Technical White Paper Series

The Logistics Institute at Georgia Tech

Logistics Composite Modeling

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Audience: This paper is intended for logistics analysts, practitioners, consultants, and other logistics professionals who wish to learn about high-level concepts for logistics modeling and analysis.

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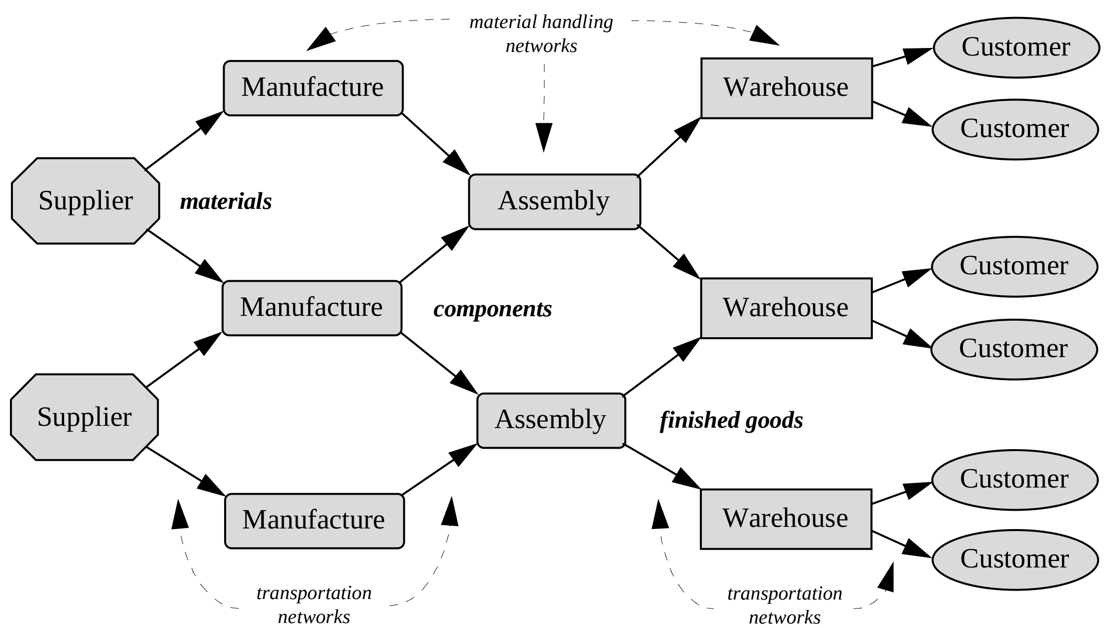
The Logistics Supply Chain

Logistics

What is a supply chain?

A *supply chain* is the collection of all components and functions associated with the creation and ultimate delivery of a product or service. ■ Figure 1 illustrates an example product supply chain.



■ Figure 1
An example logistics supply chain. Transportation networks move goods among facilities; material handling networks move goods within facilities.

What is logistics?

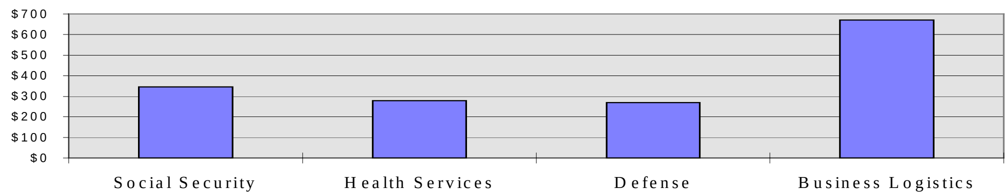
Logistics is the collection of activities associated with acquiring, moving, storing and delivering supply chain commodities (i.e., products in all stages of manufacture, services and information).[1] Logistics encompasses the business functions of transportation, distribution, warehousing, material handling, and inventory management, and interfaces closely with manufacturing and marketing.

Logistics supply chains (also called *logistics systems* or *logistics networks*) arise in numerous business segments and government functions, including: manufacturing firms, retailing firms, food producers and distributors, the military, transportation carriers (such as trucking and railroad companies), service companies, postal delivery, utilities, petroleum pipelines, and public transportation, among others.

Significance of Logistics

Logistics is a key business function for many reasons, including the high cost of operating a supply chain. Estimated total logistics costs incurred by United States businesses in 1993 was 670 *billion* dollars[2], or roughly 11% of the U.S. Gross Domestic Product (GDP). This cost is higher than the annual U.S. government expenditures in social security, health services, and defense (■ Figure 2)[3].

■ Figure 2
U.S. business logistics costs compared to major federal expenditures (1993, in billions).



Beyond costs, business logistics is *increasing* in importance due to the following:

- *Deregulation*. In the U.S., transportation (including rail, trucking, and air modes) has shifted from a highly regulated to an increasingly free market industry. The result is more choices and complexity regarding logistics services and costs, and more opportunities to improve business operations.

- *Global Markets*. The business marketplace is increasingly global in scope, with world trade projected to increase from four trillion U.S. dollars in 1993 to over 16 trillion dollars by 2010[4]. Moving products from point of origin to point of consumption on a global scale has obvious logistical challenges. Further, manufacturing wages vary widely among countries, adding complexities in determining smart locations to produce goods. For example, the average manufacturing wage is projected to be $25.40 in the U.S. in the year 2010, compared to $45.80 in Germany, and $4.00 in Mexico[5].

- *Customer Service*. Deregulation, global markets, and other factors create a more *competitive* business environment, resulting in the need for supply chains that can deliver products quickly and accurately and can adapt to rapid market changes.

- *Environment*. Current and future environmental regulations have significant implications on logistics, and may fundamentally impact the locations of facilities including plants, storage facilities, and recycling centers.

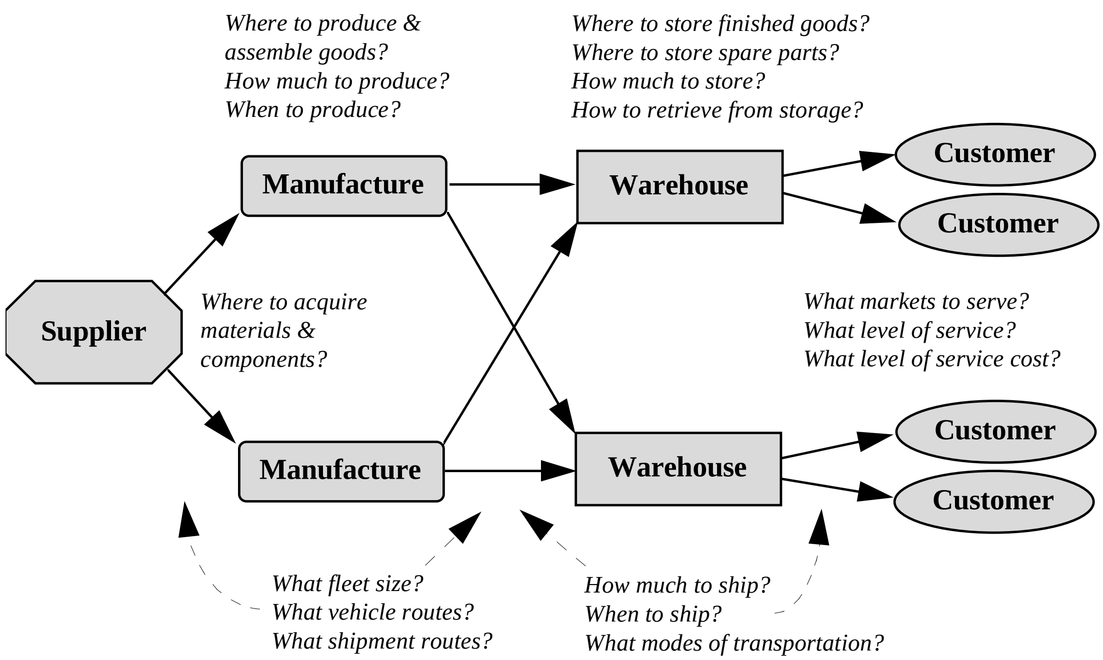
- *Technology*. Accelerating advances in technology significantly change and improve logistics operations. Examples include automated bar code tracking of equipment, management of transportation assets via satellite communications, electronic commerce, and computerized decision support.

Logistics Decisions

Types of Logistics Questions

What are key logistics decisions?

■ Figure 3 illustrates fundamental questions arising in the design and operation of a logistics supply chain:



■ Figure 3
Some of the key questions faced in designing and operating a logistics supply chain.

While this is only a sampling of logistics questions, the questions lead to a wide variety of difficult issues involving the design and operation of logistics systems. Most of these logistics decisions embody five fundamental characteristics:

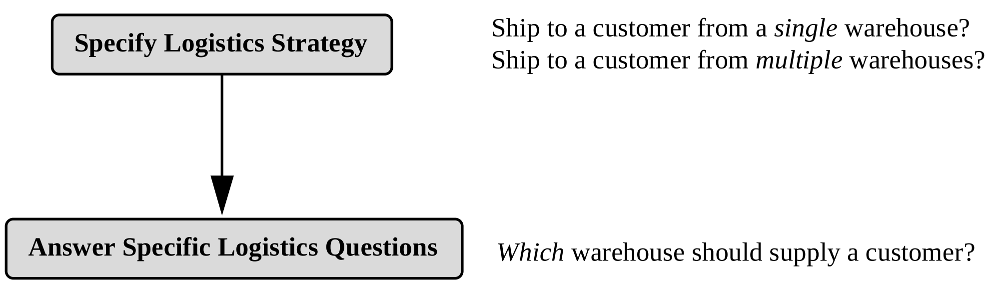
1. *Multiple* business functions are impacted.
2. There are *tradeoffs* among conflicting objectives.
3. Logistics system impacts are difficult to *precisely* evaluate.
4. There are business issues *unique* to each logistics system.
5. *Quantitative* analysis is essential for intelligent decisions.

Logistics strategies narrow down allowable logistics options

■ Figure 3 illustrates *specific* logistics questions - at a higher level, an organization must select appropriate logistics policies or *strategies* to support the company's financial, service, or other goals. Logistics strategies provide a framework for the type and scope of specific logistics decisions. Often, choosing the right strategy is more significant (from a financial or customer service standpoint) than optimizing specific lower-level decisions.

As an example, a common distribution strategy is to ship all products to a customer from a single distribution center (DC). Another common strategy is to ship to a customer from multiple DCs. Choosing the best DC(s) to serve the customer is a specific logistics decision in either strategy, but the allowable choices are shaped by the respective strategies (■ Figure 4). (The *Logistics Strategies* section discusses contemporary logistics strategies in more detail.)

■ Figure 4
At one level companies must choose smart logistics strategies, implying specific logistics questions to answer.



The following section describes a simple case study designed to illustrate a particular set of questions and an associated analysis. Subsequent sections generalize and organize ideas in this case study analysis into a logistics modeling framework.

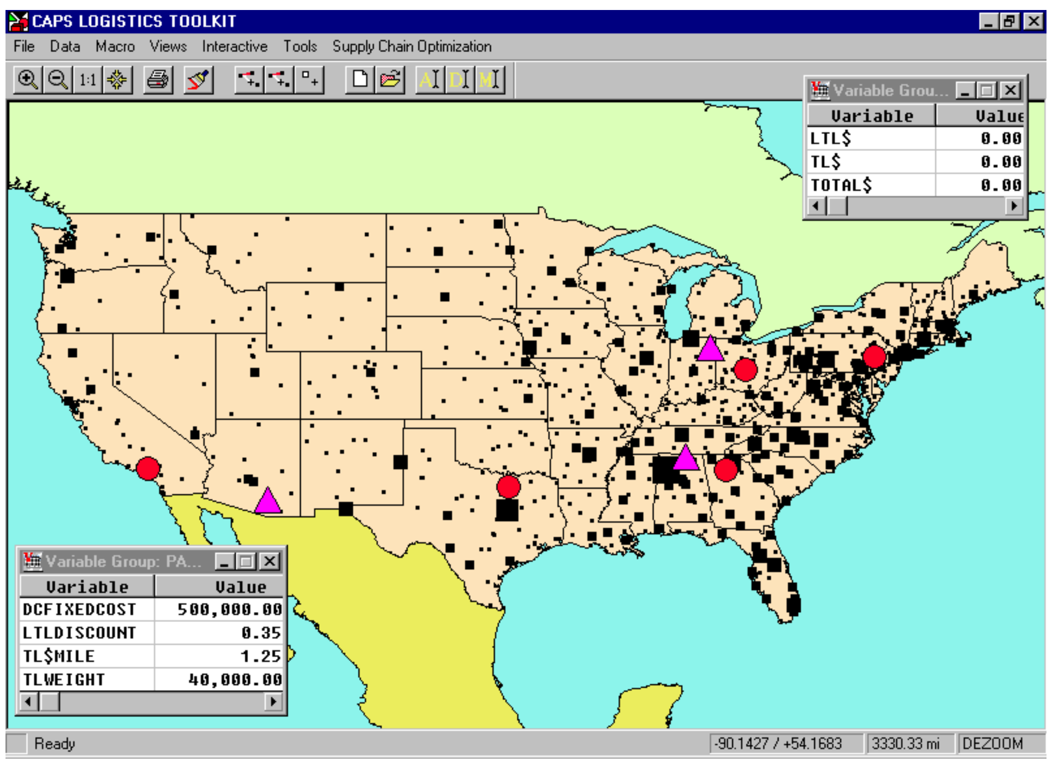
Case Study Illustration

Background

Sheridan Technologies, Inc. is an industrial products company operating three plants in the United States, located in Huntsville, Alabama; Fort Wayne, Indiana; and Tucson, Arizona. The plants are dedicated to product groups A, B, and C, respectively.

