missions at an average rate of two per second. Before we streamlined the algorithm, missions were generated at an average rate of one mission every 10 seconds. Solanki and Busch [1991] provide a more detailed description of the algorithm.

References


Rappaport, Harold; Levy; Laurence; Golden, Bruce; and Feishbach, David S. 1991, "Estimating loads of aircraft in planning for the military airlift command," Interfaces, Vol. 21, No. 4, pp. 63-78.


the point that today, it is one of the largest motor carriers in the country, handling over 11.4 million shipments annually distributed between 630 terminals and some 35,000 communities. Yellow serves over 300,000 domestic and international customers and reported revenues in 1990 exceeding 2.3 billion dollars.

From a mixed operation in the 70s, Yellow now predominately serves the less-than-truckload portion of the freight market. LTL trucking is characterized by shipments that are under 10,000 pounds, with the large majority falling under 1,000 pounds. Since a tractor-trailer combination can pull approximately 45,000 pounds (depending on whether the trailer is pulling a single 48-foot van or two 28-foot pup trailers), it is necessary to consolidate these shipments in order to form economical loads and provide quality service. An LTL carrier handles the consolidation function using break-bulk terminals. By contrast, truckload motor carriers focus on shipments that fill an individual truck. This avoids the consolidation function, which eliminates the need for a network of terminals. Under the prior regulatory environment, motor carriers were essentially required to handle both truckload and less-than-truckload freight as a result of the market entry restrictions. Under deregulation, Yellow Freight has specialized in the LTL segment of the market and truckload freight now constitutes less than two percent of its total shipments.

The 80s were a difficult decade for the motor carrier industry. Deregulation created tremendous opportunities for growth but also presented management with new and difficult challenges to manage these larger operations more efficiently than before. In addition to removing market entry restrictions, deregulation also removed a system of pricing guidelines that had controlled prices in a manner that generally guaranteed a healthy return on investment. After 1980, motor carriers were forced to compete on price, creating tremendous pressure to cut costs. Additional pressure to reduce costs came from the manufacturing community, which was facing intense international competition.

The Motor Carrier Act effectively removed a government controls.

The result was a substantial reduction in transportation rates. Between 1980 and 1990, transportation rates for Yellow Freight rose only 3.9 percent, translating to a drop in real terms of 29 percent.

In addition to rate reductions, the shipping community, in response to intense international competition, began to raise their expectations on service. For many shippers, Yellow Freight is a full partner in their total quality management programs. The timely delivery of freight, whether it be parts or raw materials to a manufacturing plant or finished goods to a retailer, is an important component of the logistics system. Furthermore, while fast delivery is important, service reliability is critical. Both late and early deliveries create slippage in the process that in the 70s was easily absorbed by large inventories, but today is unacceptable. This heightened emphasis on service clashed with some long-standing operating practices used by

Yellow the national LTL carriers. In the past, published service standards (the time a carrier is allowed before delivering the freight) provided a fairly large margin for error, encouraging some loose operating practices that emphasized reduced costs over service.

The effect of these pressures can be seen in the tremendous attrition the industry suffered. Out of the top 20 revenue-producing LTL carriers in 1979, only six remain today. Over this same period, Yellow grew from 248 terminals to 630 terminals. The incentive to grow came from two sources: first, larger LTL carriers can consolidate shipments more easily and economically than smaller ones, creating a cost efficiency that translates to lower prices; second, many shippers prefer to work with a single carrier that can handle a major portion of their business. A smaller carrier must routinely interline or transfer freight with another carrier to cover some markets. A single, large carrier simplifies tracing and billing, with fewer opportunities for errors.

