within each agent

For instance, a real-time supply chain planning tool involves the following components. Intelligent agents are located at each facility and collect information about this facility as well as enable planning and scheduling for the facility. In this case, facilities include manufacturing plants and distribution centers. Each agent interacts with other agents so that they can balance excess capacity at different plants, find missing parts, or coordinate production and distribution. A central planning agent communicates with the agents at each facility to collect status information and relate central planning decisions. The type and level of decisions made by the agents as opposed to human operators, as well as the frequency and level of communications among the agents, depends on the specific implementation.

- *Mathematical models and algorithms:* Mathematical tools, often from the discipline of operations research, can be applied to the data to determine potential solutions to problems. For example, these tools may generate the best set of locations for new warehouses, or an efficient route for a truck to take, an effective inventory policy for a retail store. These algorithms fall into two categories:
- *Exact algorithms:* Given a particular problem, these algorithms will find a solution that is mathematically the best possible solution. In general, these kinds of algorithms may take a long time to run, especially if a problem is very complex. In many cases, it is impossible to find the optimal, or very best, solution. In other cases, it may be possible but not worth the effort. This is because the input data to these algorithms is often approximated or aggregated, so exact solutions to approximate problems may be worth no more than approximate solutions to approximated problems.
- *Heuristics:* These are algorithms that provide good, but not necessarily optimal, solutions to problems. Heuristics typically run much faster than optimal algorithms. Most DSS that use mathematical algorithms employ heuristics. A good heuristic will rapidly give a solution that is very close to the optimal solution. Often, heuristic design involves a trade-off between quality of solution and speed. If is often useful if in addition to the solution, the heuristic

provides an estimate of how far the heuristic solution is from the optimal solution.
See Simchi-Levi et al. (1999) for additional discussion on exact and heuristic algorithms.

The analytical tools used in practice are typically a hybrid of many of the tools described above. Almost all decision support systems will offer a combination of tools, and many will allow further analysis using generic tools such as spreadsheets. Note that some of the tools listed above may be embedded in generic tools, such as spreadsheets.

Of course, most DSS employ analytical tools that have some specific embedded knowledge of the problem being solved. Since these problems are usually complex, the DSS employs its problem knowledge to find efficient solutions.

There are many factors that dictate the appropriate analytical tools selected for a particular decision support system, including:

- The type of problem being considered.
- The required solution accuracy—there may be no need to find the optimal solution.
- Problem complexity—some tools may not be appropriate for very complex problems.
- The number and type of quantifiable output measures.
- The required speed of the DSS. Particularly for operational systems such as lead-time quotation and vehicle routing, speed may be essential.
- The number of objectives or goals of the decision maker. For example, a DSS for truck routing may need to find a solution with the minimum number of vehicles such that total distance traveled is as short as possible.

Applications for DSS are extremely varied, and each problem will typically use a different mathematical tool. In Table 2 we describe some of these applications and the type of tools that would typically be used. Most of these problems are extremely complex, and seemingly similar problems could require a different approach.

Consider the logistics network design problem described in the previous example. For this problem, heuristic approaches as well as optimization based techniques have been developed in the last few years. The choice between heuristics and optimization depends on the complexity of the specific problem as well as on the various modeling issues, such as service level, that the user wishes to consider. For instance, optimization-based techniques may be limited in the size of problem they can handle as well as in the number of parameters and special cases they can consider. Finally, some solvers also combine heuristics and optimization.

4.3. Presentation Tools

These are the tools used to display the data to the decision maker. There are a varied number of formats including:

- Reports
- Charts
- Spreadsheet tables
- Animation

TABLE 2 Applications and Analytical Tools

Problem	Tools Used
Marketing	Query, statistics, data mining
Routing	Heuristics, exact algorithms
Production scheduling	Simulation, heuristics dispatch rules
Logistics network configuration	Simulation, heuristics, exact algorithms
Mode selection	Heuristics, exact algorithms

- Specialized graphic formats, e.g., a layout of a floor plan
- Geographic information systems

The reader is likely to be familiar with most of these items. Reports, charts, and tables are of course very common. Animation is often used as a tool to present output of the simulation models described above. This helps the user verify the validity of the simulation model and understand the simulation results. Specialized graphic formats are, of course, extremely dependent on the nature of the problem being solved. For example, a facility layout DSS may present a suggested floor plan for a new facility.