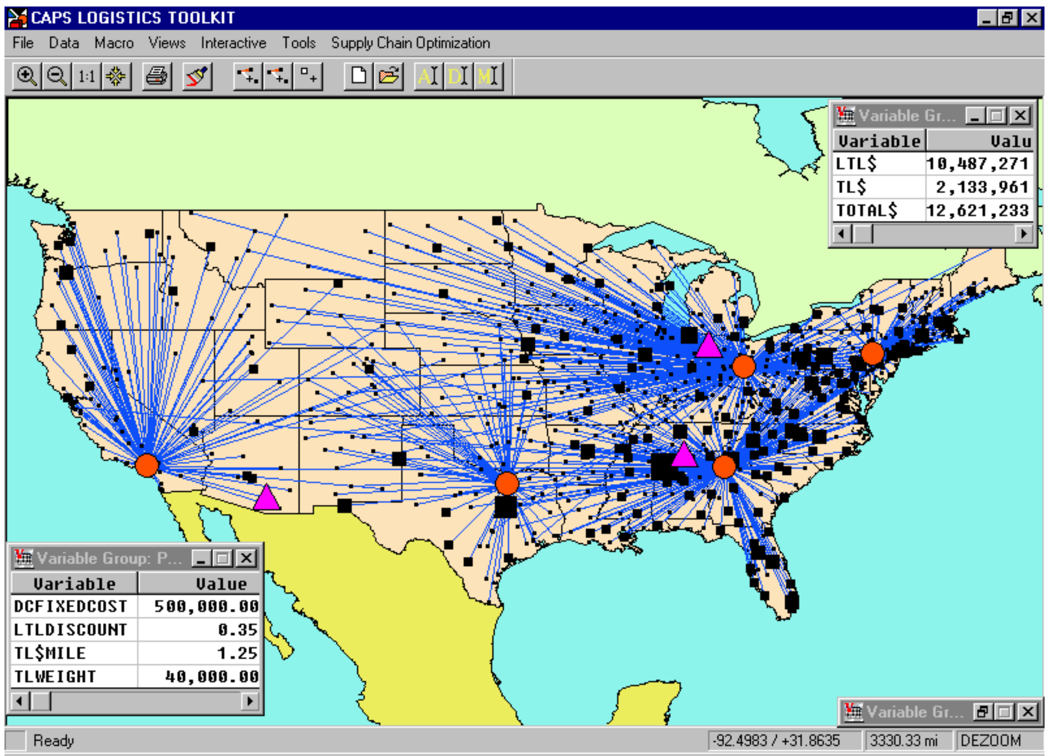
The plants ship finished products in Truckload (TL) quantities to five DCs, located in Allentown, Pennsylvania; Atlanta, Georgia; Columbus, Ohio; Richardson, Texas; and Covina, California. The company groups customers into three-digit ZIP code territories, with each ZIP3 assigned to a single DC. The company ships via Less-Than-Truckload (LTL) common carriers out of the DCs, typically weekly for each customer.

■ Figure 5 illustrates the company's current supply chain facilities and customer groups. Note the customer groups are scaled to relative average order quantities.



■ Figure 5 Facilities composing the Sheridan Technologies supply chain - plants are triangles, distribution centers are circles, and customer groups are squares.

■ Figure 6 illustrates the company's current assignment of market territories to DCs. The current sourcing assignments have developed historically over several years, and have been influenced by various factors including workload balance, company growth, politics, and historical partnerships.



■ Figure 6 Links depict the current assignment of customers to distribution centers.

The new Vice President of Logistics at Sheridan Technologies has initiated a study of the company's logistics supply chain operations, and formed a project team to analyze the following:

1. Given the company's single sourcing distribution strategy (supplying all products shipped to a customer from a single DC), are the customer territories being supplied from the *right* DCs?

2. Should the company consider changing to a *split-sourcing* distribution strategy? Which customers should be served from which DCs under this strategy?

3. Under the company's current single sourcing distribution strategy, what is the optimal *number* and *location* of DCs that minimizes logistics costs?

Developing a Model of the Logistics System

Computer-based model needed

The project team decides to develop a computer-based decision support model of the company's logistics supply chain, so potential changes to the system can be quickly generated and evaluated (both interactively and using automated algorithms). Graphics are needed to better understand the supply chain structure and tradeoffs of possible alternatives and to interactively specify alternatives.

The model is a simplified representation of the actual system

Before generating and analyzing any changes to the current system, the project team first wants to create a simplified model representation and ensure the model accurately represents the actual logistics system. A simplified model is desirable to better understand the significant elements and costs of the supply chain and to allow alternatives to be rapidly generated and easily interpreted.

Aggregate historical shipments to estimate future demand

One year's historical shipping information will be analyzed to capture any monthly or quarterly seasonal variations in customer ordering patterns. The company's mainframe computer holds over 100,000 freight bills paid to trucking companies last year, so the team decides to simplify the analysis by calculating the average order quantity and order frequency by each three-digit ZIP region.

Shipment costing and cost allocation

For each average order quantity the corresponding outbound LTL cost is determined using LTL freight rating tables. The team notes that there may be some error introduced by calculating costs in this manner (as the LTL rates are not linear but are discounted for higher volumes), but the error should be small as the company's just-in-time policy requires a fairly steady flow of products. As Truckload shipments inbound to the distribution centers are actually composed of orders from many different customer regions, the associated inbound TL costs must be fairly allocated over individual customer territories and products. The project team uses the average order quantity by product family to estimate a customer's portion of a Truckload shipment .

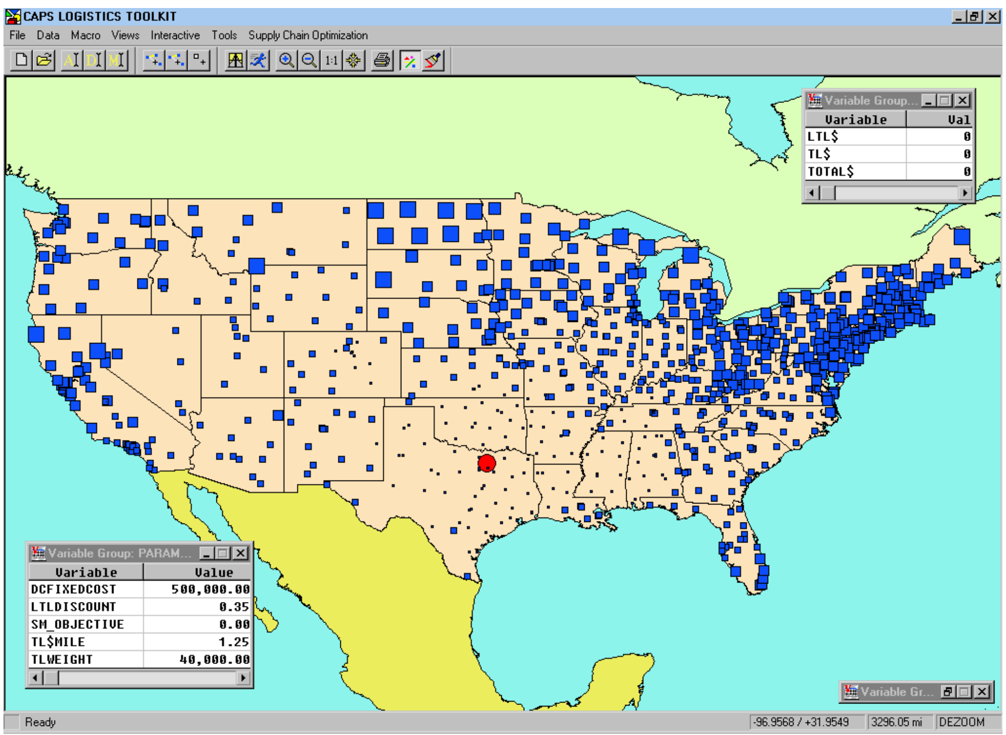
Evaluating the accuracy of the model

Using average order quantities, the estimated annual LTL and TL costs are about 10.5 million dollars and about 2.1 million dollars, respectively. The team decides to ignore storage and handling costs as they are roughly comparable among the DCs. The estimated transportation costs are very close to the actual company TL and LTL expenses for the past year. The team also checks several customer territories and compares the estimated LTL costs to the actual LTL freight costs to that customer. In all cases the estimates are within a few percent, so the team believes the cost estimation method based on average quantity shipping costs and allocated TL costs are a reasonable model of true transportation costs.

Generating and Evaluating Alternatives

Armed with a reasonable model of the company's logistics supply chain, the project team sets out to analyze and improve the transportation configuration. It is not clear if the current assignment of customer territories to distribution centers is smart - many of the current assignments in ■ Figure 6 do not look very intuitive, but the team knows LTL transportation rates are influenced by factors other than just shipping distance, such as the trucking company's own transportation infrastructure.

For example, trucking rates are disproportionately more expensive shipping to Florida, because Florida is a consuming state and trucks must often leave the state empty. The team generates graphics of LTL rate contours to better understand the relationship of current DCs and customer territories - ■ Figure 7 illustrates the rate contours for 1000-2000 pound shipments originating from the company's Richardson, Texas DC.

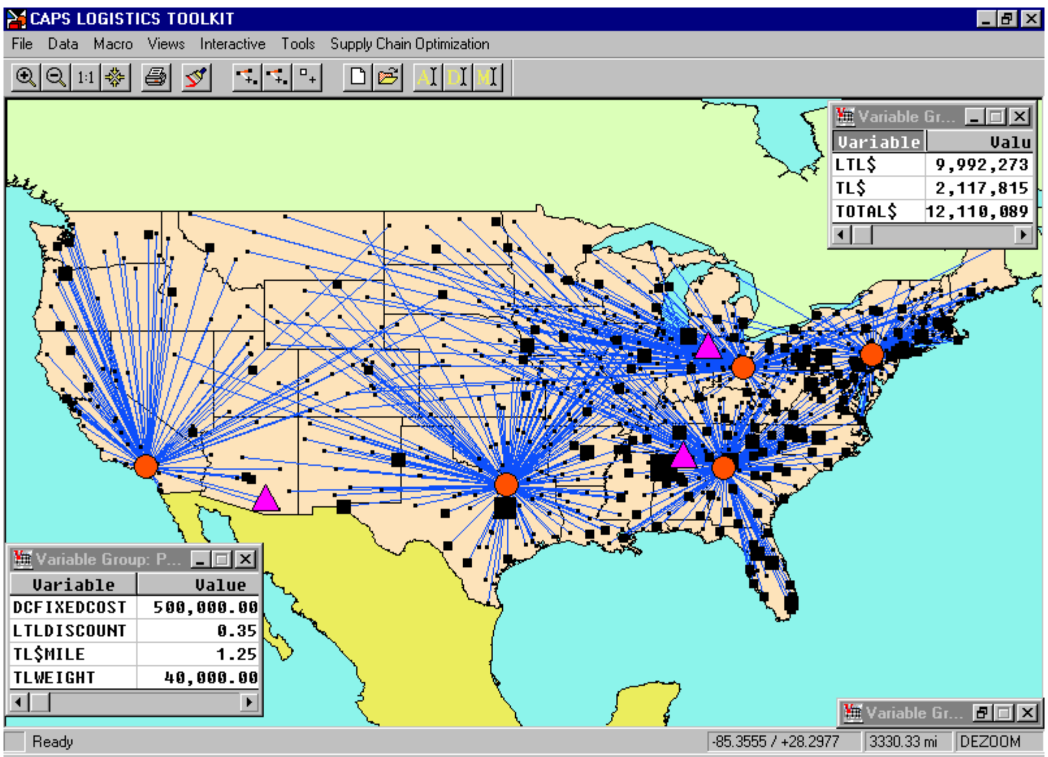


■ Figure 7 LTL $/lb. rate contours from the 750 ZIP3 code for shipments over 1000 lbs. Note the rates generally increase for longer shipping distances, but there are many exceptions.

Next, the best assignment of markets to DCs is evaluated, given the company's current single sourcing strategy. The team decides to treat DC throughput as uncapacitated as each current DC is not nearly fully utilized, and additional shifts can be run if necessary. Thus the best assignment for each market is simply the DC delivering the average market shipment at minimal total transportation cost. The team calculates the inbound TL costs to each DC and weights the TL costs to each market depending on individual product volume.

■ Figure 8 illustrates the assignment of markets to DCs minimizing total transportation costs. The total annual LTL and TL costs for this solution are roughly 10 million and 2.1 million dollars respectively, a savings of roughly 500 thousand dollars annually. The team notes the influence of the LTL rate structure and inbound TL costs on market assignments - obviously the DC nearest a market is not always the best.

■ Figure 8 Optimal single sourcing assignment using the current set of distribution centers. Each DC defines a general geographic territory, but the customer assignments do overlap due to differences in LTL shipping rates.



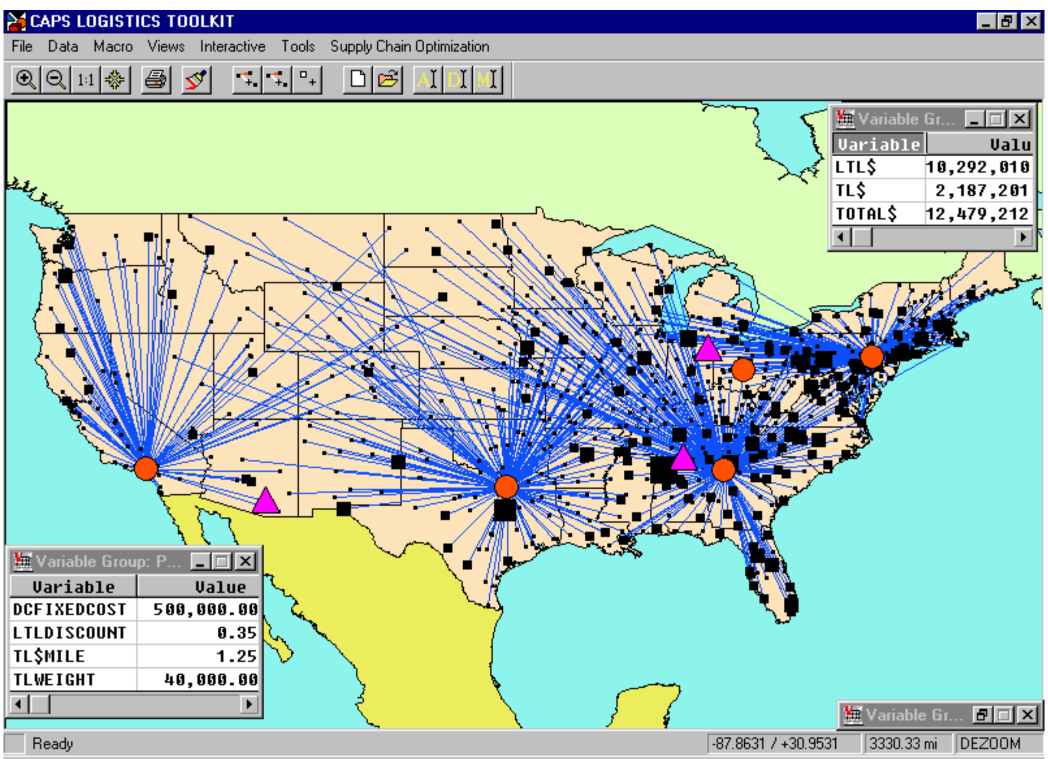
The best split-sourcing solution is calculated in the same manner, with total annual LTL and TL costs roughly 11.2 million and 2.1 million dollars, respectively. Thus the split-sourcing solution increases costs by roughly 700 thousand dollars annually over the current configuration. The project team rationalizes that single sourcing reduces costs because shipping all products together in larger shipment volumes is less expensive (though individual products may be sourced from a more expensive DC).