This growth has had the effect of creating an extremely large and complex operation. With a fleet of 45,000 tractors and trailers, Yellow picks up more than 60,000 shipments daily, with approximately 10,000 trucks dispatched each day (excluding local pickup and delivery). Furthermore, the larger network requires a greater degree of coordination than a small system, arising from the need to consolidate flows to build economical loads. In a smaller network, there are simply not that many options, allowing most of the operational decisions to take place in the field governed by a few simple rules. As a network becomes larger, the number of options for routing a trailer grows significantly, and the problem of coordinating a decentralized system becomes a major management challenge. In a network spread across the United States, many decisions are made in the field based on local information, with limited coordination among different parts of the system. Terminal managers tend to focus on specific productivity measures, such as the number of trailers they are able to load directly, over which they have the most control.

In 1986, Yellow initiated a project to improve its ability to manage a complex system. An in-house network simulation tool was reaching its limits, and Yellow was interested in using modern network methods to both simulate and optimize a large network. The project had one primary goal: improved service and service reliability through better management control of the

Yellow Freight has specialized in the LTL segment of the market.

network. This goal was supplemented by broader management objectives: to improve the accuracy of the planning process through more accurate cost and service models; to improve the speed and responsiveness of planning and analysis; and to develop a process for managing and coordinating a large network of activities. There was also an expectation that improved planning would result in better productivity and lower costs. A project team was formed with members of the operations planning depart-
ment at Yellow and an outside consultant (the last author). The development effort started with an existing model that had been developed as part of a similar project with another carrier (see Powell and Sheffi [1989]). Using this model as a base, a major programming effort was undertaken to meet the planning needs at Yellow. These modifications, which almost doubled the length of the code, included changes in logic used to model operations and in the level of detail used in costing and reporting. Particularly important were interfaces developed that allowed the model to communicate with existing data bases in use at Yellow. This ability allowed the recommendations made by the model to be sent to the field. Additional systems were developed at Yellow to facilitate the maintenance of the cost and operating parameters that define Yellow's network.

The result of this effort was SYNET®. At its core, SYNET is over 80,000 lines of FORTRAN code for performing sophisticated optimizations using modern network tools. We developed an innovative, interactive optimization methodology that places human beings in the loop, putting advanced, state-of-the-art optimization methods in their hands. These methods were essential in the development of a system that would handle the entire network without resorting to heuristic methods to reduce the size of the problem. As a result, the user is able to analyze the impacts of changes on the entire network in a simple, interactive fashion. Projects that would require weeks can now be completed in a few hours (or, in some cases, a few minutes) with a much higher degree of precision. Shipment consolidation decisions that used to be simulated are now optimized, taking into account the system effect of each decision.

Yellow uses SYNET for two sets of applications. The primary use is tactical load planning, which involves monthly planning and revision of the set of instructions that govern handling and consolidation of shipments through the network. The load plan is static, with contingency provisions to handle daily fluctuations in the freight. Each month, the load plan undergoes minor revisions to handle forecasted changes in freight volumes. The second set of applications involves longer-range planning of the network itself. These problems cover

Out of the top 20 revenue-producing LTL carriers in 1979, only six remain today. The location and sizing of new facilities, and long-range decisions that govern the flow of freight between the terminals. SYNET allows the user to optimize the load plan using powerful interactive tools. It assists with strategic planning by allowing the user to propose network configurations and then optimizing the operation of the network before calculating total costs.

At Yellow, SYNET has come to mean much more than a single piece of FORTRAN code. Instead, it embodies an entire planning methodology that has been adopted by all levels of the company. From strategic planning studies that are communicated to senior management, to network routing instructions sent right to the field, SYNET has become a comprehensive planning process that has allowed

where Yellow maintains a large consolidation or breakbulk facility. Boston is considered a satellite of Maybrook which serves as the initial consolidation terminal for 40 other end-of-line terminals in the northeast.

