CHAPTER 79

Transportation Management and Shipment Planning

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1. INTRODUCTION

Uncertainty breeds inventory. Managers involved in transportation often have to make planning decisions, like routing, that directly affect the movement of raw materials or finished goods. These decisions often affect other components in the supply chain network, in which case the transportation management team cannot afford to make an incorrect decision. Consequently, any mistakes not only jeopardize other elements within the system but also lead to customer dissatisfaction created by the delay in the delivery times (Quinn 1998).

Beyond routing decisions, however, effective transportation management will assist with solving common transportation and shipping problems by generating various scenarios and simulations in order to arrive at optimal or best solutions for shipment planning, the selection of distribution center sites, and the allocation of resources to critical system components.

2. THE OPTIMIZATION PROBLEM

Often, optimization problems seek a solution where decisions need to be made in a constrained or limited resource environment. The majority of supply chain optimization problems require matching demand and supply when one, the other, or both may be limited. By and large, the most important limited resource is the time required to procure, make, or deliver something. Since the rate of procurement, production, distribution, and transportation resources is limited, demand cannot be im-

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mediately satisfied. There is always some amount of time required to satisfy demand, and this may not be quick enough unless supply is developed well in advance of demand. In addition to time, other resources, such as warehouse storage space or a vehicle's capacity, may be constrained in meeting demand. All of these factors drive inventory levels, which in turn drive costs.

In achieving optimization, decision variables that are within the control of the planner, such as when to manufacture an order or when and how much of a raw material needs to be ordered, must be balanced with the inherent constraints or limitations that are placed upon supply.

Constraints, such as a supplier's capacity to produce raw materials or components or a customer's distribution center's capacity to handle and process receipts, can be considered either hard or soft constraints. Hard constraints, such as the number of working hours in a shift or the maximum capacity of a transportation vehicle, must be adhered to or satisfied. Soft constraints, on the other hand, can be relaxed or violated. Examples of soft constraints include customer due dates and facility storage limitations. Customer due dates can be modified or product may be temporarily allocated in a warehouse, making constraints less harsh. However, there are cost penalties if a soft constraint is not adhered to, permitting constraints to be weighted by their relative significance. For example, missing a customer due date carries more important consequences than cluttering a warehouse aisle (Lapide and Shepherd 1999).

3. SUPPLY CHAIN MANAGEMENT AND THE TRANSPORTATION ELEMENT

At the center of today's supply chain optimization technology are complex algorithms that can examine millions of variables and solve increasingly complex problems in ever-shortening time frames, enabling solutions in a matter of hours rather than days.

The traditional trade-off in supply chain management has been the maintenance of costly buffers of inventory vs. the ability to meet complex customer prerequisites. Reduce safety stocks and costs will be reduced, but customer service may suffer. Due mainly to advanced planning and scheduling systems and improved forecasting applications, production planners now have the opportunity to reduce reliance on safety stock—while still meeting customer demand—by trading inventory for information.

In transportation management, a similar trend is occurring, but rather than inventory buffers, logistics managers are doing away with time buffers. By using information technology in the elaborate mix of transportation modes, carriers, and shipment consolidation possibilities, manufacturers are obtaining more accurate estimates of the time and cost it will take to deliver goods throughout their supply chains. Transportation management applications are being used to better plan and execute shipments. The software lends visibility, consistency, and economy to the handling of complex variables. Some manufacturers have even begun to integrate their transportation and order management systems, giving transportation optimization an up-front role in supply chain dynamics.

Whether approached on a strategic level or shorter-term tactical and operational levels, transportation management, using new technology, is trimming time and cost. And time, according to most experts, is one of the most precious commodities in today's supply chains. Shortened product life cycles necessitate time-based competition throughout the supply chains (Michel 1997).

For some time now, optimization techniques have been used to solve for least-cost shipping configurations. The classic transportation problem was to solve for the best combination of routes that fulfilled all the demands, subject to all the availability and, naturally, at the least cost. With a considerable number of possible routes, the problem was too complex to solve by hand, and therefore linear programming and network algorithms provide quicker solutions to the problem.

Although times have changed, these methods are every bit as applicable today as they have ever been. While the nature of the model constraints is considerably different and more complex, optimization modeling aids in filling the supply chain more effectively. Thus, transportation vendors have been customizing their delivery systems to meet a more stringent set of customer requirements.

In our global economy, customers are demanding items having exact options, in exact quantities, of zero defect, to be delivered precisely at specific locations, on certain production lines, and at exact times. In light of this new paradigm, we are still confronted with managing transportation costs. As the marketplace demands a far more flexible delivery system, both shippers and carriers are hard pressed to balance these demands against a complicated set of constraints. Fortunately, through mathematical modeling, all the competing requirements in arriving at not only a feasible but also an efficient delivery program can be evaluated and studied.

Linear programming (LP), commonly used to solve a variety of industrial and scientific problems by arriving at an optimal solution, has been around since the 1940s. The early applications for LP that yielded the largest benefits involved creating schedules for massive capital investments such as rail, bus, and airline schedules. With ever-increasing competitive markets, however, additional requirements have been added. Linear programming still remains an effective technique to solve a variety of industrial applications problems (Lustig 1999).

Specific to transportation and logistics issues, some applications include:

1. Transportation and distribution:
   - Shipping plans: Determine optimal shipping assignments from manufacturing facilities to distribution centers or from warehouses to consumers (e.g., customer direct).
2. Site selection:
   - Facilities: Establish the optimal location of a plant or distribution center with respect to total transportation costs between various alternative locations and existing supply and demand sources.
3. Scheduling:
   - Shifts: Solve for the minimum-cost assignment of workers to shifts, subject to varying demand.
   - Vehicles: Allocate available vehicles to jobs and determine the number of trips to make, subject to vehicle size, availability, and demand constraints.
   - Routing: Solve for the optimal routing of a product through a number of sequential processes, each with its own unique capacities and characteristics.
4. Production Planning:
   - Production: Solve for minimum-cost production scheduling for an established workforce, taking into account inventory carrying and subcontracting costs.
   - Production and workforce: Solve for minimum-cost production scheduling, accounting for hiring and layoff costs as well as inventory carrying, overtime, and subcontracting costs, subject to various capacity and policy constraints.
   - Staffing: Determine the appropriate staffing levels for various categories of workers, subject to various demand and policy constraints.