Next, the project team decides to investigate the effect of consolidating existing distribution centers. As there are only five DCs it is easy to enumerate the respective solutions with each DC closed. ■ Table 1 illustrates the total inbound TL and outbound LTL costs associated with closing each existing DC one-by-one.

■ Table 1
Total annual costs (in millions) with each DC closed, respectively.

best	*Allentown*	*Atlanta*	*Columbus*	*Richardson*	*Covina*
$12.1	$12.9	$13.4	$12.5	$12.75	$12.9

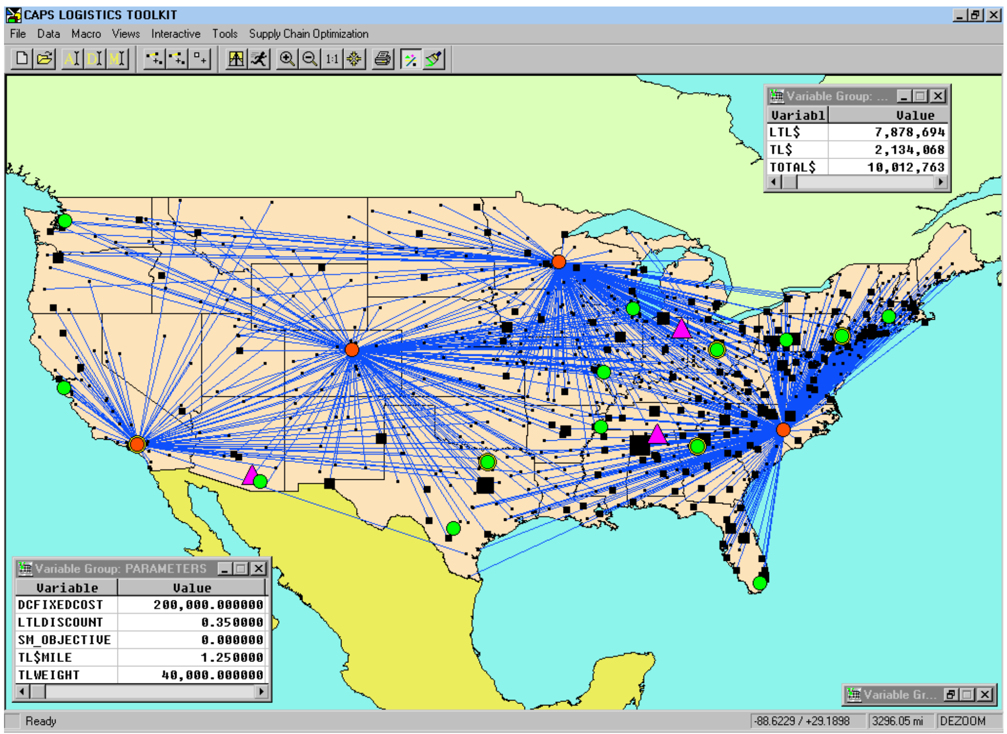
Closing Columbus increases transportation costs by the least amount, resulting in the allocation illustrated in ■ Figure 9. If the cost to operate this facility is greater than $400,000 annually, then closing this DC reduces total costs. The team intuitively believes this is the least important DC, as it is close to Atlanta and Allentown and these DCs are needed for the heavy Southeast and Northeast regions.
The project team next decides to investigate a supply chain configuration not restricted to the current distribution centers. By visual inspection of customer geographical proximity and average order volumes, the team selects 25 DC locations to be analyzed as candidate sites. Each DC is estimated to cost $200,000 annually to operate, independent of the actual shipment volume handled by the DC.



■ Figure 9
Optimal customer allocation with the Columbus DC closed. Atlanta and Allentown pick up most of the reassigned shipping volume.

Logistics Decisions (continued)

Lastly, the team develops a mixed-integer mathematical optimization formulation with open/close integer variables representing opening/closing candidate DCs. ■ Figure 10 illustrates the candidate DCs and the optimal selection of DCs to open and associated market assignments.



■ Figure 10 Optimal number and location of distribution centers, and the optimal allocation of customers to DCs. This configuration of the supply chain reduces annual costs by over 2 million dollars.

Note the existing Covina facility is selected, but Charlotte is selected to handle the Southeast and Northeast, and Denver and Minneapolis are opened to handle the Midwest and parts of the Northwest and Southwest. The total transportation cost of this solution is roughly $10 million annually, a savings of over $2 million annually compared to either the current supply chain configuration or the best single sourcing solution. The project team notes the severe overlap of DC-customer allocations due to the disproportionate structure of LTL rates.

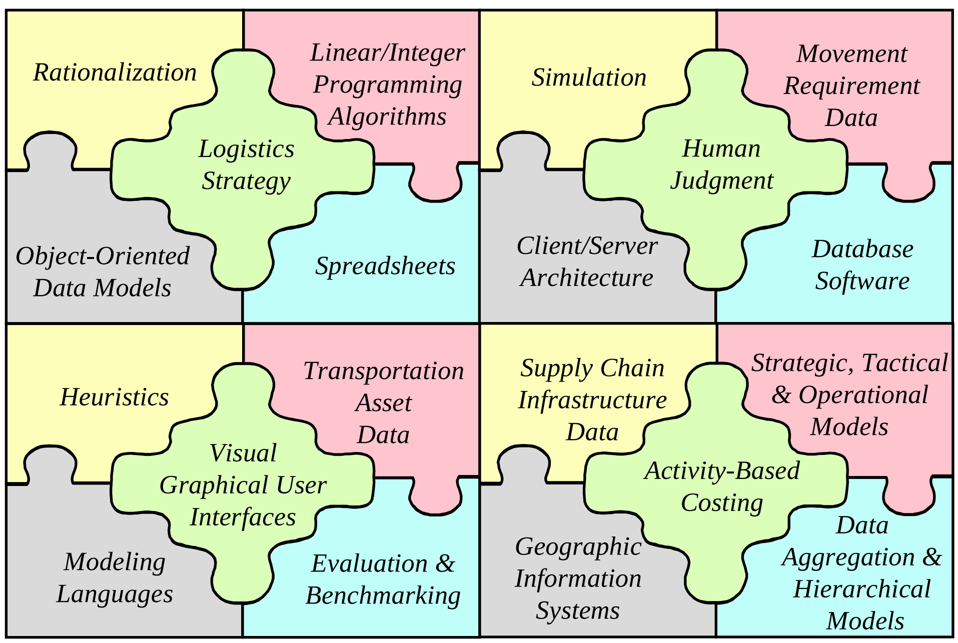
Logistics Composite Modeling

Elements of Composite Modeling

Motivation of a composite modeling approach

The scope and complexity of the logistics questions outlined in the previous section suggests *there is no single best approach, best representation, best model, or best algorithm for optimizing logistics decisions*. Each logistics supply chain has some unique characteristics which will always frustrate and complicate the job of the logistics decision maker.

However, there are a growing array of decision support concepts and tools from operations research, geographic information systems, database management and graphical user interfaces that (when properly brought together under the decision maker's control) immensely improve the quality and timeliness of logistics decisions. ■ Figure 11 illustrates concepts and tools useful in logistics analysis.

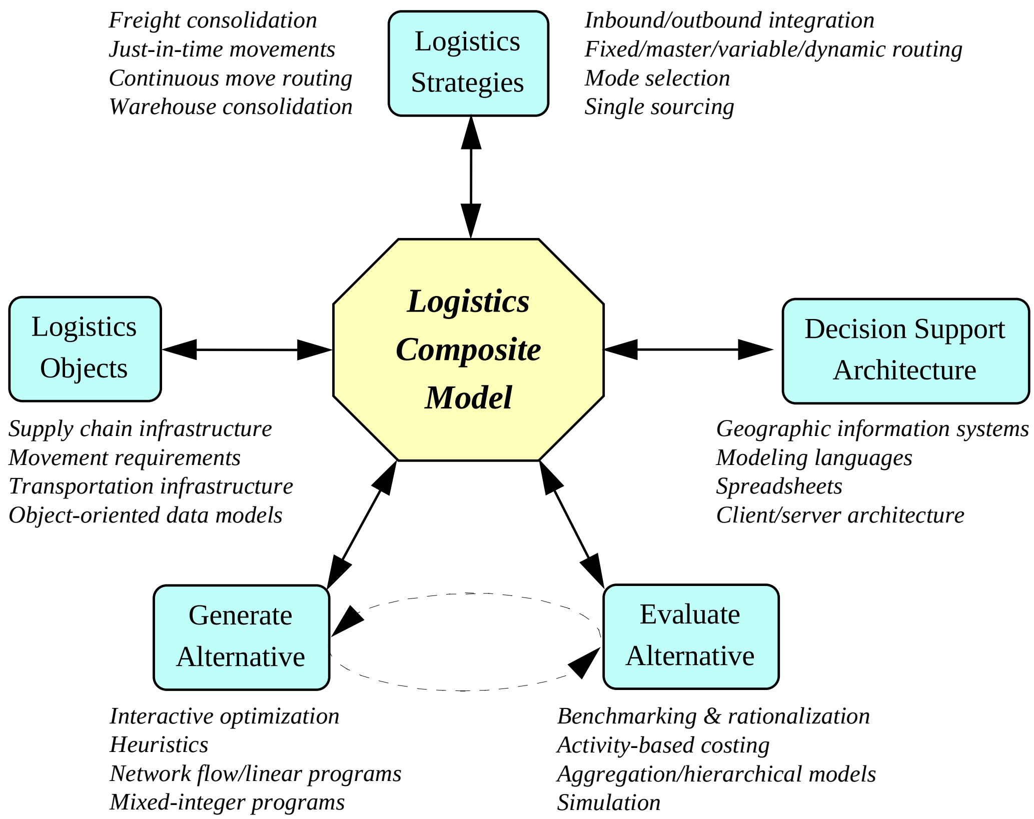


■ Figure 11 Major elements of the composite modeling approach. Each of these concepts or tools contributes to the logistics analysis process.

Logistics analysts are naturally biased to their particular modeling expertise: for example, a logistics practitioner may focus on benchmarking models; an operations research analyst may focus on mathematical optimization models; and a computer scientist may focus on object-oriented data models. However, each of these elements is important and should be included in a *composite* model. The next section organizes these elements into a framework for logistics analysis.

The Composite Modeling Process

Given the complex questions and tradeoffs involved in a logistics supply chain, the only practical way to determine how to improve logistics operations is to generate and evaluate logical alternatives. The structured approach presented here brings together a variety of tools and the logistics decision maker into a *Logistics Composite Model* (*LCM*) for optimizing logistics decision-making. ■ Figure 12 illustrates the major elements of the *LCM* analysis process.



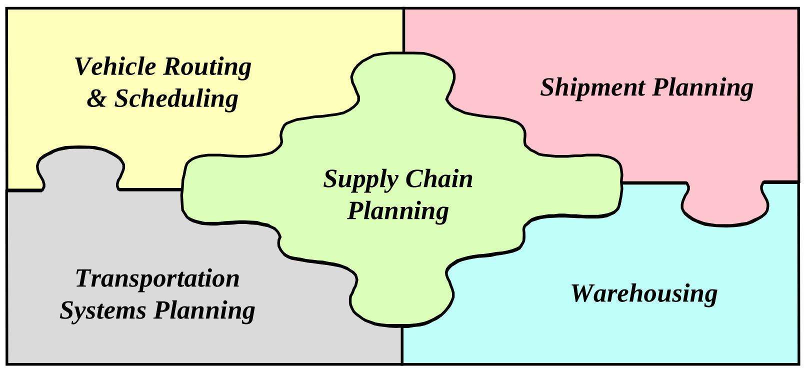
■ Figure 12
The elements of composite modeling are organized into an iterative analysis process. Iteratively generating and evaluating alternatives may suggest refinements to strategies, logistics objects, and decision support architecture.

These modeling concepts and tools of *LCM* are described in detail in the following sections.

Logistics Strategies

Introduction

Logistics Strategies includes the business goals, requirements, allowable decisions, tactics, and vision for designing and operating a logistics system. Although some logistics strategies impact decisions throughout the supply chain, for clarity the application areas of strategies can be generally organized as illustrated in ■ Figure 13:



■ Figure 13 General classes of applications in logistics modeling.

Supply Chain Planning includes the location, sizing, and configuration of plants and distribution centers, the configuration of shipping lanes and sourcing assignments, the aggregate allocation of production resources, and customer profitability and service issues.

Shipment Planning is the routing and scheduling of shipments through the supply chain, including freight consolidation and transportation mode selection.

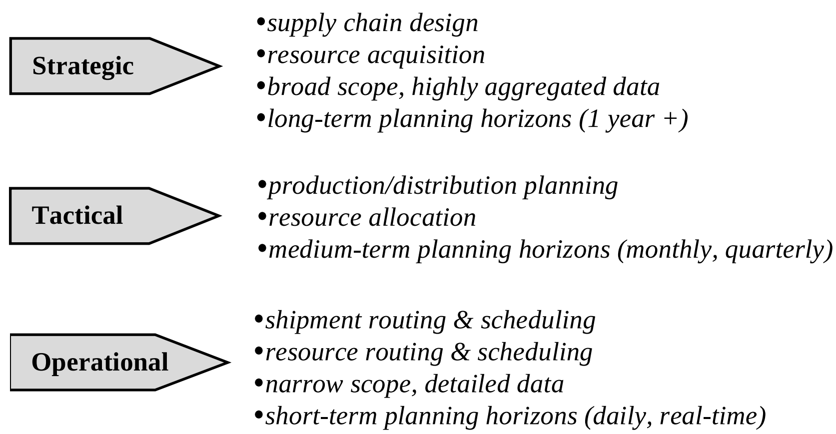
Transportation Systems Planning includes the location, sizing, and configuration of the transportation infrastructure, including fleet sizing and network alignment.