Having arrived at Maybrook, the trailer is unloaded, and the shipments are sorted onto other trailers, many of which are destined for other breakbulks. One trailer might be dedicated to shipments heading to the Chicago breakbulk, with final destinations at the various end-of-line satellites of Chicago. Shipments from Boston and from other satellites of Maybrook headed to the Chicago region will be combined on the Chicago trailer. This trailer will depart, ultimately arriving in Chicago where it is again unloaded. Then shipments with a common final destination, such as Milwaukee, will be combined on the trailer destined for Milwaukee.

An LTL network, then, uses a set of breakbulk terminals to serve as collection points for freight originating and terminating at terminals in that region. The satellites around a breakbulk form a hub-and-spoke network to perform the primary consolidation function, feeding high density lanes that join each pair of breakbulks. Figure 1 illustrates the network for selected terminals served by Yellow. From the perspective of network planning, shipments are treated as originating and terminating at the end-of-lines. Traders always move directly between end-of-line and breakbulk terminals, and normally do not make stops at other end-of-lines to fill up a trailer (they may stop at other end-of-lines for other operational reasons, but once the doors of a trailer are closed, they are nor-
Figure 1: Yellow’s line-haul network uses a hub-and-spoke pattern to perform freight consolidation.

normally not reopened until the trailer has reached its next unloading destination). The path of a trailer from one breakbulk to another will often move over a sequence of intermediate relays. In most instances, a relay will be another breakbulk, and the distance from one breakbulk to a neighboring one is typically the distance a driver can cover in a single shift. Once a trailer arrives at an intermediate relay point, a different driver will take it over the next leg. The set of individual driver legs is referred to as the line operations network, which often looks like an abstraction of the highway network. Since shipments are never loaded or unloaded at intermediate relays, the path of the shipment is identified by the sequence of points where the shipment is handled (or sorted). The shipment from Boston to Milwaukee is said to follow the Boston-Maybrook-Chicago-Milwaukee path.

This pattern of moving from end-of-line to breakbulk to breakbulk to end-of-line is often referred to as the standard routing for national LTL carriers. In many instances, however, it is possible to use a more efficient path. For example, assume that the terminal manager in Boston notices that he has enough freight bills to fill a trailer going directly to Chicago. As a large terminal, he may normally send 20 trailers each day to his primary break in Maybrook, and by loading a Chicago

Figure 2: The service network allows trailers to bypass consolidation facilities to improve service and reduce costs.
which shipments should go on a trailer. For a large carrier, there is often more than one path from origin to destination over the service network. The routing of a shipment over a network of services is referred to as the load plan (or load pattern, or freight movement plan). The load plan is a set of instructions that, in its simplest form, can be stated as a shipment being handled at terminal A (independent of its origin) with destination C, should be put on a trailer headed to B.

A routing such as this from A to C implies that the carrier offers direct service from A to B. It is possible that A is the origin terminal in Boston, and B may simply be the first breakbulk in Maybrook. However, assume that a shipment from Boston to Milwaukee has two routing options: the first runs from Boston to Maybrook and then direct from Maybrook to Milwaukee, and the second goes direct from Boston to Chicago, and then from Chicago to Milwaukee. In the past, the standard solution to this would always be to put the shipment on the trailer going to Chicago, under the philosophy that it is always better to load a shipment to the terminal closest to its final destination. Determining the best routing of the shipment, which includes the problem of determining where to run directs, is called the load-planning problem.

Determining when and where to run directs and what shipments to put on a direct is the central problem addressed by SYNSNET, and it is one of the largest and most challenging problems faced by large LTL carriers. A small regional carrier typically only uses three to five breakbulks. It has few opportunities to run directs, since the majority of its shipments are handled through a single break. If an opportunity to run a direct arises, then the cost and service advantages make it imperative to do so. For these carriers, the basic operating strategy is to run a trailer direct whenever and wherever possible. Furthermore, since shipments rarely run through two breakbulks, the only place to run a direct is from the origin end-of-line to the destination end-of-line. Such a strategy requires no central coordination or planning, as all decisions are made in the field.