4. TECHNOLOGY REQUIREMENTS

A general trend exists toward increased systems integration within the supply pipeline in order to create and provide better information faster. In turn, this has decreased standard transactional costs but has also led to a fundamental restructuring of industry practices for distributing and supporting goods and merchandise. Over the last few years, decision points, such as supplier selection, price, quantity, routing, and delivery, have required greater coordination throughout the supply chain. Hence, these critical activities have become more and more integrated systems themselves in order to govern the flow of physical goods between shipper and consumer (Lewis and Talayevsky 1997). According to Donald J. Bowersox, the John H. McConnell Professor of Business Administration at Michigan State University, ‘‘technology serves as the primary enabler to facilitate supply-chain-wide integration while simultaneously allowing key business relationships to be conducted on an exclusive enterprise-to-enterprise basis.’’

4.1. The Need for Information

As cycle times are reduced and more efficient inventory processes are embraced, transportation buyers have become more increasingly concerned with the location of a shipment in the logistics pipeline than with the shipment itself. Providing information on a shipment, including its contents, its current location, its destination, and its expected time and date of arrival, is critical in transportation planning.

This desire to have timely and accurate shipment information has transportation providers investing millions of dollars each year on high-tech bar coding, communications, and networking equipment. This desire has also made information one of the most important factors in the transportation equation.

The factors that have made shippers demand more information on their shipments reflect major shifts in business practices, new shipping patterns, and the availability of new and more affordable technology.

Advanced manufacturing research (AMR), a market-analysis company that specializes in supply chain technology, estimates that there will be a 48% compound annual growth rate for supply-chain management software until 2003. That will put annual sales of these integrated suites at nearly $19 billion. Transportation management systems, with 1998 sales of $314 million, are expected to reach $1.9 billion by 2003 (Forger 1999).

Simply stated, businesses do not operate the way they used to. Instead of stockpiling finished goods in warehouses, shippers are adopting just-in-time (JIT) and lean manufacturing strategies, which operate with little or no inventory. And this has had a significant impact on transportation management, shipment planning, and the information associated with it.

4.2. Information Exchange

In order for shippers really to improve their operations, they must be willing to share critical information, such as production, supply, and cycle time data, with their transportation providers and other supply chain partners in order to make the entire process more effective.

Sharing this type of information with suppliers allows for many new transportation and distribution alternatives, allowing carriers to reroute loads in transit, consolidate shipments for more efficient distribution, and merge shipments so they arrive to customers as a single order. In the information technology age, sophisticated shippers will know not only where to get accurate data on their shipments but also how to leverage that data to improve operations along their companies' supply chains. This information is being used by shippers and transportation suppliers in the following manner (Minahan 1997):

By shippers:

- Process orders
- Tender freight
- Shop for rate and schedule data
- Generate, transmit, and file shipping documents
- Manage inventory and multiple-point distribution
- Trace shipments
- Measure carrier performance
- Identify supply chain weaknesses
- Process and pay freight bills
- Budget and manage costs

By carriers:

- Receive freight bookings
- Construct rate quotes
- Issue bills of lading
- Track and manage equipment
- Plan routings
- Determine load sequencing
- Manage documentation
- Trace shipments in transit
- Monitor equipment utilization
- Respond quickly to failure situations
- Coordinate consolidated loads and multiple-point distribution
- Confirm pickup and delivery
- Generate performance, accounting, and other reporting
- Issue freight bills

In the context of industrial engineering, many times industrial engineers will be charged with the development, integration, and execution of the complex systems used in supporting these activities.

5. TRANSPORTATION MANAGEMENT SYSTEMS: SUPPLY CHAIN'S FINAL STAGE

The real potential of transportation management systems (TMS), beyond operational efficiencies, is the substantial cost savings that it is capable of generating for shippers. Recognizing the enormous logistics costs that are transportation related, transportation management is as complex and difficult as any other problem associated with an organization's business environment.

Transportation management, an integral part of a firm's logistics strategy, involves purchasing, monitoring, and controlling freight transportation services (Temple, Barker, and Sloane 1982). Considering that, on average, 3.5% of a manufacturer's sales costs and 40–60% of total logistics costs are devoted to the movement of products, transportation management is essential in today's business environment. Therefore, incorporating TMS into a supply chain management strategy is also essential

(Weil 1998). The potential savings from identifying, for example, shipment inefficiencies, excess labor, and other unnecessary costs on a regular basis can be substantial.

The identification of cost-savings opportunities occurs primarily because the system automates the shipping and carrier selection process. In addition, TMS functionality includes load planning, rating, pickup scheduling, shipment consolidation, freight payment, and claims management. With this type of real-time information available, TMS introduces flexibility into a company, allowing the shipping department to make last-minute, but accurate, decisions as priorities and carrier costs shift (Forger 1999).

Standard software packages (see Table 1) are available that directly reduce operating costs by optimizing shipment plans, including freight consolidation, mode/carrier selection, and dedicated fleet routing and scheduling. Other benefits include improved service due to more accurate and timely shipments and the automation of manual processes. The best transportation management software, however, has strong strategic and tactical planning modules, which allow extensive "what-if" capabilities to optimize the design of a transportation network. They also aid the planner in the determination of fleet size, the design of fixed/master routes, consolidation strategies, optimal shipment size/frequency, and territory design.