Vehicle Routing & Scheduling includes the routing and scheduling of drivers, vehicles, trailers, etc. Other applications include dynamic dispatching, customer zone alignment, and frequency of delivery questions.

Warehousing includes the layout design and storage/picking operations of distribution centers.

Strategic, Tactical, & Operational Model Views

Analyzing the various logistics strategies requires appropriate modeling views of a logistics supply chain. *Strategic*, *tactical*, and *operational* models are three fundamental classes of modeling views, with general properties shown in ■ Figure 14:



■ Figure 14 General scope and properties of strategic, tactical, and operational model views.

The logistics application areas in ■ Figure 13 can be organized into modeling views as shown in ■ Table 2. Examples of strategies for these application areas are illustrated in the next section.

■ Table 2 Logistics application areas by modeling views.

	supply chain planning	*transportation planning*	*shipment planning*	*vehicle routing*	*warehousing*
strategic	site location capacity sizing sourcing	site location fleet sizing	outsourcing bid analysis fleet sizing	fleet sizing	warehouse layout material handling design
tactical	production planning sourcing	routing strategy network alignment	consolidation strategy mode strategy	routing strategy zone alignment	storage allocation order picking strategies
operational	MRP, DRP, ERP	load matching	shipment dispatching	vehicle dispatching	order picking

Contemporary Logistics Strategies

Just-in-Time Logistics

Historically, products have been "pushed" through a supply chain based on forecasts of future customer demand. This strategy allows scale economies in the purchasing of raw materials, manufacturing batch runs, and transportation shipments. However, costly inventories build up to protect errors in forecasts, and the logistics system is slow-moving and inflexible to rapid market changes.

If we knew precisely where, when, and how much material is needed at each stage of a logistics supply chain, goods could be moved through the supply chain *just-in-time* (JIT) for use by the next process, without a need to build up inventories. Thus product replenishments are "pulled" all the way through the supply chain from the point of sale. To control the precise movements of products, computerized integration and tracking of supply chain operations is necessary.

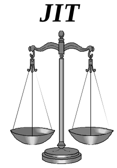
JIT is a shift in thinking from inventory *levels* to inventory *velocity or "turns."* For a specified time period, the turn rate for a product is calculated by dividing total throughput by the average inventory level. Note the turn rate is only one performance indicator of a logistics supply chain, and by itself is not a very good measure. Often, higher inventory turn rates also mean higher transportation and service costs - ■ Figure 15 illustrates this tradeoff:

■ Figure 15
Cost and service tradeoffs of a just-in-time logistics strategy.

Inventory Costs

- *leaner supply chain*
- *reduced inventory levels*
- *reduced inventory costs*

JIT



Transportation & Service Costs

- *smaller and more frequent shipments*
- *increased transportation costs*
- *much greater service required from suppliers and the transportation system*

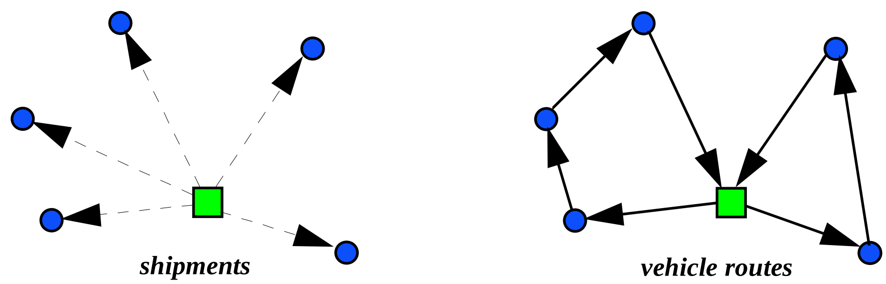
JIT logistics impacts all five application areas illustrated in ■ Figure 13, particularly shipment planning and supply chain design. Shipment planning is fundamentally affected as smaller and more frequent shipments impact transportation mode selection and freight consolidation opportunities. The design of a supply chain is also impacted as there is less emphasis on product storage.

Freight Consolidation

Strategies for consolidating freight are fundamental to shipment planning decisions. Shipments in the logistics system can be routed and scheduled independently of each other or can be combined to try and achieve transportation economies-of-scale. There are many ways to consolidate freight, including:

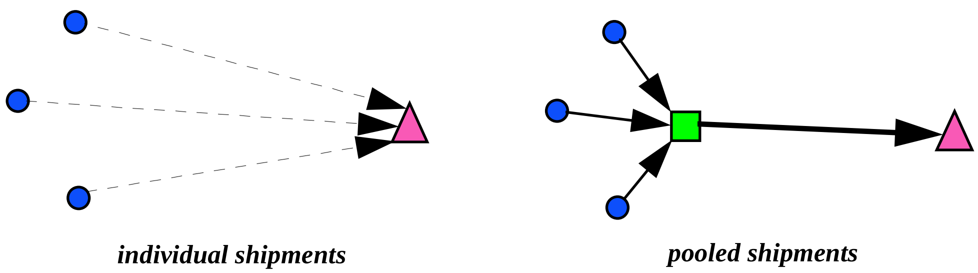
1. *Vehicle routing*. Individual shipments can be combined to share a transportation asset making pickup or delivery stops at different facilities. This type of consolidation is called *multi-stop vehicle routing* (■ Figure 16).

■ Figure 16 Consolidating freight by combining shipments onto multi-stop routes.



1. *Pooling*. Individual shipments can be brought to a central location or *pooled*, creating large shipments suitable for economy-of-scale transportation modes such as truckload or rail carload (■ Figure 17).

■ Figure 17 Consolidating freight by pooling shipments at a facility.



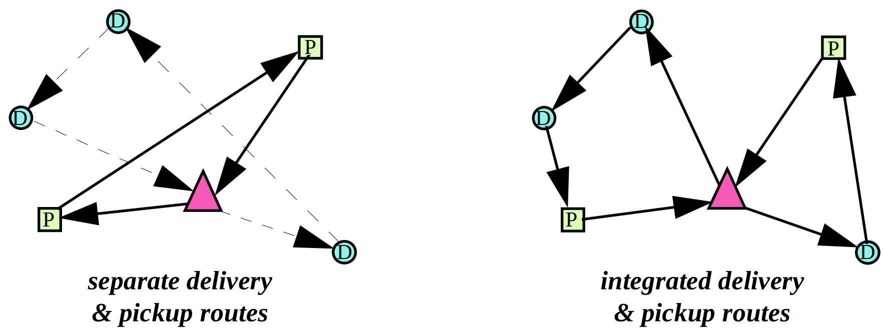
1. *Scheduling*. Sometimes shipment schedules can be adjusted forward or backward in time so they can be combined with other shipments.

Integration of Inbound and Distribution Logistics

Historically the purchasing and scheduling of supplier-to-plant *inbound* shipments have been treated independently of the distribution of goods coming out of the plant. Coordinating inbound and outbound shipments and resources requires more control of the logistics system, but can increase the utilization of resources.

This strategy particularly impacts shipment planning and vehicle routing and scheduling. For example, ■ Figure 18 illustrates separate delivery and pickup routes (left), and integrated delivery/pickup routes (right).

■ Figure 18 Integrating separate pickup and delivery routes into combined routes.



Fixed/Master Routes & Variable/Dynamic Routes

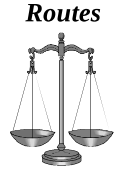
Fixed and master routes are regular vehicle route sequences and schedules developed using average demand forecasts. Fixed routes are regular run each period without considering actual customer demand, while master routes are adjusted slightly based on actual demand. In contrast, variable or irregular routes are tailored to actual customer demand information. The extreme case of variable routes is dynamic routes, which are adjusted dynamically as the routes are run. ■ Figure 19 illustrates the tradeoffs of these strategies.

■ Figure 19 Tradeoffs of fixed vs. Variable routing strategies.

service & control costs

- regular routes are easier to manage
- drivers develop familiarity with customers and territories

Fixed/Variable Routes



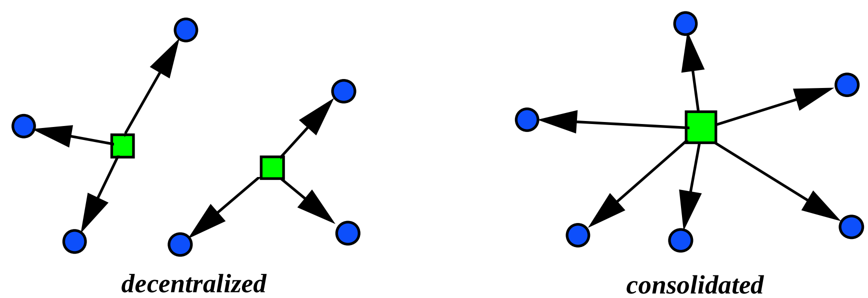
transportation costs

- increased utilization of transportation assets.

Distribution Center Consolidation vs. Decentralization

Fundamental decisions in supply chain design include the number, location, sizing, and product configuration of distribution centers. ■ Figure 20 illustrates two basic strategies: *consolidated* distribution (fewer but larger distribution centers) and *decentralized* distribution (more but smaller distribution centers).

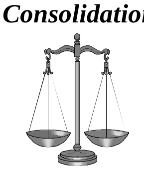
■ Figure 20 Customers can be served from smaller, regional distribution centers or from larger, centralized distribution centers.



■ Figure 21 illustrates the decision tradeoffs involved in the consolidation of distribution centers. Note also that an increased number of distribution centers allows closer positioning of inventory to customers, reducing delivery time to customers.

■ Figure 21 Cost and service tradeoffs of consolidating distribution centers.

DC Consolidation



inventory & facility costs

- reduced facility costs
- it *may* be possible to reduce inventory while maintaining equivalent customer service (because of a "wash" effect in demand forecast errors)

transportation & service costs

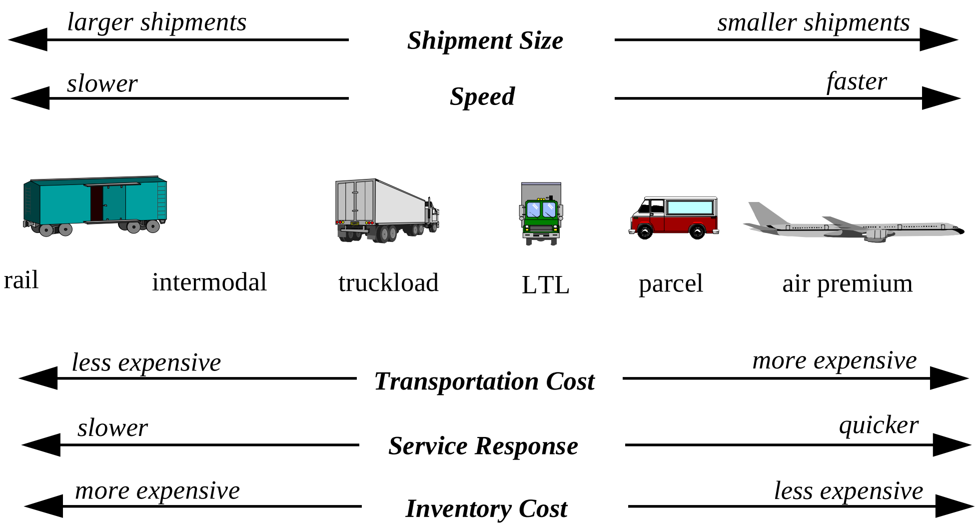
- lower volume outbound lanes
- increased transportation costs
- products further from customers
- increased service costs

Private Fleet vs. For-Hire Fleet

Some manufacturing and retailing firms choose to own and operate their own transportation fleet. This gives more control over transportation costs and service, but forces the firm into operations secondary to the business. Private fleets are becoming less attractive as competition from transportation deregulation has resulted in better service and lower costs from transportation providers. Additionally, deregulation allows organizations to negotiate discounts for longer-term *dedicated* services from transportation providers.

Transportation Mode Selection

Mode selection is another fundamental concept in shipment planning. Common transportation modes include overnight package, parcel, less-than-truckload (LTL), truckload (TL), and rail carload (CL), for example. Each mode offers different cost and service advantages and disadvantages - ■ Figure 22 illustrates the tradeoffs in choosing a transportation mode for a shipment.



■ Figure 22 Cost and service tradeoffs of different transportation modes. These are general and not strict relationships among modes - for example, Truckload mode is geared for larger shipments compared to LTL, but is also generally faster.

Transportation mode and inventory costs

Transportation mode impacts inventory costs in three different ways. First, slower transportation modes create more *in-transit* or pipeline inventory. Second, larger shipment sizes may create *order quantity* inventory, which arises if the batch shipment size is more than the amount of current demand. Third, slower transportation modes may raise *safety stock* inventories needed to protect uncertainties in supply and demand. A slower transportation mode increases the order lead time (the time between placing an order and actually receiving the shipment), so more safety stock may be needed to protect against the lack of knowledge about demand during the lead time. Thus smaller shipments via faster modes reduces all three types of inventories, but associated transportation costs increase.