Of course, particularly in the area of supply chain management, much of the output of DSS is geographic in nature. For example, logistics network design, sales territory analysis, and truck routing software all include geographic-related output. In the last few years, geographic information systems (GIS) have become more and more common as the presentation vehicle of choice for many supply chain management decision support systems. In the following we describe GIS systems in more detail.

4.3.1. Geographic Information Systems

A geographic information system (GIS) is an integrated computer mapping and spatial database management system that provides a broad array of functions for the storage, retrieval, management, analysis, and display of geographically referenced data.

Typical GIS capabilities include:

- Mapping and thematic mapping
- Database management
- Interactive data query
- Spatial data retrieval
- Geographic data manipulation
- Spatial data analysis
- Geocoding
- Geographic data import/export
- Buffering/polygon overlay

The advantage of using a GIS platform is that it combines database, query, and reporting tools as well as geographic display and analysis. In logistics modeling, GIS has the further advantage of allowing automated distance and travel time calculations. Some limited forms of GIS are now included in spreadsheets (Excel 7.0) but are not as extensive as the full-blown packages. These systems originally came only on high-end UNIX workstations, but there are now many excellent, relatively inexpensive systems that run on PC platforms and networks. A major issue in deploying GIS is the availability and quality of the geographic data. Excellent data, with information about the geography, street networks, and census information, are available for the United States at a very low price. However, in other countries the data itself may not exist or may be tightly held so that they can be a major expense and deterrent to the effective use of GIS. Even in the United States the data may not be perfect for every application or may be outdated and need to be upgraded to be used effectively.

Originally, GIS was extensively used in applications such as:

- Market analysis
- Census and demographic data analysis
- Real estate
- Geology
- Forestry

More recently, however, GIS has found application in areas of potentially more interest to the supply chain manager, such as:

- Network analysis—transportation, telecommunications
- Site selection
- Routing
- Supply chain management

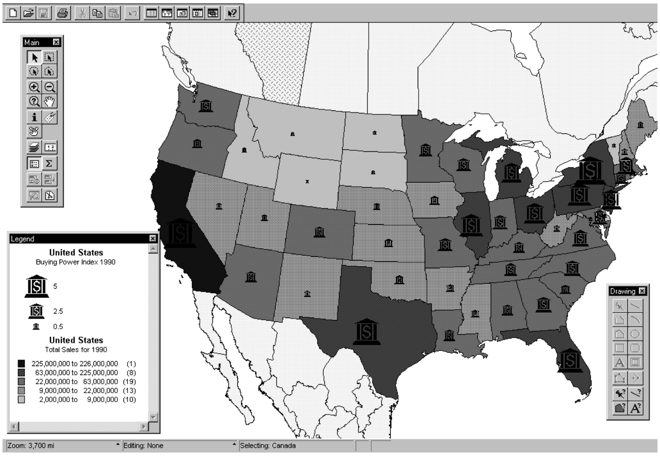

Figure 5 A Typical GIS Interface.

Figure 5 presents a typical GIS interface. The screen includes a thematic display of a typical marketing application with data on 1990 U.S. buying power index given by state.

Not surprisingly, there are special considerations when using GIS in logistics modeling. Often, time must be spent geocoding and estimating travel time. Geocoding is the translation of addresses into geographic coordinates. Geocoding requires databases that can assist in the translation. Although widely available in the United States, these data may be hard to come by in other countries. In order to prepare customer data for use by a DSS, this step is required and may be lengthy, depending on the quality of the address data.