5.1. Pickup, Delivery, and Routing

A primary transportation management concern is the determination of how to utilize a given fleet of vehicles efficiently. To minimize total cost, whether small-parcel, less-than-truckload (LTL), ship-

TABLE 1 Leading Transportation Management Products

Software Provider	Product	Functions	Platforms
CAPS Logistics Inc.	TransPro	Freight consolidation and mode/carrier selection	Windows, Windows NT
i2 Technologies Inc.	Rhythm Transportation Optimizer	Load consolidation, routing, and carrier selection	Windows NT; Unix version due shortly
Manugistics Inc.	Transportation Management	Plans and optimizes shipments for multipoint distribution; includes freight payment to facilitate Web-based carrier tenders	Windows NT, Unix
McHugh Software International	McHugh TMS	Mode/carrier selection, electronic load tendering, carrier assignment, Web tracking, and rating/auditing	Windows NT, Unix
Optum Inc.	Optum SCE Transportation	Optimizes transportation for timely delivery by the most efficient carrier	Windows, Unix
Provia Software Inc.	FreightLogic (formerly from Pinnacle Distribution)	Optimizes order processing to plan most economical loads	For hosted model, PC with Internet connection; for in-house model, Windows NT server
Sabre Inc.	OptiBid	Solicits carriers, analyzes bids	Client/server technology that runs on Windows NT
	OptiFlow	Freight consolidation and routing and scheduling	Unix workstations
	OptiMatch	Evaluates and processes real-time load demand data to recommend mode and carrier	Dedicated networked workstations

Source: Tausz 1999.

ments that are typically too large for the package companies and too small for truckload (TL), or carriers that transport trailers direct from origin destination, determining the pickup and delivery sequence of shipments assigned to each vehicle is subject to a variety of constraints (e.g. vehicle capacity and pick-up/delivery times).

This problem can be modeled as a vehicle routing problem (VRP) with numerous side constraints. Recognizing that the VRP is notoriously hard, the size and scope of the real-world data sets can make it impractical to just formulate the problem as an integer program (IP) and use an advanced IP solver to get an optimal solution. Therefore, practitioners usually seek solution techniques that yield acceptable solutions within a reasonable time frame (see Chapter 30). Some of these techniques include:

- Route-building heuristics select arcs greedily in a sequential manner until a feasible solution has been formulated.
- Route-improvement heuristics start with a feasible solution and seek a minor change that reduces cost while maintaining feasibility.
- Mathematical programming-based heuristics solve to optimality some mathematical programming approximation of the problem using several techniques (e.g., Lagrangian relaxation algorithm and column generation).
- Artificial intelligence/self-adaptive methods start with initial feasible solutions, then repeatedly make a local change to the current solution (such as swapping shipments between vehicles). In turn, each new solution is accepted if it satisfies certain criteria. Whereas traditional local improvement methods accept a local change if it strictly decreases the cost and stop when such a change does not exist, taboo search and annealing, for example, allow the selection of nonimproving solutions under certain conditions.

Regardless of the chosen technique, it is important to understand the business rules concerning fleet and vehicle utilization. Therefore, observing current procedures and obtaining real data early in the development process will allow the business rules to be incorporated directly into the model as constraints or applied in a preprocessing step to drastically reduce the problem size. This will make the problem more manageable and help ensure that the plans the transportation management software generates can be implemented in practice (Ergun 1998).

5.2. Case Study: Electronics Industry

An electronics manufacturer had 400 transportation providers within its United States distribution network. Only 42 carriers delivered 98% of the volume. Of this select group, United Parcel Service was the primary carrier handling outbound ground movements, inbound shipments, and less-than-truckload freight to their customers or from suppliers. Due to either the physical product or package constraints, there were few exceptions that prevented them from having a minimum number of carriers within their distribution network. That network consisted of two plants (Syracuse, NY, and Salt Lake City, UT) and four distribution centers (Atlanta, GA, Chicago, IL, Dallas, TX, and San José, CA).

Since transportation represented more than 40% of the company's total logistics expenditures, they began to aggressively pursue opportunities to create additional value through their service providers.

Their primary goal, from a logistics perspective, was to maintain or expand delivery coverage while the number of distribution centers would be potentially reduced to zero. Ultimately, all customers would be served from only the two plants, Syracuse and Salt Lake City, within two days. The offer of a two-day delivery for all products to all customers would be a first within their industry and would give them a tremendous competitive advantage by freeing up cash and generating sales.

Serving customers within two days, however, required an entirely new operating plan for both UPS and the electronics firm. Based upon 18 months of historical distribution data (e.g., traffic lanes, product distribution by customer, mode usage, etc.), various cost scenarios were determined by specific transportation provider, origin, destination, ZIP codes, weight, number of packages, and so on. Every element related to transportation that could be measured was analyzed and associated with a specific product and product group. From this, a plan was developed that met the objectives to lower inventory, reduce overall logistics costs, and improve customer service levels.

The preliminary analysis indicated that a reengineered network and operation, customized to the customer's specific characteristics and requirements, could function with two sites that could deliver 35.5% of the shipments the next day, followed by 63.6% and 0.9% by the second and third day, respectively.

To implement the second-day coverage, the planning team developed a master operating plan divided into phases over a few years. Within each phase were various scenarios that addressed package characteristics, overall volume, pull times, hub sorts, and so on. For example, the plan called for direct loads to be built for final destination hubs, bypassing intermediate hubs, reducing handling and processing time. This reduced costs and increased the geographic coverage. As additional volume entered the system, more direct loads were made. The plan was highly customized with the manufacturer's and the carrier's requirements, which incorporated shipment origin data, destination ZIP codes, volume adjustments, trailer departure times, linehaul transit times, and hub sort start and stop times.

Their annual logistics costs, with an average inventory of $500 million, was $186 million at the beginning of the project. This was composed of:

- $38 million in transportation
- Inventory carrying costs (including cost of capital, depreciation, obsolescence, damage and shrinkage) at 25% the value of the inventory or $130 million
- Fixed distribution expenses added another $18 million

As mentioned before, management wanted to decrease total logistics costs by reducing warehouses. A consolidated network would reduce inventory levels and other associated costs. Transportation costs could increase since it was estimated that there would be a trade-off in this case between less critical next-day air shipments and stock transfer shipments but more direct and smaller customer shipments.