Continuous Move Routing

Some trucking companies offer discounts for *continuous move* routes, where drivers and tractors are kept highly utilized by coordinating the dropoff of an inbound trailer with the pickup of an outbound trailer. ■ Figure 23 illustrates combining two truckload shipments into a continuous movement route. This route reduces costs if the continuous move discount is more than the deadhead cost to travel to the origin of the second shipment

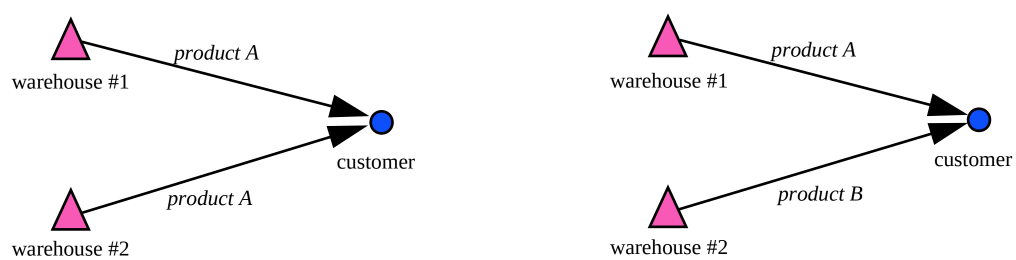
■ Figure 23 Continuous move routes combine separate trips to increase vehicle utilization.

truckload shipments ***continuous move route***

Single Sourcing

Single sourcing refers to satisfying all product demand at a location from one supplier - in contrast, *split sourcing* refers to multiple suppliers satisfying the same demand location. The most common form of single sourcing is between distribution centers and customers or markets, with each customer assigned a single distribution center. ■ Figure 24 illustrates examples of split sourcing.

■ Figure 24 Split sourcing can refer to shipping the same product or multiple products from different origins.



split sourcing - same product ***split sourcing - multiple products***

Single sourcing simplifies the logistics supply chain which can reduce management and operational costs. Single sourcing also creates larger volume shipments along lanes, which may reduce transportation costs. However, single sourcing requires each supplier to stock all products - split sourcing allows each product to be shipped via the cheapest shipping route to a customer. Split sourcing can also reduce costs if the supply points are capacitated, as the least cost allocation of supply may require split shipments.

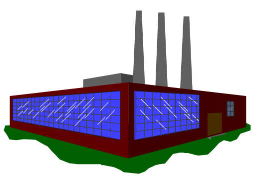
Logistics Objects

Introduction

What is object-oriented modeling?

To develop a computerized model of a logistics supply chain, a strategy for representing logistics information and supply chain operations is needed. *Object-oriented modeling* is one approach which focuses on the natural elements or building blocks of a logistics supply chain. In this approach the *data* and *operations* of a logistics entity are combined to form a *logistics object*. Figure 25 illustrates an example plant object:

■ Figure 25: An example of a logistics object for a manufacturing site. The object includes both data and associated tools operating on the data.



Atlanta plant

Sample data attributes

address: 2575 Cumberland Parkway, Atlanta, GA 30339 USA

number of production lines: 10

operating hours: Monday thru Friday, 10 hours/day

Sample tools

draw (on a computerized map)

allocate production capacity to demand

schedule production lines

There are three basic families of objects in a logistics system:

1. *Supply Chain Infrastructure*. This family includes physical sites such as suppliers, plants, distribution centers, and customers. This family also includes connections and territory groupings among sites, such as shipping lanes, facility-to-facility assignments, and customer zones.

2. *Movement Requirements*. This family is all shipment information including what commodities to move, when commodities are needed, special instructions or requirements for movement, etc.

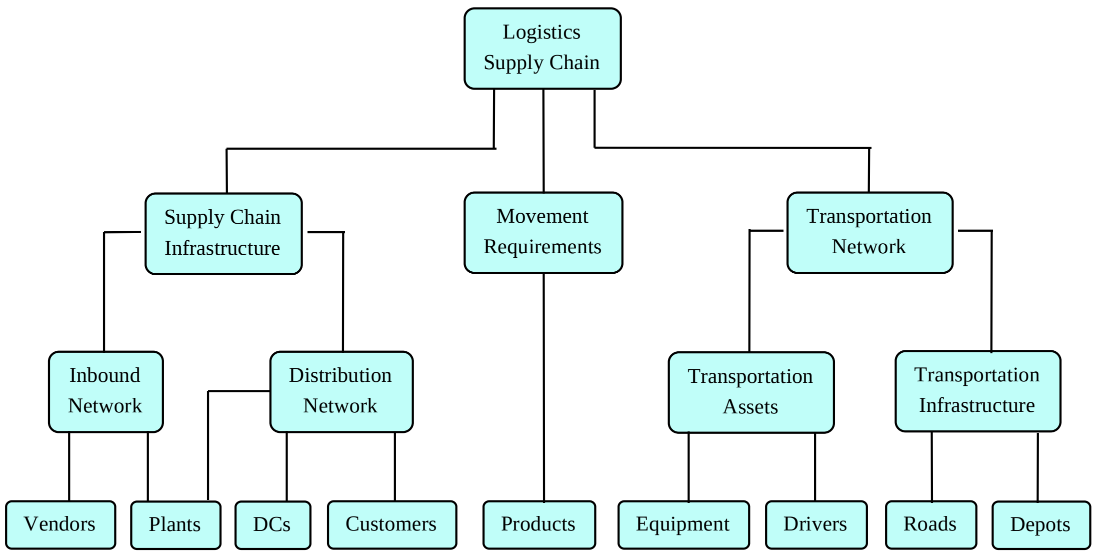
3. *Transportation Network*. Transportation network objects include the physical components of the transportation infrastructure (road and rail networks, ports, depots, pool points, intermodal exchange locations, etc.), assets that are either owned or available for hire (drivers, trucks, trailers, containers, planes, ships, rail cars, intermodal containers, pallets, etc.), and asset locations and transportation capabilities (such as maximum loads or transit speeds).

Logistics Objects (continued)

Class hierarchies of logistics objects

Objects in these three families can be *hierarchically* organized into *classes* to provide an intuitive representation of a logistics system. ■ Figure 26 illustrates one example hierarchical organization of logistics objects, representing the logistics system of a manufacturing firm (note there are many different and valid ways to describe a logistics system using object hierarchies).

■ Figure 26 An example hierarchy of logistics objects. Higher-level views of a logistics system are found at the top of the hierarchy - one can "drill down" through the hierarchy for more focused views.



Other properties of hierarchical models

A hierarchical model provides a systematic way to adjust the *resolution* of a model. By navigating a hierarchical model we can back up and look at the "big picture" in a logistics system, or focus in on detailed components. A hierarchical representation also provides a systematic way to *extend* a model - a new object class (such as *European* manufacturing plants) can be quickly created by first *inheriting* data and operations from an existing object class.

Other benefits of object-oriented modeling

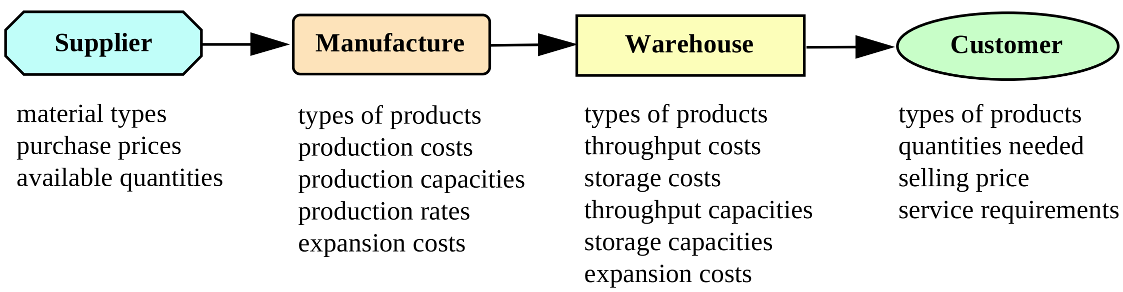
There are many other benefits of an object-oriented modeling approach. Combining data and operations (or *tools*) together into objects allows the tools to protect or *encapsulate* what can be done with data. Further, the binding of data and tools makes it clear how data can be manipulated. Object-oriented modeling is also particularly suitable as a basis for computerized decision support systems. Modularity makes objects easier to maintain and extend, and the hierarchies of object classes encourage reusable programming code.

Developing a Supply Chain Model

Facilities

Supply chain infrastructure

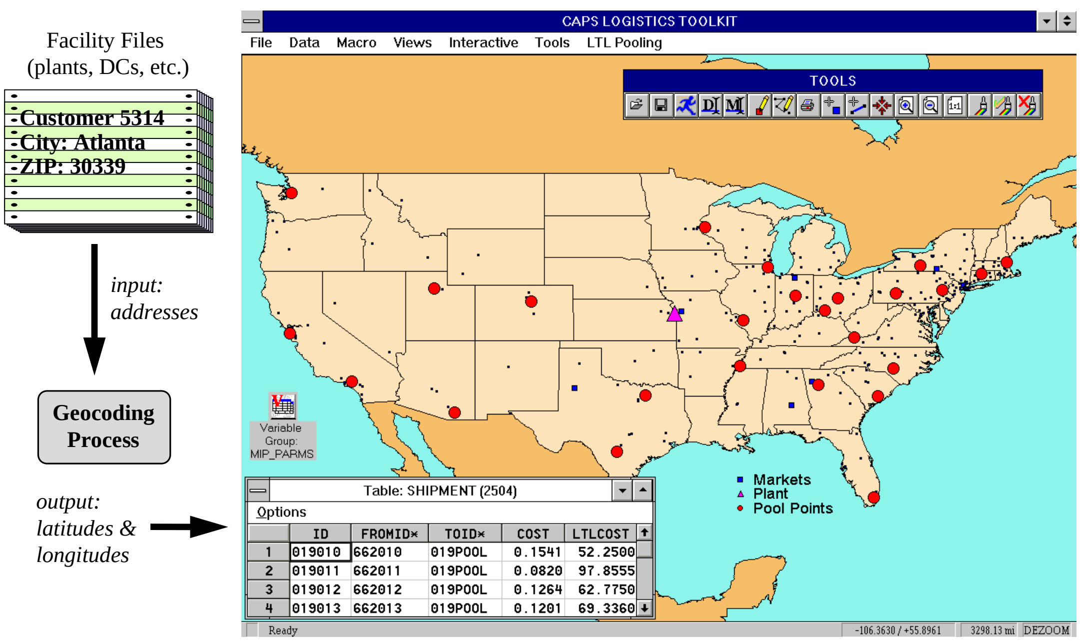
Facilities are the foundation of the supply chain infrastructure and include suppliers, plants, distribution centers, and customers. ■ Figure 27 illustrates facility data that is needed or useful in logistics modeling.



■ Figure 27 Types of facility data needed or useful in a logistics model.

What is geocoding?

Geocoding is the process of determining the geographic (longitude and latitude) coordinates or *geocodes* of a facility, given a description of the facility (■ Figure 28). The description of a location could be a street address, city name, or postal code.



■ Figure 28 Geocoding is the process of finding map coordinates for locations of facilities.

Why are geocodes needed?

Geocodes are needed for many types of quantitative analysis tools where nearness among facilities is important, such as the routing of vehicles or the location of new facilities. Geocodes also allow the logistics supply chain to be visually represented using map-based graphical user interfaces (discussed in the *Interactive Generation of Alternatives* section later).

A large number of commercial databases are available to support geocoding, including databases of postal codes and metropolitan streets - an extensive reference of available databases is the GIS World Sourcebook[6].

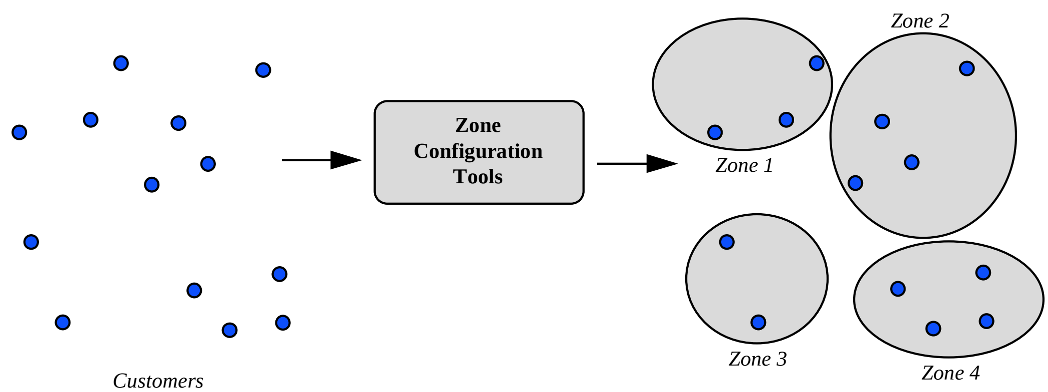
Facility Zones

Zones define the geographical territories of facilities, such as sales regions, customer territories, or distribution center areas. Zones can be pre-determined (such as marketing territories) or can be created automatically by rules or algorithms. ■ Figure 29 illustrates example zones defined for a set of customers - individual customer data such as demand is aggregated to determine total demand by zone.

Why define facility zones?

Facility zones play an important role in *simplifying* a logistics model, as aggregate regions can represent the demand of hundreds or even thousands of individual customers. Effective zones usually define logical geographical clusters of facilities, adjusted to balance some attribute (such as total zone demand or transportation workload, for example).

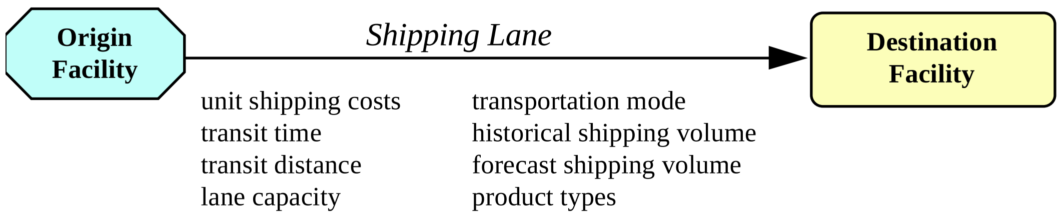
■ Figure 29 Facility zones are logical geographic clusters of facilities, with boundaries often adjusted to balance some attribute.



Shipping Lanes

Shipping lanes are the product movement connections between supply chain facilities. ■ Figure 30 illustrates shipping lane data relevant in logistics modeling.