In most logistics applications, it is necessary to use the distance between two locations in order to estimate travel time and transportation costs. This can be done in several ways. One is to calculate the straight-line distance between the two coordinates and multiply it by a factor that estimates the circuity of the roads between the two points. This, of course, is a very simplistic approach, and it does not require more information than the coordinates. In this case, the DSS typically apply different factors for different zones. Another way to calculate travel distance is to use the actual road network, identify the best route, and determine the distance. This requires extensive accurate information about the road network, including one-way streets and other details. It is also an extremely time-consuming process to calculate the network even for a moderate-sized problem.

In both types of calculations, assumptions need to be made about the speed of travel in order to estimate the travel time. It is always possible to let the user enter the travel time between each pair of locations in the model, but this is usually not practical in large problems.

Although users of routing systems may demand a road network since it intuitively seems to be a more accurate solution, experience has shown that this approach may not produce significantly better results than using estimates of the distance. This is true even in shorthaul distances and inner city routing, such as school bus routing. See Table 3 for an analysis of road vs. estimated distances.

DSS may come with an embedded GIS or use a commercial GIS as a platform or server for presentation of geographic data. The U.S. geographic data available are mostly based on TIGER/line files. TIGER stands for Topologically Integrated Geographic Encoding and Referencing, for the system and digital database developed at the Census Bureau to support its mapping needs for the

TABLE 3 Road and Estituated Distance

Item	Estimated distance	Road Distance
Data	Cheap	Expensive
Complexity	Low	High
Accuracy	Medium	High
Speed	High	Low

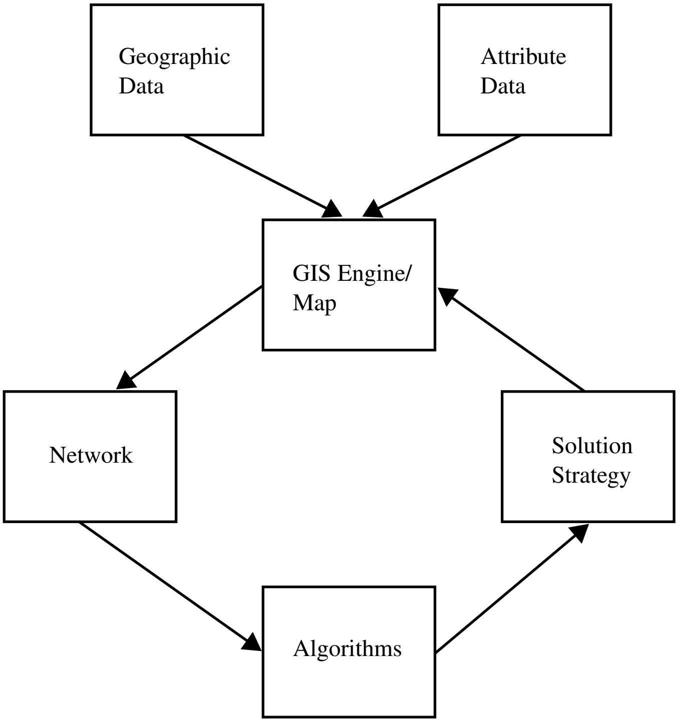

Figure 6 A General Framework for Integrating Algorithms and GIS.

Decennial Census and other Bureau programs. The TIGER/line files are publicly available extracts from the TIGER database. Most GIS vendors allow the user to load these files or distribute their own versions and formats based on this data. There are otherwise no agreed-upon standards for geographic data representation apart from the leading vendors' formats, which can usually be converted from one system to another.

4.3.2. Integrating Algorithms and GIS

As mentioned earlier, GIS has found application in areas important to supply chain management. These include logistics network design, routing, and mode selection. The idea in all these applications is to integrate the GIS with mathematical models and algorithms. Figure 6 provides a schematic representation of such a system.