Unlike most carriers, Yellow started as a regional carrier with much the same strategy. As it grew, the policy of running directs whenever possible remained in place, and the management of directs also retained a largely decentralized process. Efforts to control the routing of shipments were easily overridden in the field. As the company grew into a national carrier, making the transition to the standard two-breakbulk routing, the number of possible routings of shipments mushroomed. Particularly problematic is the effect that the behavior of one terminal manager can have on the performance of another. For example, when Maybrook loads a trailer direct to Milwaukee (Figure 3a), part of this trailer is filled with freight arriving from Boston. Boston may decide that it wants to start loading a trailer direct to Chicago, using the freight to Milwaukee to help fill the trailer (Figure 3b). This change in strategy affects the flow of shipments into Maybrook, which may have the effect of forcing Maybrook to eliminate the Milwaukee direct, routing all the freight through Chicago. The resulting service network may be more expensive for several reasons. First, the cost of handling freight at Chicago may be higher than at Maybrook, implying that the savings in handling at Maybrook may be more than offset by higher handling costs at Chicago. Second, Chicago may be closer to capacity, creating additional congestion problems. Third, it is possible that the change in routing actually increases the overall distance a trailer must cover.

A fourth issue addresses a systematic problem with directs run out of end-of-lines. As a rule, the pounds per trailer, or load average, for direct trailers departing from end-of-line terminals is lower than for direct trailers departing from breakbulks. Breakbulks have both a greater volume and a broader mix of freight (small and large, light and heavy shipments), that allows people to pack more pounds in a trailer. The practice of allowing the Boston end-of-line the option of loading a trailer direct to Chicago creates a pattern of favoring directs out of end-of-lines over directs loaded out of breakbulks.

Despite these issues, the basic policy used not only at Yellow but at most of the national carriers was to run direct, whenever possible, wherever possible. Running directs to bypass a breakbulk was considered so beneficial that extraordinary strategies were designed to increase the number of directs that were run. For example, the rule of thumb was that avoiding a breakbulk was equivalent to saving a day in transit time. As a result, if the Boston terminal did not have enough freight on Wednesday to fill a trailer to Chicago, the trailer could typically be held until Thursday or Friday (taking advantage of the industry pattern of not counting weekends as service days). The single biggest effect of this practice was to introduce tremendous variability in the service a shipment received. From an operational perspective,
this strategy also tended to disrupt the natural flow of trailers, since the ability to hold freight on Wednesday would often create an artificial wave of trailers moving out on Friday.

The terminal manager faced a strong financial incentive to load directs but lacked the information needed to make effective decisions. It was not unusual for a terminal manager to try to load a trailer direct and 36 hours later find that the trailer still was not full (terminal managers were also evaluated on the average number of pounds they put on trailers). At this time the manager would be forced to make a judgment about whether to hold the trailer a third day or simply to run it into the primary break. Conversely, freight that could have been run direct often was not, simply because the terminal manager sometimes did not realize that there was that much freight going to a common destination.

This operating strategy had four principal limitations:

1. Lack of direction and information in the field created uncertainty and variability in operations, with a significant impact on service reliability;
2. The rule to run a direct was based on flow (the ability to fill a trailer) rather than cost;
3. Decisions made by one terminal manager were not coordinated with the rest of the system; and
4. Decentralized decision making restricted management control over the operation of the network.

The challenge of the SYSNET project was to overcome these limitations.

The Planning Process

We developed SYSNET to address two sets of problems. The first covers the operational task of managing the load plan that controls network flows. The second covers a broader set of tactical and strategic planning problems that arise routinely when managing a large network. These include:

—Breakbulk capacity planning: Using five-

year forecasts of demand, we simulated flows through breakbulk to estimate future capacity needs, which determine corporate capital requirements, needed for financial planning.

—Breakbulk location: As growth requires new consolidation facilities, we needed to plan the location of these terminals and their integration with the rest of the network.