Although logistics problems such as this one are complex because there are so many possible combinations of the underlying variables, a good solution was found. With two-day service recognized as the only acceptable service level, the key criterion was known. Incorporating the parameter to ship using mostly ground transportation established the overall cost objective. Utilizing optimization-based software to determine the best routing within the UPS ground network identified the necessary geographic coverage. Anything beyond two-day ground capability was supplemented with two-day air shipping (meeting the criterion of eliminating next-day air shipments).

The project was successfully implemented and has achieved the original goals. The reduction of warehouses and the associated inventory resulted in significant savings. With reliable transportation services established throughout the redesigned distribution network, inventory levels dropped to $385 million. In turn, the logistics budget was reduced by approximately 28% to $134 million:

- $32 million in transportation
- Inventory carrying costs (including cost of capital, depreciation, obsolescence, damage, and shrinkage) at 25% the value of the inventory, or $96 million
- Fixed distribution expenses adding another $6 million

The keys to successful implementation of this type of project include:

- *The approach to implementation:* Use a team-based concept for all project implementations, from inception to completion. To accomplish this, immediately identify the most qualified individual to be the project manager and begin formulating the project-implementation schedule itself. The schedule, which will be a mutually agreed-upon timeline, will incorporate the strategies of all parties.
- *The implementation team:* Experienced managers who represent critical areas that will be impacted by any potential changes. For example, industrial engineering, logistics planning, information technology, and finance are all essential functions to be represented in a cross-functional team.
- *Milestones:* Establish significant tasks that must be accomplished and acknowledged by the team before proceeding with other critical assignments. Validation of data and requirements or system testing or training of management and staff, for example, are important steps as the project proceeds. In addition, discussing and validating the original project charter is also critical in order to stay on the intended course.
- *Critical dependencies:* Since each party recognizes that the project must adhere to an aggressive timeline, all critical points must be responded to quickly. To complete the implementation process on time, both parties must reach consensus and respond as soon as possible.
- *Contingency planning:* Although there is an established implementation timeline, adhering to it is challenging. There is always the probability that an issue or a variety of circumstances can delay or jeopardize the final implementation date. Therefore, if changes occur that can potentially affect the optimum design plan, for example, dates should be extended past the date originally set forth in the beginning of the project.

5.3. The Traveling Salesman Problem

The traveling salesman problem (TSP) (Lawler et al. 1985), the classic problem in which a mythical traveler must find a minimum-length cycle through a set of nodes in a completely connected graph, has an important place in computational complexity theory. But more significant for the transportation and logistics industry is that it has an important place in a continuously expanding field of operations research: vehicle routing.

As an illustration of a TSP application, suppose that a traveler starting from Chicago must visit several U.S. cities exactly once and return to Chicago. A solution to this problem is shown in Figure 1.

A computer scientist would call the TSP a ‘‘hard’’ problem because of the long computer times needed to solve large TSPs optimally. Yet transportation dispatchers, faced with the real problem of routing large fleets, would find that their problems include factors that the TSP does not account for, including:

- *Route capacities and times:* Each cycle is constrained by the available space in a vehicle, which might be measured by cubic volume, weight, number of pieces, or floor space (if items are not stackable). The cycle is also constrained by the time in a driver’s day, which itself depends on safety regulations, company work rules, and whether the driver has already handled other loads.
- *Time windows:* To remain competitive, companies are much more responsive to their customers’ needs and deliver shipments exactly when customers want them. These requirements are stated as time windows, either as rigid lower and upper bounds or as soft time windows, which can be violated with penalty.
- *Dynamic routing:* Planning out the stops in advance is not always possible. Often all stops aren’t known until the vehicles are in the field, partway into their routes, forcing them to double back or circulate to finish their tour. In addition, travel times and costs are time dependent because vehicles confront the commuter rush hours on the road, as well as at the loading and receiving docks.
- *Randomness:* Finally, nothing is certain. A shipment that is supposed to have 10 pieces turns out to have 25, and immediately there’s not enough space to finish the route. Or perhaps a driver is detained with paperwork and doesn’t have time to visit the rest of the stops or get back to the airport gateway in order to connect with the next flight out.

Thankfully, industrial engineers and software developers are aware of these real constraints, which are handled by various extensions of the TSP (Ball et al. 1995; Golden and Assad 1988). For example, route capacities and times are considered by the vehicle routing problem (VRP), while time window constraints are included in the TSP with time windows (TSPTW) and the VRP with time windows (VRPTW). Advances in telecommunications make it now possible to implement models that take into account the dynamic aspects of vehicle routing, while time-dependent vehicle routing problems take into account time-dependent travel times and costs. The stochastic aspects of cost, time, demand

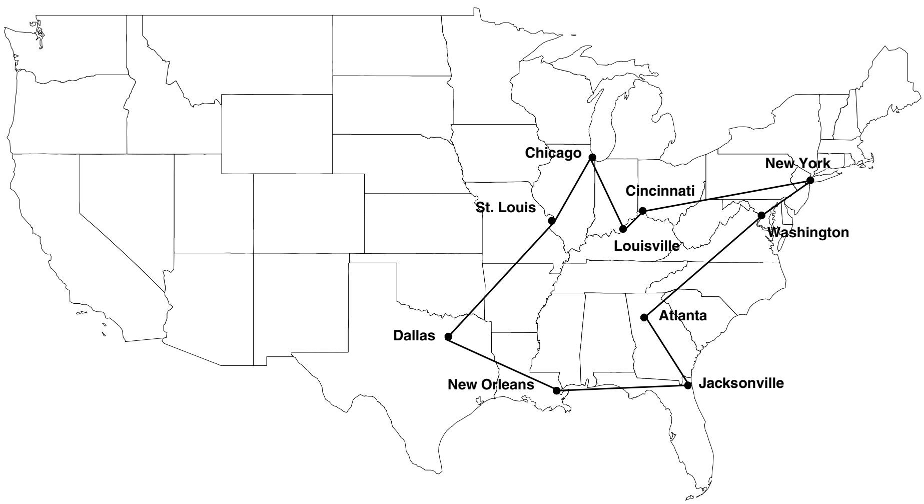

Figure 1 A TSP Tour through 10 U.S. Cities.

size, and even the presence or not of a customer are considered in the stochastic versions of the problems.