In such a system, geographic data are provided by the GIS while attribute data, including demand information, costs, production and storage capacities, are downloaded from standard databases. This data is sent to the GIS engine that is the heart of the system. The engine constructs a symbolic network that represents the various relationships among the components of the supply chain. The network is then used by a collection of exact and heuristic algorithms to generate a number of solutions or strategies minimizing various objectives and satisfying all the constraints in the system. These solutions can be viewed, modified, and analyzed by the user so that the most appropriate one is implemented.

What are the advantages of integrating GIS and mathematical models and algorithms?

1. The system allows the user to visualize the data and the model and thus verify that they truly represent the supply chain environment.
2. It provides accurate street-level database (if needed) including one-way streets and turn difficulties.
3. It allows the user to visualize the solution and strategies generated by the system.
4. It allows for sensitivity (what-if) analysis.

5. THE IMPACT OF DECISION SUPPORT SYSTEMS ON LOGISTICS MANAGEMENT

In the last few years, we have seen many companies investing in, and relying on, decision support systems. The reason, of course, is these companies are trying to become best-in-class. As observed recently by PRTM Director Mike Aghajanian, "For a company with annual sales of $500 million and a 60% cost of sales, the difference between being at median in terms of supply chain performance and in the top 20% is $44 million of additional working capital."

Of course, the main reason companies use DSS is to reduce cost and increase service level. Indeed, reducing cost in the supply chain is a key challenge because, as observed by Rick L. Adams, VP Logistics, Grainger Industrial Supply, "A 5% cost decrease has the same impact on profit as a 30% increase in sales."

Thus, it is no surprise that logistics management has been transformed in the last 10 years from a largely manual process to a more automated one. Major advances in computer and communications technology and the introduction of the Internet and e-commerce have effected this trend. These developments provide new opportunities and increase expectations for a fast and flawless logistics process. The Internet also provides new models in how information systems are deployed. For instance, companies may not need to own the sophisticated DSS—they are able to lease them based on their needs. This mode of deployment is now referred to as application service provider (ASP) and is considered one of the most important trends in information systems, especially for mid-sized companies who cannot afford expensive systems.

We summarize the article with major trends that many experts (see, e.g., Shepard and Lupide 1999) envision for the future in applying DSS for logistics management:

1. The utilization of DSS will increase at all levels of decision making. The DSS will provide decision makers with assistance in quickly making effective decisions.
2. DSS will need to handle real-time data and must have a short processing time so that users can respond in the time frame that drives their business. As we have seen in transportation planning, this is an important issue in operational systems.
3. DSS will become better integrated with user's ERP and other management systems. This will allow users to access DSS information seamlessly in order to provide better customer service.
4. Users require better visibility of their data so that systems will provide users with accessible interfaces to their data in various formats and at different aggregation levels. In order for DSS to become effective, they will need to provide this capability or link with tools that already have that capability.
5. Users require collaborative tools—DSS will need to allow for collaboration in the same company and across different companies. One of the first tools in this area is the forecasting portion of collaborative planning forecasting and replenishment (CPFR), which allows partner companies to collaborate on forecasting and utilizes a DSS that assists in finding discrepancies in the process.
6. DSS at various levels will need to become better synchronized so that decisions at the strategic, tactical, and operational levels are all coordinated and accessible. As we have noted, it is difficult to perform efficient production planning without coordinating with demand planning and distribution planning.

This chapter is based on, and borrows extensively from, two chapters from our book *Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies,* which was written together with Philip Kaminsky and published by McGraw-Hill in 1999. The chapter is also based on material from *The Logic of Logistics,* by Julien Bramel and David Simchi-Levi, published by Springer in 1997. In both cases this has been done with permission from the copyright holders. Research supported in part by ONR Contracts N00014-90-J-1649, N00014-95-1-0232, and N00014-01-1-0146, NSF Contracts DDM-8922712, DMI-9322828, DMI-9732795, and DMI-0085683.

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