—Capacity management: Because seasonal shifts in freight can create capacity problems at individual breaks, Yellow wants to route flow to divert freight around problems, congested breakbulk.

—Satellite alignment: Although most of the freight out of an end-of-line passes through its primary breakbulk, when there is more than one logical choice for the primary breakbulk, Yellow may want to determine the optimal choice(s) based on the overall directionality of the freight.

—Opening new end-of-lines: Yellow may open new end-of-line to enter a new market or to better serve an existing one. Since the number of end-of-line terminals in an area affects their ability to load directs, the trade-off between one large terminal or several smaller ones must be analysed.

At the heart of these strategic-planning problems remains the load-planning problem, since each question must be evaluated in part based on its effect on the routing of shipments and the ability of terminals to load directs.

In developing a new planning process, we had the following specific goals:

1. To develop an accurate, company-wide cost model;
2. To use optimization methods for certain sets of decisions;
3. To improve the overall responsiveness of the planning process through enhanced speed and ease of use; and
4. To handle the entire network simultaneously, allowing individual changes to be evaluated in terms of their impact on the entire system.

The SYSNET planning process at Yellow Freight encompasses demand forecasting, data-base management, simulation, optimization, and monitoring and control. A summary of SYSNET can be divided between a description of the mathematical model; the solution strategy; and the systems and methods required to develop and maintain the input data files and to communicate results to the field. Powell and Sheffi [1989] provide a detailed discussion of the mathematical model and solution strategy. Elements that were particularly important to this project included the way the system handled service and the role of interactive optimization.

Modeling Service

Yellow Freight has always made service its highest priority, an emphasis we felt throughout the project. The time to deliver a shipment consists of driving time, trailer unloading time, and the schedule delay that occurs while waiting for an outbound trailer to fill up prior to dispatch. Since it can take anywhere from six to 24 hours to load and dispatch a trailer, schedule delay is not only an important source of total travel time, it is one of the major sources of travel time variability. Schedule delay, however, can be reduced through effective planning. If Maybrook is currently loading five trailers per week to Chicago, shipments will wait on average half a day for the trailer to fill and leave. More Chicago
freight can be routed through Maybrook, trailers will fill faster and the schedule delay will decrease.

The second issue in service is reliability. For a shipper, it actually can be more important to reduce the variability of transit times than to reduce the average transit time. Under the old strategy, which allowed terminal managers considerable latitude as to when to load direct, service could fluctuate widely, reflecting the availability of opportunities to load direct and the ability of the terminal managers to recognize and act on these opportunities. Perhaps more important than the effect a manager might have on the terminal’s freight is the impact the actions of one terminal can have on other parts of the network. Each time the Boston terminal decides to load the Chicago freight direct, the arrival of freight to Maybrook headed to Milwaukee is affected. Thus changes in the routing of the freight out of the origin terminal create higher variability in the flow of shipments on other legs in the network. In fact, the high volume of relatively small LTL shipments originating at a terminal tends to be surprisingly stable. The variability arising from changes in how the freight is routed can be much larger than the day-to-day variations in the shipments.

These issues argue in favor of operating a network of direct services that is stable and reliable. Directs should be identified that can be efficiently run on a regular, daily basis. Of course, opportunities to load directs will arise due to random fluctuations in the freight. However, these opportunities must be controlled since directs can work against the system.

SYNSNET employs a model that addresses the combined concerns of speed, reliability, and economic efficiency by using a simple set of rules. If direct service is offered between two terminals, it is assumed to do so on a regular basis with a minimum frequency of, say, eight trailers weekly. Freight is assumed to follow a single path from origin to destination over the course of the week. If a direct is offered that does not have eight trailers per week of freight, then the model still assumes that eight trailers are sent each week. If more freight is available, the number of trailers needed is assumed to rise linearly. Of course, if the direct service is not needed (implying zero flow) then the cost is zero.