Since these problems are very difficult to solve optimally, TMS packages employ a blend of heuristic and optimization algorithms to assist dispatchers in routing their vehicles. In addition to creating more efficient routes, meaning fewer miles, fewer labor hours, and fewer vehicles, not to mention getting stops served on time, today's transportation management software is being integrated into the overall supply chain process to manage the movement of goods from source to destination, tracking the productivity and quality of drivers and generating information for planning purposes, all in a paperless environment.

5.4. The Vehicle Routing Problem

The vehicle routing problem (VRP) (Christofides 1985) is a capacitated version of the TSP. A fleet of vehicles is available at one or more terminals to serve a set of defined stops. A shipment size is associated with each stop, and a cost is associated with the movement between each pair of stops (and between a stop and a terminal). The goal is to deliver the shipments to all the stops at minimum total cost in a set of cycles without violating vehicle capacity. The VRP formulation matches well local pickup and delivery problems where the pickup stops are known before the vehicle starts on the route.

Solving the VRP or its variants may necessitate actually solving additional problems. First, the input to the problem needs to be obtained, such as the distances, travel times, or costs between each pair of stops. This can be achieved either by approximate calculations or by using geographic information systems (GIS). Using approximation, the coordinates of each stop are determined and the distances in a straight line are computed. Since a vehicle cannot drive straight from point to point, the distances must be adjusted upward by about 15% to approximate actual road mileage.

When GIS is used, distances between stops are derived from shortest path algorithms applied to very large networks rather than by simple algebraic calculations. GIS distances are more exact than approximations (especially when stops are separated by bodies of water or mountains), but they are not without flaws. Errors in the input data can occur, and sometimes only an experienced truck driver knows that a fast car route is impossible for a semi-tractor negotiating sharp turns. Nevertheless, GIS are an invaluable source of point-to-point distance and time data, particularly for shorter-length trips, where accuracy becomes even more important. GIS is fast enough to be practical, but GIS data are much more expensive to acquire than by using simple approximations.

From the distances between each pair of stops, travel times are computed assuming specific speeds. Costs are computed assuming vehicle and driver costs particular to each application.

Solving the VRP determines which vehicle serves which stops and in what sequence. There are different solution methodologies for solving the VRP, either optimally or heuristically. Since optimal algorithms can solve only small problems, emphasis is given to heuristics algorithms that aim at finding near-optimal solutions.

Some algorithms assign stops to vehicles and determine the stop sequence concurrently. Other algorithms use the so-called cluster first, route second approach, which consists of the following two steps. First a service area is partitioned into smaller regions, where each region represents a feasible collection of stops for a single route. These regions can overlap, especially when time windows are involved or when requests for pickups arrive dynamically throughout the day. Determining the sequence of stops in a single region amounts to solving a TSP (or a TSPTW, if time windows need also to be satisfied).

If the same 10 cities were considered as in the TSP example but a capacity constraint was added that necessitated the use of three vehicles, the VRP solution could look as in Figure 2.

While the previous description represents a generic implementation, specific vehicle routing applications may have their own individual characteristics, requiring that transportation management and shipment planning software be customized to reflect the operating environment, customer needs, and the characteristics of the transportation mode (Hall and Partyka 1997).

Chapter 30 presents a detailed overview of the VRP and its applications in transportation.

5.5. Other Vehicle Routing Problems

The VRP matches quite well local pickup and delivery routing in the trucking industry. Long-distance truck routing, however, is much more focused on crew-assignment issues, along with balancing interregional freight flows. The problem is much more closely related to transshipment problems than to the VRP, where the objective is to balance the flow of equipment and drivers in and out of terminals while minimizing empty mileage. This must be solved within the context of routes that can take up to several days to complete, requiring driver or equipment exchanges or possibly sleeper/driver teams that operate almost continuously.

Vehicle routing can be divided into three primary categories: service vehicles, passenger vehicles, and freight vehicles. Service vehicles usually do not move things or people from place to place

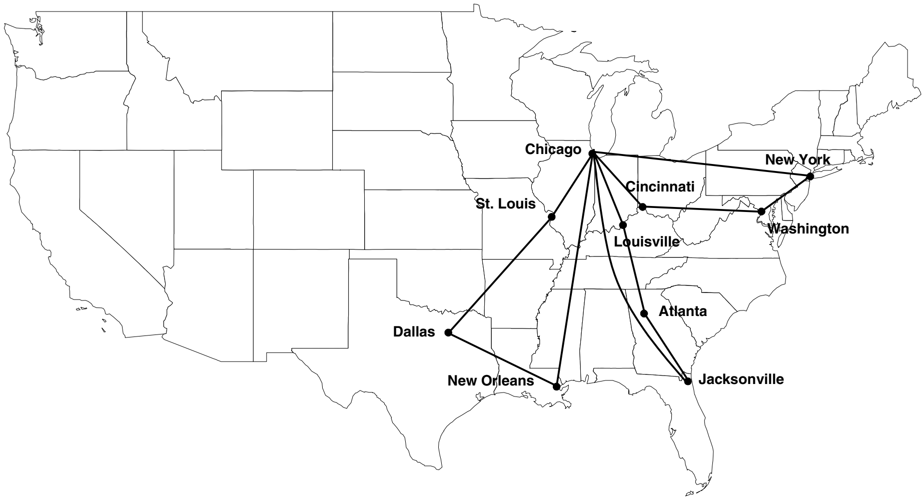

Figure 2 A VRP Solution Using Three Vehicles.

(snow-salting vehicles are an exemption to this) but are used to support jobs in the field (e.g., vans for the copier repair technician or trucks fixing potholes). When service routes are not constrained by shipment sizes and vehicle capacity, the route lengths are constrained only by the time in the driver's day or shift. Local pickup and delivery in the package transportation industry is also dominated by the duration of driver shifts rather than capacities, while time windows are of primary importance to this industry.