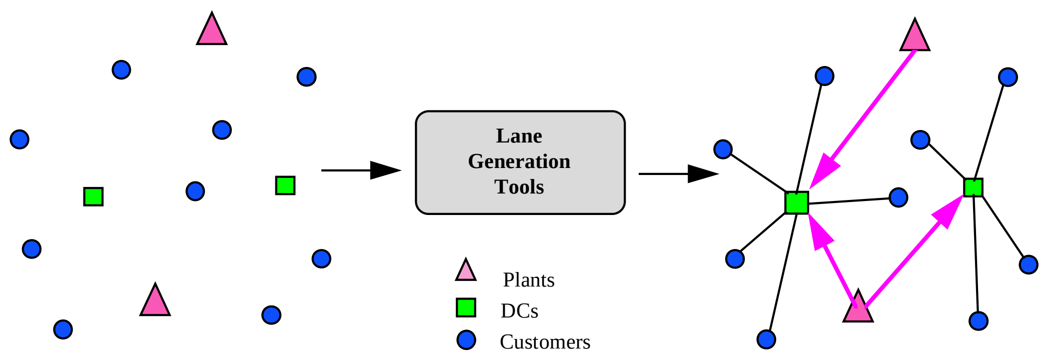
■ Figure 30 Types of shipping lane data needed or useful in a logistics model.



Shipping lane *generation* defines the shipping lanes between facilities that are *candidates* for product flow. Lane generation tools help to pare down the large number possible transportation lane combinations to a practical or logical set. These candidate lanes are inputs to analytical tools deciding actual product flows and schedules.

Shipping lanes can either be pre-determined or generated by rules or algorithms (such as all lanes of distance less than 500 miles, or by product compatibility issues). ■ Figure 31 illustrates example lanes generated between facilities.

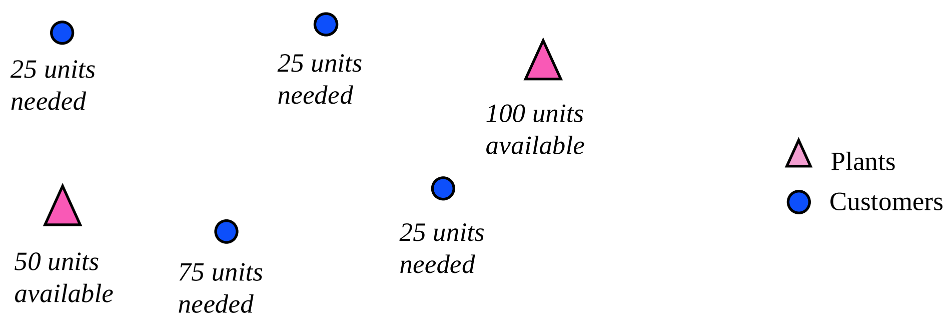
■ Figure 31 Candidate shipping lanes between facilities are automatically created and can be limited to a realistic set based on rules.



Representing Movement Requirements

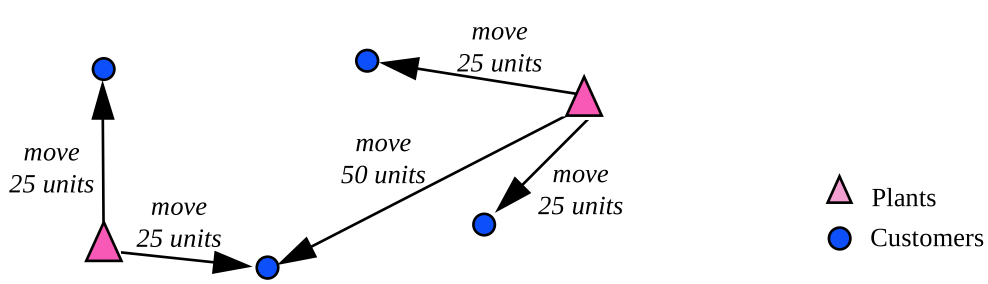
Movement requirements indicate product demand or shipments, including when and how many products or components are needed at specific facilities or zones. One way to indicate movement requirements is to specify the *aggregate* supply and demand for products at facilities or zones (illustrated in ■ Figure 32). Aggregate supply-and-demand models are appropriate where the origins and/or destinations of movements are unknown. Aggregate models are also useful for answering strategic design questions.

■ Figure 32 One way to represent demand for product is to specify aggregate supply and demand information at facilities.



Another fundamental way to represent movement requirements is to describe *explicit* shipments, including origins, destinations, products, volumes, due dates, and pickup dates. Origin-destination shipment models are useful for answering routing and scheduling questions involving explicit shipments and transportation assets. ■ Figure 33 illustrates origin-destination movement requirements.

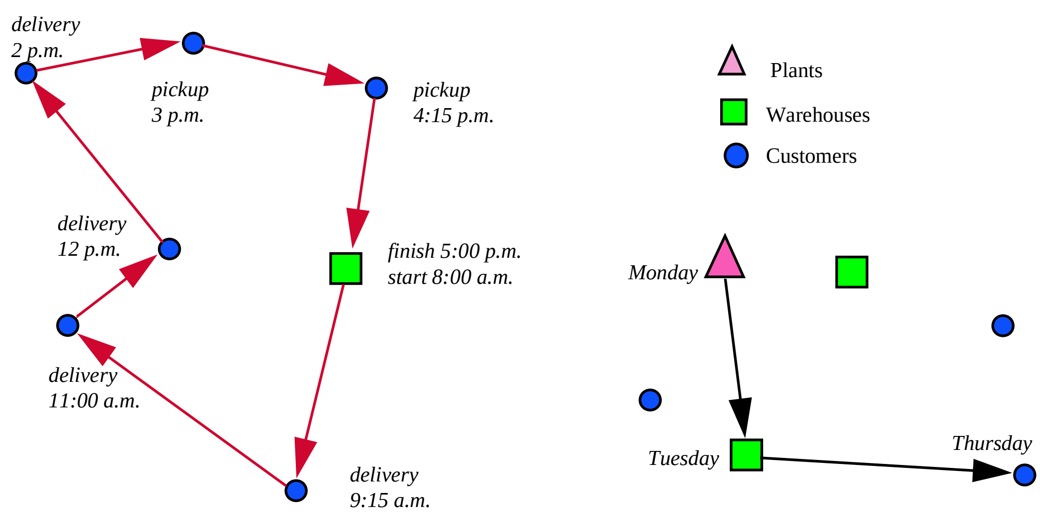
■ Figure 33 Another way to represent product demand is to specify origin-destination shipments.



Representing the Flow of Shipments and Assets

Logistics objects that are *moving* include shipments and transportation assets. *Paths* and *routes* are used to represent the movement of goods and transportation equipment among facilities. *Schedules* describe timing information associated with the movements. ■ Figure 34 illustrates examples paths, routes, and schedules. Note transportation assets include trucks, drivers, and trailers, each with possibly distinct routings and schedules.

■ Figure 34 Examples of paths, routes, & schedules for transportation assets and for shipments.



Vehicle route & schedule ***Shipment route & schedule***

Other Data Issues

Sources of Data

Data for logistics objects can be generated in three basic ways:

1. *Current* information.

Some logistics models are based on current logistics information. For example, vehicle dispatching models need information about today's orders, vehicles available, driver status, etc.

2. *Forecasts.*

Other models are based on forecasts of future information - historical data is used to predict future customer demand, available production capacity, etc. The estimates can be generated in a variety of ways, from using sophisticated forecasting algorithms to simply rolling up a year's worth of historical data to give an annual view of a supply chain.

3. *Historical* information.

Still other models use actual historical data to calibrate model accuracy - model outputs can be compared to what actually happened to ensure the model is a valid representation of the logistics supply chain.

Time-related Data: The Modeling Horizon

A key modeling issue is defining the time span or *horizon* of a logistics model. Some models are *single-period* models - there is only one time period, so data in these models does not change over time. A popular single-period model is a one-year view of a supply chain, with relevant facility data including the total production capacity or demand forecast for the entire year. Single-period models are useful for analyzing solutions to strategic design models.

In contrast, some models are *multi-period* models, with data potentially changing from one time period to the next. For example, the customer demand for soft drink products increases during the summer months. A popular multi-period model is a one-year view of a supply chain by month, with relevant facility data including the production capacity or demand forecast for each month, for example. Multi-period models are useful for analyzing solutions to resource scheduling models.

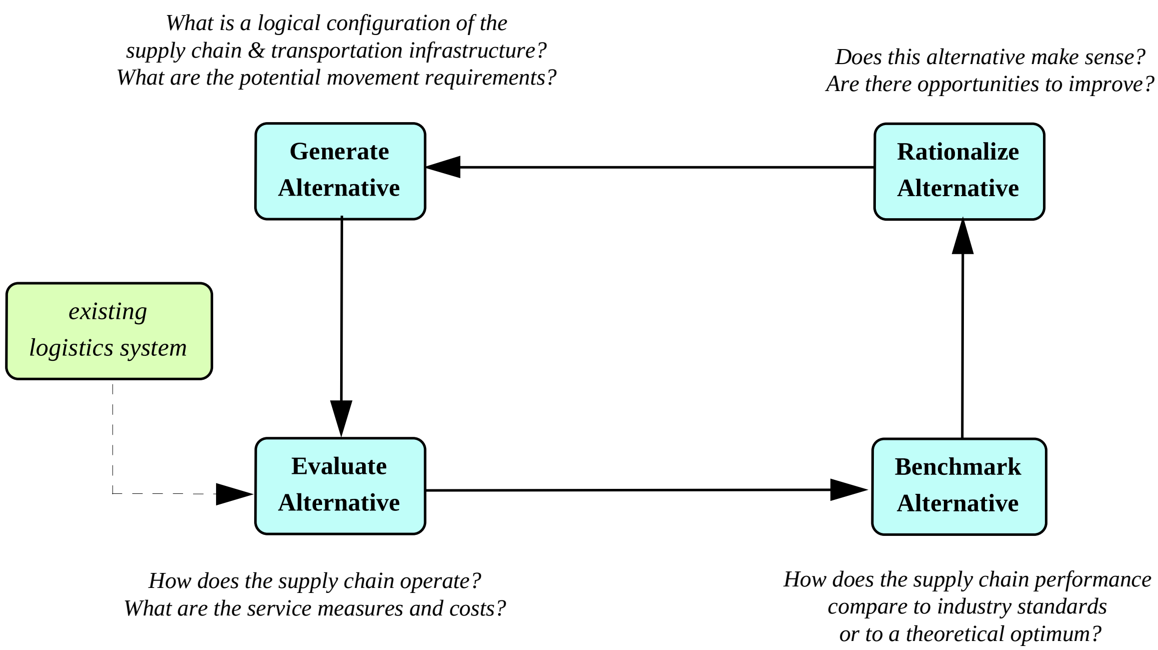
Evaluating Alternatives

Introduction

Evaluating Alternatives is "playing out" or *simulating* the operation of a logistics supply chain using a model and analyzing the attractiveness of the supply chain configuration. Cost and service performance measures, resource utilizations and bottlenecks, and other statistics of the logistics system are calculated in this phase of *LCM*.

Evaluating Alternatives is composed of the *Evaluate*, *Benchmark*, and *Rationalize* steps, each geared towards answering particular analysis questions. These three steps combined with the *Generate Alternatives* step (discussed later) form an iterative analysis cycle, illustrated in ■ Figure 35. The analysis process is naturally iterative because evaluating one alternative often suggests new alternatives to investigate.

■ Figure 35
The logistics analysis process iterates between generating and evaluating alternatives - benchmarking and rationalizing steps help to measure solution quality and illuminate different alternatives to investigate.



Model Simplification

Logistics supply chains can be very large systems composed of hundreds of facilities moving tens of thousands of products or more. These systems are far too large and complex to work with all at once in the *Generate, Evaluate, Benchmark,* and *Rationalize* steps. The only practical way to analyze and improve a logistics system is to *simplify* the logistics decisions into smaller interrelated and manageable components. Two model simplification techniques are *aggregation* and *partitioning.*

Model Aggregation

What is aggregation?

Aggregation is collecting or "rolling up" *related* data up to a simpler or more *approximate* representation. Examples of logistics supply chain aggregation are the following:

- Grouping individual products or stock-keeping units (*SKUs*) into *product families*, representing groups of similar product items.
- Adding up the individual product demand for customers to get the total demand by *customer zone*.
- Adding up the manufacturing capabilities of individual production lines and assembly stations into a *total production capacity* for a manufacturing plant.
- Representing large numbers of individual truck trailers by a few basic *trailer types*, such as refrigerated, 48 foot, etc.

Model Partitioning

Another way to simplify a logistics system is to decouple or *partition* the supply chain into more manageable components. For example, we could divide the distribution system into regions, and develop vehicle routing models separately within each region. Of course, a key part of supply chain modeling is treating the logistics system as an integrated process, so care must be taken to provide enough "linkage" between the components to capture the relevant decisions and issues.

Model Accuracy

In the ideal logistics model:

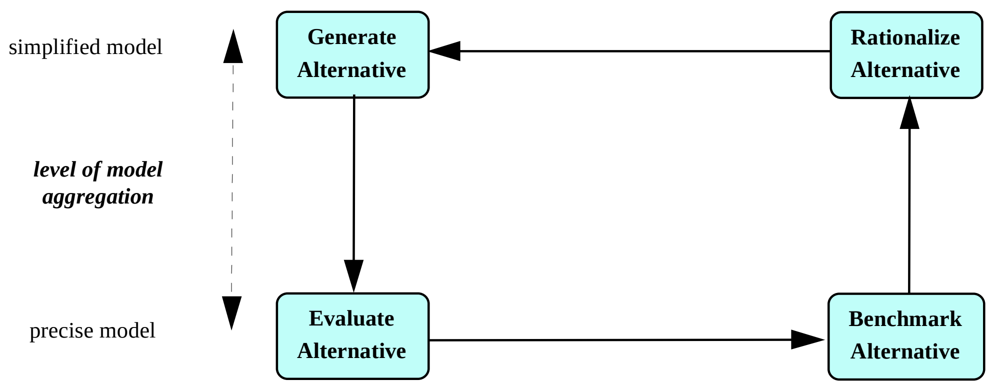
- All data is available and correct.
- There is no error in forecasts of future data (including customer demand, availability of supply, availability of resources, etc.).
- The model exactly captures all of the relevant issues in the logistics supply chain.

Unfortunately, in most situations some data is missing or incorrect, the forecasts of future data are wrong, and some supply chain characteristics are too fuzzy to capture precisely in a model. Thus most logistics models are at best *approximate* representations of the actual logistics system.