If we plot the flow of trailers as a function of the flow of freight (measured in units of trailers per week) the result is the plot shown in Figure 4. The implication of this function is that the decision to offer a direct service means that Yellow must be willing to pay the cost of at least eight trailers per week. The imposition of a high minimum frequency implies that service will be both fast and reliable. Freight will be able to follow this pattern every day with a minimum of schedule delay. It is now up to the cost model to determine if this new service is cost effective. If there are only five or six trailers of freight (or less), then it is likely that the service will not be offered. The important feature is that the direct is all or nothing; a service is not offered unless it makes sense for all the freight moving in that traffic lane. If the direct is cost effective, we are assured that we are offering quality service at a reasonable cost.

The Model

The essential features of the model are

- Handling costs at breakbuckles,
- Relay costs, and
- Pickup and delivery costs within the city.

We calculated all flows and costs on an average weekly basis, using forecasts of freight flows. Included in the loaded transportation costs are trailers moving partially full as a result of service constraints. SYNSNET specifically tracks what came to be known as the "cost of moving air," which represents a measure of the degree to which trucks are running only partially full as a result of the minimum service frequency constraint (known as running for service). If a particular change to the network produced a sudden increase in the cost of moving air, then this was a flag that trailers were now running partially full suggesting further investigation. Pickup and delivery costs were included for model calibration purposes but did not change as a function of the load plan.

Solution Approach

This optimization formulation can be characterized as a nonlinear, multicommodity network design problem. The challenge of solving this problem arises from recognizing its large size. Ignoring the possibility that direct service can join end-of-line terminals, there are approximately 30,000 different opportunities to potentially offer direct service between end-of-lines and breakbuckles. Heuristic pruning rules can further reduce this to about 7,000 elements. There are over 400,000 integer routing variables governing the path followed by each shipment over the service network. Added to these numbers are 1.2 million network flow variables for tracking flows of shipments and 50,000 empty flow
variables. A separate set of concerns further complicates the issue. Despite the tremendous effort put forth in building and tuning an accurate cost model, ultimately it is still an approximation, with simplifications introduced either in recognition of basic limitations of the data or to maintain a semblance of tractability in an otherwise large and complex model. These limitations of the model ranged from the use of steady state flows to the inability to explicitly model special service constraints on individual lanes.

We devised a solution approach that recognized the inherent hierarchy in the decisions that are being made. Decisions about the location of terminals and breakbulks are made at the highest level. Second is routing loaded trailers over the line-haul network, which must take into account the balance of driver flows into and out of terminals. Next is determining where to offer direct service. This is followed by routing shipments over the network, which determines the flows of loaded trailers. Finally there is the optimal routing of empty trailers to balance the flows of loaded trailers.

<table>
<thead>
<tr>
<th>Decision</th>
<th>Level of User Interaction</th>
<th>User Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal size, location, and alignment Routing loaded LTL trailers Add/drop directs</td>
<td>High</td>
<td>User initiated “what if”; User initiated “what if” with least-cost path suggestion Computer generated suggestions; user reviews and accepts/rejects suggestions</td>
</tr>
<tr>
<td>Routing LTL freight (the load plan) Routing empties</td>
<td>Low</td>
<td>User review and override User review, but no control</td>
</tr>
</tbody>
</table>

Table 1: SYNSNET provides different levels of user and computer involvement for different types of decisions.

We adopted an interactive optimization approach to take advantage of the skills of a knowledgeable user in two specific areas. First, while some of the decisions can be optimized by the computer with some confidence, others, such as locating terminals or designing a network of direct services, are mathematically very complex. Human beings are very effective at recognizing certain special patterns and guiding the computer toward good solutions. Second, the user can monitor the progress of the search and identify areas where limitations of the model may create problems.

On an IBM 3090, this complete evaluation of a single direct can be completed in under one second. This speed was critical to the use of the system in an interactive fashion. Optimization theory was central in helping us to accurately prune the list of candidate direct, and extensive engineering of network optimization algorithms was needed to produce the high speed attained in performing exact evaluations of each addition or deletion.