In contrast to service vehicles, passenger fleets or carriers carry something from one place to another. Buses and vans, for example, carry people, so the lengths of their routes are constrained by the number of seats, or possibly by a combination of standing and sitting room. Freight vehicles, including ships, trucks, rail, and air, are also capacity limited. When a shipment or passenger is carried from one place to another, it may be transported through a logistics network of terminals connected by a variety of different routes. For example, the less-than-truckload (LTL) industry specializes in shipments that are typically too large for the package companies (such as United Parcel Service) and too small for truckload (TL) carriers, which transport trailers direct from origin to destination.

LTL shipments are commonly handled in at least two, and probably up to four or five, terminals. First the shipment is picked up from the origin and taken to a local end-of-line terminal. Next it may be shuttled to a regional consolidation center, where it is consolidated with shipments originating throughout the general metropolitan area or geographic region. Next the combined load is transported on a long-haul route to another consolidation center, near the final destination. From there, the reverse takes place. The shipment is shuttled to an end-of-line near the destination and finally on a delivery route to the customer's destination.

Each segment of the LTL shipment's journey demands a different kind of route and has a different routing challenge associated with it. Local pickup is a dynamic problem that requires flexibility to serve shipments as they are called in. Shuttle routing necessitates careful driver scheduling to ensure that workshifts are fully utilized. Linehaul routing requires balancing interregional flows to minimize empty equipment miles and reduce driver and fleet downtime. In the end, only the final segment of the trip—the delivery route—closely matches the VRP formulation, while the rest of the problems are solved by a variety of network design and crew-scheduling problems that often need to be customized.

6. SHIPMENT PLANNING

Shipment planning starts with the receipt of orders in the planning system. Transportation management actually begins far in advance of individual shipments. It starts with the configuration of a transportation network.

Recognizing that transportation management is a multidimensional discipline, one must look horizontally at all domains of control that comprise the supply chain and vertically at strategic planning, tactical planning, and execution. This establishes the business model for a supply chain, including all the physical locations, constraints, and processes. With strategic development modeling tools, a manufacturer can provide a better shipment forecast, by transportation lane, for carriers. With a more accurate model, collaboration between manufacturers and carriers will improve, leading to forecasting tighter carrier commitments and even the planning of sales and promotions around low-cost transportation lanes.

Transportation management systems are able to balance carrier rate, mode, and shipment consolidation variables because they contain carrier rate and equipment data and feature planning algorithms that suggest the fastest or lowest-cost options. Although the planning capabilities of software programs may vary, one of the most basic capabilities is consolidation of small orders into larger shipments. Effective consolidation planning means that multiple orders can be combined to form a full-truckload (TL) shipment rather than having orders go out individually as more costly, less-than-truckload (LTL) shipments.

More advanced shipment planning options in TMS include continuous moves—routing options that seek to keep trucks loaded on all transit legs—as well as sequential loading of shipments to shorten transit times and minimize handling.

Another shipment-planning option built into some transportation management systems is pooling. In pooling, small orders for multiple destinations are combined together and delivered in a full truckload to a cross-docking or distribution facility within the same geographical area as the orders' final destinations. At the pooling point, the freight is separated into small shipments or individual packages and routed to their individual destinations. Other desirable planning features within a TMS and shipment-planning program include the ability to meet short delivery windows, avoiding traffic gridlock at shipment destinations, and restocking options in which replenishment of a shipper's warehouse can ride for free when consolidated with customer orders.

Ultimately, the goal is to understand the trade-off between cost and customer service. Transportation management software strikes a balance between what customers want and what the carriers can deliver (Michel 1997).

6.1. Tactical and Operational Considerations

Transportation management systems can be categorized into three fundamental types:

1. Network planning and modeling applications
2. Transportation resources planning and management (TRPM) applications, which perform tactical planning
3. Transportation administration and management systems, which are operational execution applications

Typical TRPM systems perform some of the same operational tasks as transportation administration and management systems but have the ability to plan and execute enterprise-wide plans rather than single business unit plans. Such systems, therefore, must consider inbound, outbound, and replenishment demands throughout a global supply chain network.

For instance, one inbound and outbound optimization planning software package has the ability to manage shipments from multiple origins to multiple destinations and builds and consolidates loads as orders are imported into the system, using a library of transportation algorithms. Combined with a costing module, it rates, ranks, and selects carriers based on customer needs.

After the system selects the best transportation mode, it determines the best travel path, which loads to deliver first, and which orders should go on the trucks first—an important consideration since customers do not want to hold inventory, making scheduling much more significant due to the pressure to meet on-time delivery (Dilger 1998).

Roadnet Technologies, a leading provider of routing, loading, and planning and dispatch software for the transportation industry, has helped users streamline their supply chains by optimizing their transportation operations with Roadnet 5000 and Territory Planner. (See the Roadnet Technologies website, www.roadnet.com.)

Territory Planner strategically plans delivery and route sales territories. This analytical tool can streamline a company's operation and suggest routes that are in line with the way a shipper does business. Similar tools save reroute time, reduce transportation costs, and improve customer service. Similarly, Roadnet 5000 routes and schedules delivery vehicles by considering the parameters of a company's operation. The consolidated routes that are created provide a competitive advantage by improving driver performance and information management.

Ideally, the optimal TMS will permit transportation and logistics personnel to configure the parameters or rules for processing shipments in relation to the firm's entire customer base (e.g., optimal parcel carriers for each region of the country, discounts applicable to each carrier and region of the country, and carriers available for expedited service, including next-day and two-day delivery). Subsequently, the TMS manages the dynamic characteristics and unique variables of each customer order (e.g., final destination, shipment weight, and delivery date requirements) to make an intelligent rating decision within seconds. In turn, the system alleviates manual ship-rate shopping and guarantees that the shipper is using the least-cost carrier defined within the dynamic parameters of the order.