Evaluation lets us validate simplified and approximate models

How do we know if an approximate and simplified model is an accurate representation of the logistics supply chain? This is the heart of the *Evaluate Alternatives* step. This modeling step "plays out" a given logistics system configuration, so more detailed data can be used. The result is that baseline statistics can be calculated and used to gauge the precision of more simplified models (■ Figure 36).

■ Figure 36 Simpler, higher-level models are often attractive when generating and rationalizing alternatives - more precise models are possible during evaluation and benchmarking steps.



Evaluation lets us calibrate aggregate models

For example, in aggregate models it is common to use average or approximate values for costs and demand quantities. Given the movement of actual shipments, we can evaluate the true shipping costs and compare with the approximate costs. We can then modify and improve how we estimate the approximate costs and demands based on what actually happened. Thus the evaluation step measures the accuracy of a simplified model.

The output of Generate is not the answer, but the input to Evaluate

Simplified models are particularly useful in the *Generate* step, as solution generation tools can examine a greater number and variety of decision alternatives using more aggregate models. It is important to note that the output of the *Generate* phase is the input to the *Evaluate* phase. For example, the optimal solution generated by a mathematical optimization model is not necessarily the "answer" but rather must be played out and evaluated to judge the solution's true attractiveness. More aggregate model views are also useful in the *Rationalize* step, as these models are easier to understand and manipulate.

In general, the right level of model simplification balances accuracy (so that judgments based on the model are correct judgments about the actual logistics system) with practicality (illustrated in ■ Figure 37).

■ Figure 37 Tradeoffs of simple and precise modeling views.

Simplified (aggregate) model

easier to understand
more manageable & practical
faster computer processing

Precise (disaggregate) model

model accuracy

Simulation

Simulation is a general term for a class of tools and models that play out a given logistics system. While these tools are descriptive only (and do not prescribe smart alternatives), simulation tools can handle a large amount of detail, and can effectively represent the *probabilistic* elements of a logistics system. Thus these tools are effective for evaluating the actual behavior of a logistics system and calibrating the accuracy of more approximate models.

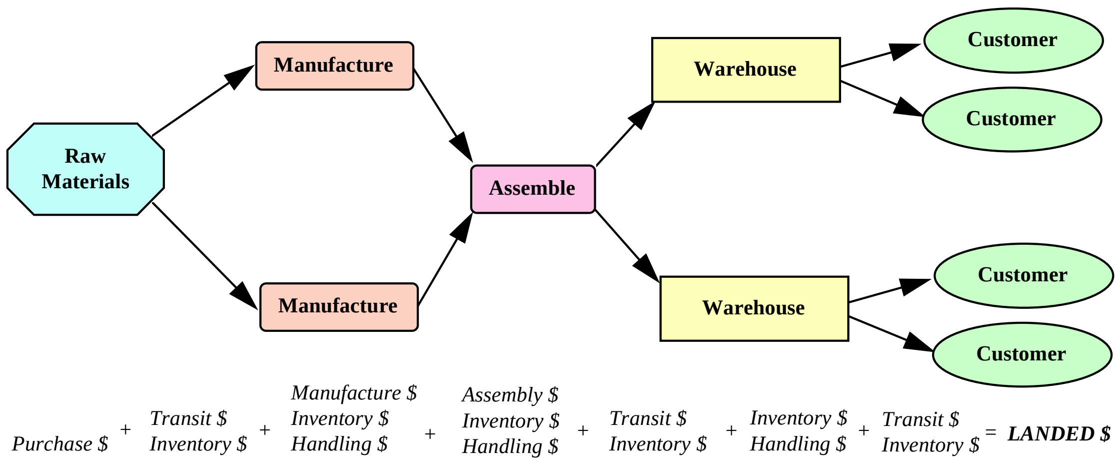
Costing

Landed customer costs

The process of determining the product cost *delivered to the customer* forces the specification of cost models for the various components of the entire logistics supply chain. The cost to deliver a unit of product to the customer is called the *landed customer cost*.

■ Figure 38 illustrates the various types of costs incurred as a product moves through a logistics supply chain. The result is the cost to get a product to two different customers is *almost always* different.

■ Figure 38 Some of the key cost components in a logistics supply chain. The result is the total cost to deliver product to two different customers is almost always different.



Activity-based costing

Some cost components are easy to determine for specific products and customers, but other costs are shared among products or customers and must be fairly allocated. *Activity-based costing* is one allocation method that attempts to accurately allocate resource costs by focusing on the activities performed by the resources. Costs are then allocated based on the activity *levels* needed by individual products or customers.

For example, we could allocate the cost of a vehicle route over a set of customers by first identifying specific route activities, such as driving, loading, and unloading. Some activities are tied to individual customers (such as unloading), and thus the corresponding costs are easy to allocate. Other activities (such as driving) are jointly influenced by customers and must be allocated using some estimate of an individual customer's contribution to the activity.

Benchmarking and Rationalization

Benchmarking is comparing the performance of a logistics supply chain to organizational or industry standards or to some theoretical "ideal." If data is available, it may be possible to compare the supply chain to so-called "best-practice" standards or corporate supply chains that are recognized as industry leaders in logistics operations.

Benchmarking metrics generally fall into two basic groups: *costs*; and *service measures*. Sometimes costs and service measures can be measured directly, but frequently *surrogate* indicators must be used to estimate performance (particularly for service). For example, the inventory turnover rate, the total cycle time of a product in a supply chain, and the movement accuracy (timeliness of actual shipment movements compared to predicted movements) are commonly used as estimates of the level of customer service provided by the supply chain. In general, the more surrogate the metric, the more carefully it should be treated when evaluating supply chain performance.

The *Rationalize* step is the interpretation of the *Evaluation* and *Benchmark* results, and the justification of the logistics supply chain configuration. Tools to use in this step include cost reports, service metrics, and the utilization of resources. Model aggregation is important in this step, as it is important to see the "big picture" of the logistics supply chain and focus on the key opportunities for improvement. Rationalization relies heavily on strong graphical user interfaces that can illuminate resource bottlenecks, high cost elements, service problems, etc.

Generating Alternatives

Introduction

Generating Alternatives includes any change to the logistics strategy, supply chain infrastructure, transportation infrastructure, movement requirements, or the relevant operating parameters. There are four fundamental ways to generate logistics supply chain alternatives:

1. *Existing system*. If the logistics supply chain already exists, then the first alternative analyzed is the current system, and the analysis proceeds directly to the *Evaluating Alternatives* phase.

2. *Specified*. The alternative to investigate could be given, such as a strategic plan that the organization's management would like to evaluate.

3. *Automatic*. The alternative could be generated automatically, using computer algorithms based on mathematical optimization, heuristics, rules, etc.

4. *Interactive*. The alternative could be generated interactively, in an exploratory or "what-if" style.

Automatic Generation of Alternatives

Mathematical Optimization

Analytical models are natural representations of logistics supply chains

One of the most important steps of *LCM* is developing an *analytical* or mathematical model of the logistics supply chain. An analytical representation is natural because of the many quantifiable elements in logistics (such as shipping costs, storage costs, transit times, inventory levels, production capacities, and demand forecasts). *Mathematical optimization* is a powerful class of quantitative models, tools, and algorithms that can be used to *automatically* generate and examine vast numbers of decision alternatives and pinpoint smart alternatives.

Elements of optimization models

A mathematical optimization model consists of the following three components:

- *Objective.* Usually we wish to maximize or minimize some quantifiable goal. For example, common logistics objectives include maximizing profitability, minimizing landed costs, maximizing on-time shipments, or minimizing the number of trucks needed.

- *Decision Variables.* Decision variables represent choices in a logistics supply chain. For example, common logistics decision variables include where to locate facilities, how to route freight, and when to send shipments.

- *Constraints.* Constraints represent restrictions or requirements of the logistics supply chain. For example, common logistics constraints are storage space in a warehouse, available manufacturing capacity at a plant, the number of trucks available, and the shipment delivery time required by a customer.

"Easy" Optimization Models

"Easy" optimization models, linear programming models

Some mathematical optimization models are "easy" in the sense that there are algorithms available that can consistently find the optimal solution in a predictable amount of time. The most useful models in this class are *linear programming* (LP) models. In an LP model the objective and all constraints are linear equations, and all decision variables are "continuous" (i.e., fractions are okay). Very large linear programs with tens of thousands of decision variables or more can be optimized quickly using efficient computer algorithms.

Network linear programs

A special class of linear programs are *network* linear programs which have many natural applications in modeling supply chain networks. *Minimum cost network flows, shortest paths,* and *matching* tools belong to this class, and have applications in resource allocation, production scheduling, and supply chain design.

"Hard" Optimization Models

What are "hard" optimization models?

Some mathematical optimization models are "hard" in the sense that there are algorithms available that can consistently find the optimal solution in a reasonable amount of time, *if the problem size is sufficiently small*. Thus these are "limited size solvable" models. For these models we can optimize small problems but either cannot optimize large problems or cannot solve them with consistency.

Mixed-integer programming models

Many of the most important logistics models fall into the "hard" class. This includes most models of vehicle routing and scheduling, facility location and sizing, shipment routing and scheduling, freight consolidation, and transportation mode selection. These problems can be represented as *mixed-integer programming models,* a class of models with some of the decision variables restricted to integer values. For example, the number of drivers and trucks assigned to drive a certain distribution lane could be 0, 1, 2, etc., but could never be 2.7; a manufacturing plant can either be constructed or not constructed, but not partially built.

Mixed-integer programming models are intractable

Mixed-integer models are often difficult to optimize, as there may be an exponential number of possible decision alternatives. For example, the number of possible combinations of opening or closing n distribution centers is 2^n. There is no algorithm available which can *guarantee* finding the optimal alternative without the possibility of examining many of these alternatives.

A further complication is the effort required to solve a mixed-integer program is often dependent on the specific problem data, and a very slight change to a model may transform a solvable problem to an unsolvable problem. Thus mixed-integer programming models are often better suited for planning when there is sufficient time to use alternative approaches if the solution effort becomes too great.

Heuristics

What are heuristics?

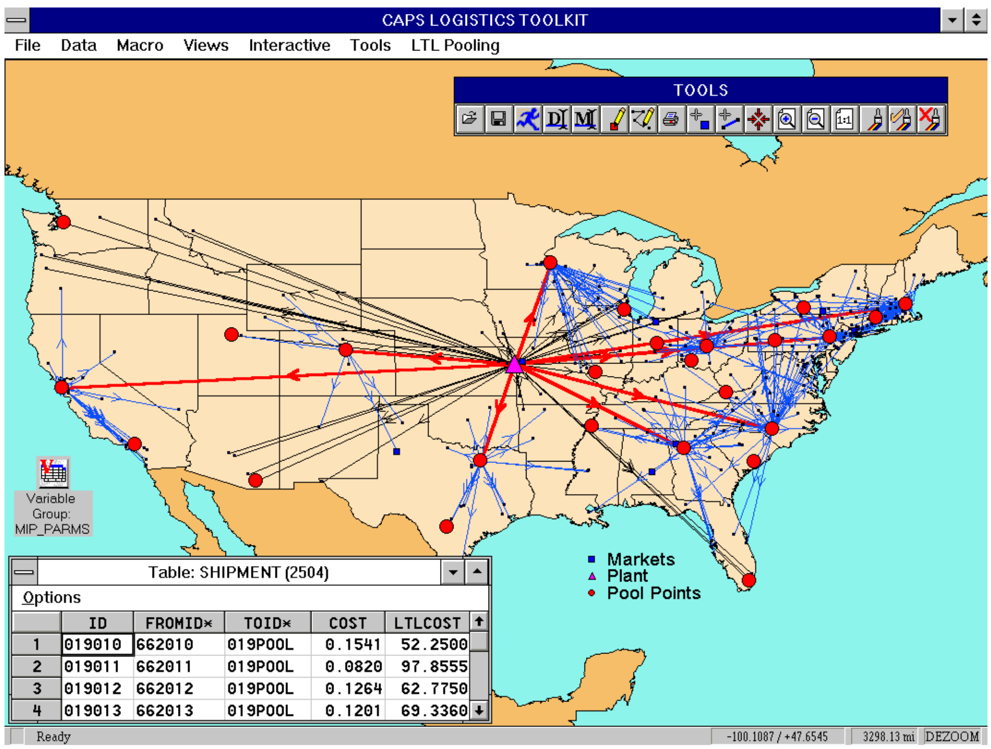
Heuristics are another important class of methods for automatically generating supply chain alternatives and decisions. A heuristic is simply any intelligent approach that attempts to find good or plausible solutions. The heuristic may be based on mathematical optimization, rules, or any other method that can generate alternatives.

Heuristics are often based on optimization techniques

The word "heuristic" sometimes implies a "seat-of-the-pants" solution approach, with little or no intelligence or sophistication used to make decisions. This is unfortunate, as analytical heuristics can be as technically sophisticated as mathematical optimization approaches. Many heuristics are actually based on mathematical optimization methods and algorithms such as using practical rules to formulate a mathematical optimization model. A powerful heuristical approach is to modify a mixed-integer program by temporarily treating the integer variables as linear variables, creating an approximate but much more solvable logistics model. The solution to this problem is then used as a basis for constructing a solution to the integer program.

Interactive Generation of Alternatives

One of the most powerful techniques for generating and analyzing alternatives is *visual logistics modeling*. Visual logistics modeling allows logistics analysts to specify decision alternatives via a combination of mathematical optimization, heuristics, and graphical user interfaces (■ Figure 39). The visual interface shows computerized maps, supply chain infrastructures, transportation infrastructures, flow requirements, schedules, etc. Visual logistics modeling is also ideally suited for understanding a supply chain, as graphical solution representations can often best portray resource limitations, service or cost problems, structural problems with the supply chain, inefficient vehicle routes, and other improvement opportunities.



■ Figure 39
Visual logistics modeling allows the planner to generate logistics supply chain alternatives through logical and interactive map-based and schedule-based user interfaces.

Digital geographic data is an important part of visual logistics modeling, and is also used directly in computations for many types of logistics models. Examples include computing transportation distances, routes and schedules over a highway network, or determining the closest distribution center for a set of customers. Another common application is the use of geographic *zones* as a part of the modeling process (e.g., assign all customers in this area to a particular distribution center).

Comparison of Solution Generation Approaches

Mathematical optimization, heuristics, and visual logistics modeling are all tools that can generate logistics alternatives. Which method is best?

No single solution generation approach is appropriate for all logistics modeling situations, and each method has certain complementary benefits. In *LCM* we first try to represent logistics decisions using a mathematical optimization model because of the power of quantitative models to consider large numbers of alternatives and pinpoint optimal solutions. Note that this means we may wish to use simplified models in order to pose a quantitative model that can be solved in a reasonable amount of time.

We can rely on the mathematical optimization solution if we are confident that our model is a precise representation of the logistics supply chain. But what if:

- The quantitative model is only an approximate representation of the actual logistics supply chain?
- The data is estimated and likely contains errors, or there is operational variability in the supply chain which cannot be predicted?
- There are objectives, decisions, or constraints which are not naturally quantifiable, and require human judgment?
- The model is a “limited size solvable” optimization model?

These are all common aspects of logistics modeling, and require the “composite” approach of *LCM* to bring together various complementary tools. If the quantitative model is a high-level approximation of the real logistics system, then it is critical that the output of a mathematical optimization model is treated as the *input* to the *Evaluate Alternatives* step rather than the final solution.

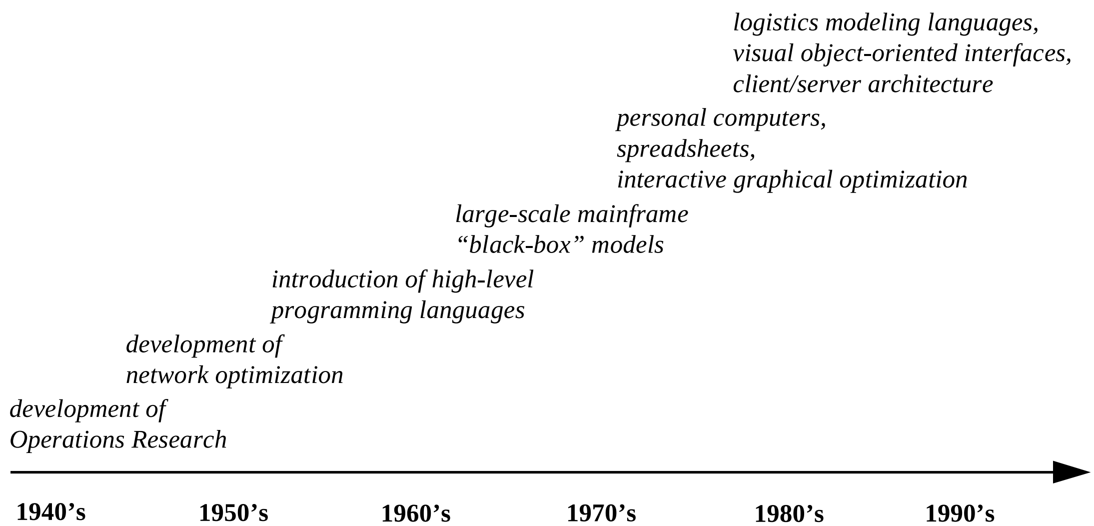
Heuristics are a key part of *LCM*, as heuristics may be able to best handle non-quantitative business issues or rules, imperfect data, and limits on solution time and computing capacities. Generating alternatives using visual logistics modeling software is an excellent way to take advantage of human judgment and control of the decision-making process, increasing the understanding and control of mathematical optimization models.

Decision Support Architecture

Introduction - Evolution of Decision Support Tools

Logistics decision support tools have advanced steadily since the development of Operations Research, and very rapidly in the last ten years. Major milestones are illustrated in ■ Figure 40.

■ Figure 40
The evolution of logistics decision support tools and architecture over the past fifty years.



The next sections summarize classes of these tools particularly useful in logistics modeling.

Computing Architecture

Logistics Modeling Languages

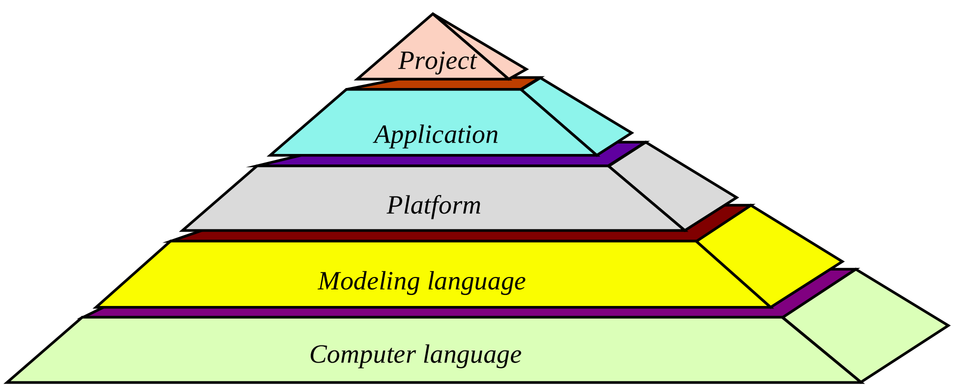
The scope and complexity of logistics systems and models necessitate the use of computer-based decision support systems. Two fundamental classes of software applications are "custom-built" systems developed for unique situations, and "off-the-shelf" systems developed for more general use. Each type of system has inherent problems for use in logistics decision support. Custom systems can be tailored to the unique needs of a business, but generally take a long time to build, are expensive, and are difficult to change as the business needs change. Off-the-shelf systems are less expensive and quicker to implement, but often do not fit the unique logistics issues of an organization.

Combining custom and off-the-shelf benefits

One successful approach for developing flexible and tailored software quickly and cost-effectively features high-level, reusable tools and data objects that can be configured and "programmed" by business analysts and end users. This type of programmable software system features a *high productivity* language. Spreadsheet and database software applications are two excellent examples of high productivity software languages.

Spreadsheet and database systems are useful in logistics modeling, but a richer architecture is needed as a foundation for *LCM*. ■ Figure 41 illustrates a hierarchical architecture for logistics decision support based on a logistics modeling language. At the lowest level, a low-level programming language such as C++ is used to develop the logistics modeling language, comprised of logistics data objects such as those described in the *Logistics Objects* section, analytical tools, and a macro control language.

■ Figure 41
A flexible logistics decision support architecture includes layers for programming tools, modeling tools, classes of models, specific systems, and scenarios.



Decision Support Architecture (continued)

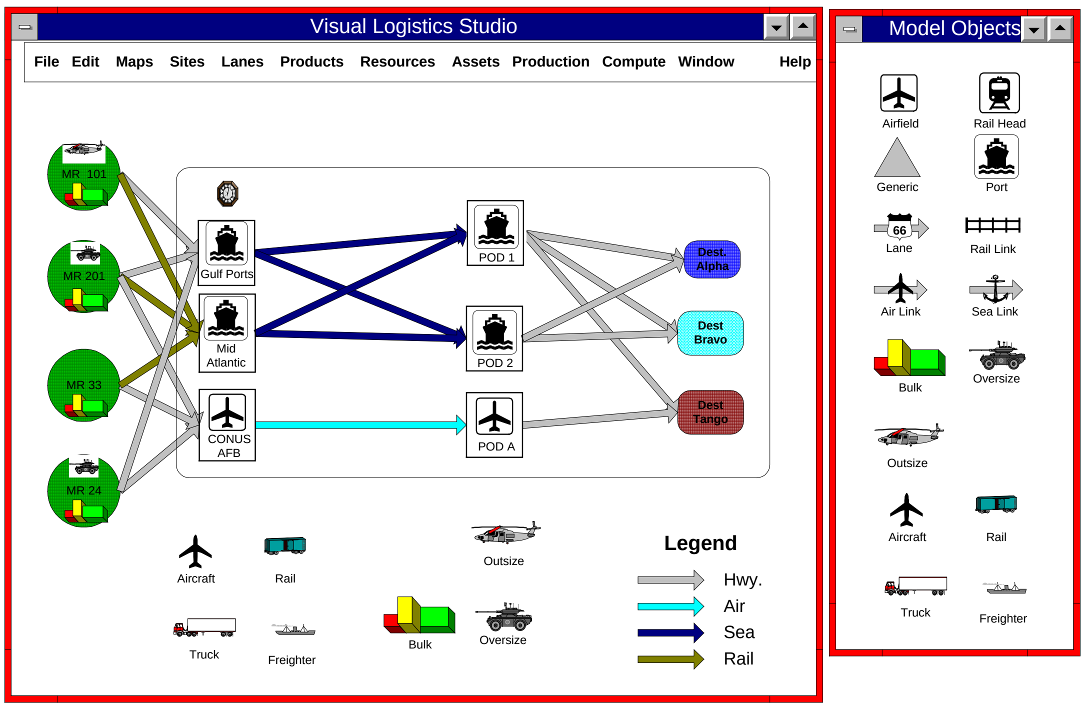
Next, a "platform" or set of macro libraries is assembled, providing an almost off-the-shelf software application to a well-defined set of logistics issues (such as vehicle route dispatching, fleet sizing, supply chain facility location, and production planning). Note that a platform can be easily modified or extended to form a unique application (such as an organization's private fleet routing scenario), as platforms are written entirely in the modeling macro language.

Finally, scenario alternatives to a specific application can be represented as distinct projects. Note each layer of the decision support architecture becomes more focused towards a specific set of logistics issues, culminating in a well-defined problem and set of logistics decisions.

The advantages of the layered architecture approach are many: a custom software solution is possible; systems are developed quickly; platforms and applications can be changed and enhanced; and software quality is high as reusable tools and data objects comprise the foundation. The first commercial logistics decision support system based on a layered architecture supporting *LCM* is the ***CAPS LOGISTICS TOOLKIT®***[7], introduced in 1989.

Visual Logistics Modeling

Contemporary software applications are characterized by highly visual and object-oriented user interfaces, providing a natural conceptual representation of a logistics problem. Data representations are raised to natural and intuitive representations (icons for ports, planes, etc.), and commands are issued through direct manipulation of these visual objects. ■ Figure 42 illustrates this type of user interface.



■ Figure 42 An advanced visual logistics modeling interface features object-oriented representations of logistics systems and models.

A visual and object-oriented user interface includes galleries or libraries of logistics objects, strategies, and model templates. The interface manages the various model representations useful in logistics modeling, including map-based geography, time-based scheduling charts, algebra-based mathematical optimization formulations, row-and-column-based spreadsheets, and table-and-record-based database views.

Modeling-by-example

The user can sketch out a conceptual picture of a logistics problem using this type of user interface in a “modeling-by-example” style. Lower-level and more procedural details such as model formulation and generation, data connections, data validation, etc. are handled automatically. Object-oriented approaches in particular are more productive because we can efficiently specify objectives, costs, and constraints for entire classes of logistics elements.

Client/Server Computing Architecture

Computing architecture has evolved from mainframe computers, to personal computers, to networks of desktop client computers linked by servers to form a *client/server* architecture. This type of computing architecture is ideally suited to *LCM*. Desktop computers are suitable for highly interactive personal productivity tools such as a logistics decision support system based on visual logistics modeling concepts. Host database servers allow large logistics databases to be shared throughout the various business functions forming an enterprise's logistics supply chain.

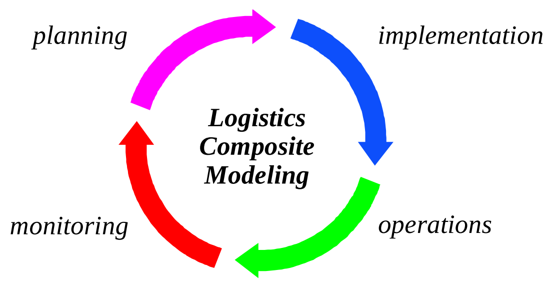
Summary

Review

LCM is suitable for logistics business decisions spanning a range from *planning* to *operations*. Operations refers to the actual management and execution of a logistics supply chain. Planning includes all of the analysis and design studies undertaken prior to system operation. Planning also includes an understanding of how the logistics system is expected to operate after system implementation and/or modification, although not in as much detail as required during actual operation.

More time is available in planning, so many decision tradeoffs and alternatives can be evaluated and there is greater opportunity for user interaction with models. This is important, because changing a logistics supply chain is complicated, disruptive, time-consuming, and expensive. In contrast, supply chain operations require immediate decisions, so little time is available for generating and testing alternatives. Hence automation is more important here, but pre-planning is still extremely important in order to control and limit the scope of operational decisions. Note planning and analysis activities should continue even after a logistics system becomes operational, in a continuous review and improvement style (■ Figure 43).

■ Figure 43 Logistics modeling is an ongoing process and should iterate between planning and operations.



Another opportunity to apply *LCM* is in the integration of supply chains across entire enterprises. Similar to the integration of inbound and distribution logistics within an enterprise, enterprise supply chains such as vendor systems, manufacturing systems, and customer systems can be viewed as interacting processes. Further, logistics customers and service providers are increasingly sharing information about future needs and capabilities, allowing service providers time to anticipate and plan for efficient resource utilization, which creates logistics savings that can be passed back to the logistics customer. *LCM* provides a common foundation of logistics objects and analytical processes, allowing closer integration of data and decision support models across enterprises.

Notes

[1] The United States Council of Logistics Management , Oakbrook, Illinois, defines logistics: "*Logistics is the process of planning, implementing, and controlling the efficient, effective flow and storage of raw materials, in-process inventory, finished goods, services, and related information from point of origin to [point of consumption (including inbound, outbound, internal, and external movements) for the purpose of conforming to customer requirements.*"

[2] Fortune, November 28, 1994.

[3] Via gopher://sunny-state-usa.gov:70/00/budgetfy96/perspectives/bud96p26.txt.

[4] Business Week, January, 1994.

[5] Ibid.

[6] *The GIS World Sourcebook*, published by GIS World Inc., Fort Collins, Colorado, or *http://www.gisworld.com*.

[7] CAPS Logistics, Inc., Atlanta, Georgia, USA, or *http://www.caps.com*.

Suggested Readings

Ballou, R.H., *Basic Business Logistics* (Englewood Cliffs, N.J.: Prentice-Hall 1987).

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Rumbaugh J. et. al., *Object-Oriented Modeling and Design* (Englewood Cliffs, N.J.: Prentice-Hall, 1991).

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