6.2. The Total Shipping Solution

If shippers incorporate TMS as part of their total supply chain execution solution, they will be able to achieve a strategic advantage and improve supply chain performance. Properly integrated, transportation management software, which can cost between $300,000 and $1 million (Cooke 1998), can enhance numerous areas within the supply chain. Some common areas for improvement include (Weil 1998):

- Order entry/customer service:
  - Real-time rating and routing information with customers on the phone
  - Real-time tracing and tracking of the shipment, including details and value of individual packages
  - Guarantees on customer carrier preference
  - Guarantees that the customer's delivery date will be complied with while still providing a cost-effective order of shipping
- Purchasing:
  - Inbound freight expense and shipment delivery analysis, including back-hauling capabilities or preferred carrier delivery service
- Invoicing:
  - Transportation charge line items automatically added to invoices
  - Ability to configure, maintain, and invoice customer program costs
- Shipping:
  - Increased parcel processing throughput and accuracy via bar code data and scanning to capture package details, package weight, and package tracking numbers
  - Automate carrier and shipment documentation generation, including bills of lading with preassigned carrier freight bill numbers, unique customer reference numbers, shipment labels complete with carrier tracking numbers, retail vendor-compliant data, international documentation, and EDI advanced shipping notice (ASN) bar codes.
- Accounts payable:
  - Automation of freight payment and matching processes
  - Introduction of self-invoicing practices that place claim maintenance in the hands of the carrier, not the shipper.

6.3. Case Study: Manufacturer of Medical Instruments

While many shippers have talked about making changes in their shipping and distribution practices for years, the supply chain service division within a medical instruments organization acted on its beliefs and made changes. In 1998, the company decided to review how small shipments were processed within their distribution centers. Everything had to be considered, from order picking to paying the freight bill. Adding value, taking the cost out of the supply chain, and the desire to improve their logistics network mandated an audit of their entire logistics system.

Their existing routing guidelines and system indicated that small shipments, primarily small parcel freight, were very cost effective based on current transportation rates. However, when all aspects of the shipment process (e.g., picking and packing process, label printing) were incorporated in the analysis, smaller shipments appeared to be less cost effective when compared to, for example, LTL orders. Thus, the planning team reviewed the shipping areas, compared processing times, and identified the costs of each. In addition, their primary carrier, along with the third-party warehouse provider, evaluated proposed warehouse layouts and procedural changes to streamline the shipping process.

Observations and studies were made of the distribution center's activities to quantify current practices. Any assumptions or atypical occurrences observed were evaluated on their individual merit in order not to adversely affect the study. To deliver better alternatives, accurate information was essential for the activity-based costing models utilized in the study. In addition, all exceptions had to be considered to maintain the integrity of the information being supplied to the manufacturer.

In addition, the team identified all the existing procedures inherent to processing a small parcel shipment as well as an LTL shipment. This comparison, which included all aspects of the process, from order entry to packing and transporting the merchandise, was conducted so that each mode of transportation could be effectively evaluated on its true value. In other words, actual costs would be clearly identified and allocated to processing orders. Since the manufacturer's goal was to improve the overall process within the existing cost structure, they recognized that requesting carriers to lower their transportation prices would produce only minimal gains and not enhance their value to their customers within the market. Focus on transportation rates had been the previous and predominant belief regarding reducing overall costs. Thus, the weight break between small parcel shipments and LTL shipments had been established only to reflect that element. All costs associated with the shipping process were to be included in order to illustrate effectively the actual expenditures. In turn, the weight break for small parcel shipments would be raised from 100 to 150 pounds.

The team's success was successful because they had planned prior to redesigning the procedures within the facility. Relevant data on the products were first gathered, such as:

- Sizes and weights of the products being handled
- Anticipated throughput requirements
- Weighing requirements
- Manifest requirements
- The current and projected packaging and labeling requirements (such as compliance labeling) for the products handled
- The packaging material(s) specified by the customer
- How the products were shipped (pallet loads or loose cartons)
- The company's experience base with various packaging and unitizing methods
- The projected number of inventory turns per year
- EDI or ASN requirements
- Any special handling requirements (e.g., DOT restrictions)

The study revealed that some orders took longer and were actually more costly when processed as a LTL shipment rather than as a small parcel shipment. The primary difference was the consolidation of the cases to a master identification number and application of the shipping labels. While a small parcel shipment underwent a similar procedure, the existing shipping system streamlined several of the steps that were otherwise manually entered for a LTL shipment. Completing the bill of lading, pick/pack time within the warehouse, stretch wrapping, and moving the pallets also contributed to additional time for the LTL order. Additional costs were also realized with the expenditures for pallets, stretch wrap, shipping documents, and administrative costs related to freight payment.

From this base, the planning team considered alternatives that ranged from simple procedural changes that could be implemented immediately to extensive automated sortation designs that required time and capital. With many considerations, the team recognized that the order-selection process was the most labor-intensive activity performed in the customer's warehouse. As a result, it offered the greatest opportunity for improvement. The team identified and implemented several ideas to reduce the order-picking costs:

- Separating broken-case picking from full-case picking to eliminate the need for the selector to change materials-handling equipment.
- Clearly marking the pick-slot numbers in one place eliminated confusion and reduced errors.
- Sequenced slot numbers in a logical pick path reduced travel distance and time.
- Translating quantities ordered into pick quantities on the pick document to eliminate errors from miscalculations (e.g., if the product is packaged in cartons of 12 units, the pick sheet needs to indicate to select 10 cartons, not 120 units).
- Establishing selectors, where appropriate, to pick with labels rather than from a picking sheet. For example, a selector using labels attaches them to each carton picked for an order. The labels indicate one of four in an order, so the selector knows an order is complete when the labels are gone.

The manufacturer quickly benefited from this basic process change and was now well positioned to explore more elegant alternatives to meet future business needs.

This medical instruments company has enjoyed reductions in both the costs of processing and transporting shipments. With all elements assessed, a better conclusion could be drawn in order for the shipment planning process not to affect the outbound shipments adversely. If the manufacturer's original conclusions have been acted upon, the weight break level between small parcel shipments and LTL shipments would have been lowered even further. With a detailed analysis performed, a new, higher weight break was established. In conjunction with the existing transportation rates, the average cost per shipment was lowered.

7. LOCATION PROBLEMS

The transportation models discussed in this chapter assume that the location of the facilities involved is given. Obviously, the location of various facilities plays an important role in the total transportation costs incurred. The location of factories, warehouses, and distribution centers plays a major role in the quality of service and competitiveness of a manufacturer, while transfer terminals and depot facilities greatly influence the cost structure and effectiveness of a transportation company.

It is to be expected, therefore, that an extensive body of work exists dealing with optimization models that are used to find optimal facility locations (Daskin 1995; Mirchandani and Francis 1990). These optimization models try to provide answers concerning:

- The number and size of facilities
- Where the facilities should be located
- How demand for the facilities is allocated among them to minimize the cost or maximize the profit of satisfying the demand for a commodity

The problems usually involve fixed costs for locating the facilities and distribution costs for transporting the commodities between facilities and customers that are distance related.

A large class of facility location models assumes that facilities can be located on a network composed of nodes and links. Travel can occur only on the links of this network. This is to be contrasted with planar models, which can locate facilities anywhere on the plane. Often, facilities are characterized by capacities (e.g., warehouses) or throughput (e.g., transfer terminals). We present next a qualitative overview of some useful network location models, drawing primarily from Daskin (1995).

- *Set-covering problems:* The set covering problem finds a set of facilities of minimum cost from a finite set of candidate facilities (each with a given cost) so that every demand node is covered. A node is considered covered if at least one facility is located within a given distance of the node. The set-covering problem does not account for possible congestion in the facilities since it does not consider the number of demand nodes that are served by each facility or the size of the demand of each node.
- *Center problems:* The vertex P-center problem finds the locations of P facilities on the nodes of a network that minimize the maximum distance between a demand node and the nearest facility to the node. A better solution can be obtained if facilities are allowed to also be located on the links of the network, resulting in the absolute P-center problem. Center problems are appropriate for locating emergency services like fire fighting, emergency medical vehicles, etc.
- *Median problems:* The P-median problem finds the location of P facilities on a network that minimize total cost, where the cost of serving demands at a node is represented by the product of the demand at the node and the distance between the node and the nearest facility. It can be shown that at least one optimal solution of the P-median problem locates facilities only on the demand nodes of the network. Median problems are appropriate for locating nonemergency services like transportation terminals, post offices, etc.
- *Facility-location problems:* The uncapacitated facility-location problem finds the location of facilities (that have no capacity limitations) so that the total cost of locating the facilities and the operating costs of transporting a commodity between the facilities and clients are minimized. When each candidate facility has a capacity indicating the maximum demand that it can supply, the problem becomes the capacitated facility-location problem. The model is used to locate plants, warehouses, transportation terminals, etc. and is most appropriate for the private-sector type of problem, where both the costs of locating the facilities and the operating costs are borne by the same organization and can be made comparable.
- *Location/routing problems:* The facility-location problems described previously assume that each customer is served on an individual route from the facilities being located. This is sometimes inappropriate, especially for the transportation industry. Location/routing problems refer to problems that involve locating a number of facilities from a candidate set of facilities and establishing delivery routes so that the combined total cost is minimized. The decisions involved in such a problem may include: (1) determining the number and location of the facilities, (2) allocating customers to facilities, (3) assigning customers to routes, and (4) determining the sequence of serving the customers on each route. Location/routing problems are extremely difficult to solve. Problems need to be modeled as location/routing problems only if the stra-

tegic, long-term decision of locating facilities has to be made jointly with the tactical, short-term vehicle routing decisions. Otherwise, the problem can be broken into two separate problems, a location problem and a routing problem.

The problems presented above can be extended further when the facilities are not all similar but are organized hierarchically, resulting in hierarchical facility-location problems. Similarly, when multiple, and sometimes conflicting, objectives are present, multiobjective facility-location problems are obtained. Finally, many models exist that deal with the location of undesirable facilities (e.g., hazardous waste dumps) where instead of wanting to minimize, we want to maximize some measure of the distance between the demand nodes (e.g., population centers) and the facilities.

8. SUMMARY

Transportation management system software is finally getting the attention and recognition it deserves from logistics professionals. Software that aids shipment tendering and carrier selection has become an essential front-line tool in the battle to cut supply chain costs and bolster efficiency. More manufacturers now view TMS as a strategic extension of their enterprise resource planning (ERP) system and no longer delegate it to second-tier status.

The transportation component used to be seen as the stepsister of information technology systems. Only recently, the action was focused on warehouse management systems (WMS) to reduce inventories. Now it is transportation that is getting attention from manufacturers as the last corporate savings frontier.

Since becoming more sophisticated in the past few years because of real-time optimization capabilities (determining the best tender, given pricing and volume discounts, delivery schedules, and consignee), TMS packages will continue to be connected to a company's other business systems.

Interfacing transportation applications with an organization's other business enterprise systems has typically had a quick payback for most organizations. With annual logistics savings of 3–12% in usually less than one year, effectively implementing a TMS (Tausz 1999) for $300,000 and $1 million, as mentioned earlier, is a very economical decision.

Advances in operations research techniques and computing power have revolutionized transportation and shipment planning. Gone are the days of dividing the country into separate regions and assigning a freight planner to each one to find manually the best driver-to-load pairing within the region. Now many carriers are relying on global optimization systems that generate the best possible system-wide matching between drivers and loads, introducing new options to planners that were almost impossible to find using the traditional methods.

As supply chains and logistics cycles become more complex and diverse, transportation and distribution planners are forced to consider multiple points of origin and destination throughout the world. Reduced product life cycles stimulate time-based competition, and customers require better delivery service and inventory-reduction plans. In turn, managers are looking to optimize their transportation and logistics network. Thus, they will continue to define and deploy solutions aimed at finding the most economical means of transporting both inbound and outbound product via shipment and load planning, freight management, consolidation or pooling processing, accounting and analysis, and mileage and location tracking.

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