Finally, the user is presented with a ranked list of suggested changes to the network. This list contains the impact of each change, broken down into different cost categories. Table 2 shows a typical menu of suggestions. For each suggestion, the menu shows if it is an add or a drop; the origin and destination of the direct; the gain or loss of flow in trailers per week; and the changes in costs around the system. Cost changes are divided among line-haul transportation costs; line-haul variance (a measure of the partially full trucks moving for service); handling costs at breakbulks and end of lines; and changes in the movement of empty trail-
Table 2: SYNSNET suggests directes that can be added to or dropped from the network and provides summary information to help the user make decisions.

<table>
<thead>
<tr>
<th>Chg</th>
<th>From</th>
<th>To</th>
<th>Flow</th>
<th>Line</th>
<th>Var</th>
<th>H-BB</th>
<th>H-end</th>
<th>Mpty</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>ADD</td>
<td>KCM</td>
<td>BOS</td>
<td>12.55</td>
<td>409</td>
<td>85</td>
<td>-890</td>
<td>0</td>
<td>-61</td>
</tr>
<tr>
<td>#2</td>
<td>ADD</td>
<td>KCM</td>
<td>CVE</td>
<td>8.48</td>
<td>-345</td>
<td>121</td>
<td>-747</td>
<td>0</td>
<td>-72</td>
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<tr>
<td>#3</td>
<td>ADD</td>
<td>ATL</td>
<td>MIL</td>
<td>9.21</td>
<td>-280</td>
<td>53</td>
<td>-587</td>
<td>0</td>
<td>128</td>
</tr>
<tr>
<td>#4</td>
<td>DROP</td>
<td>BOS</td>
<td>STL</td>
<td>-3.45</td>
<td>57</td>
<td>-915</td>
<td>248</td>
<td>0</td>
<td>-161</td>
</tr>
<tr>
<td>#5</td>
<td>ADD</td>
<td>CVE</td>
<td>HWU</td>
<td>6.20</td>
<td>37</td>
<td>220</td>
<td>-705</td>
<td>0</td>
<td>-54</td>
</tr>
<tr>
<td>#6</td>
<td>ADD</td>
<td>MBK</td>
<td>TEL</td>
<td>6.87</td>
<td>45</td>
<td>186</td>
<td>-439</td>
<td>0</td>
<td>-181</td>
</tr>
<tr>
<td>#7</td>
<td>ADD</td>
<td>JMI</td>
<td>WOU</td>
<td>7.02</td>
<td>188</td>
<td>65</td>
<td>-519</td>
<td>0</td>
<td>-54</td>
</tr>
<tr>
<td>#8</td>
<td>DROP</td>
<td>BAL</td>
<td>CGB</td>
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<td>-102</td>
<td>-287</td>
<td>405</td>
<td>-125</td>
<td>-11</td>
</tr>
<tr>
<td>#9</td>
<td>DROP</td>
<td>BAL</td>
<td>HWU</td>
<td>4.20</td>
<td>-78</td>
<td>-394</td>
<td>489</td>
<td>-125</td>
<td>18</td>
</tr>
</tbody>
</table>


The user may decide to accept or reject each recommendation or to perform further detailed analyses using a submenu. Of course, the impact of each change is calculated in isolation, and it is important to consider potential interactions. If the user accepts a change, the system recalculates its cost impact to ensure that savings are still realized even though they may be somewhat different from those originally estimated. The user may also request that the system "refresh" the cost calculations by rescanning the entire list of suggestions. A knowledgeable user can usually identify strong interactions and guide the process accordingly.

The interactive aspects of the code proved important in two respects. First, the user was needed to guide the search for changes in the network. The user might know, for example, that freight levels are increasing in the midwest or that a particular breakdown is experiencing capacity problems. In other cases, the user might know that the current solution is a local minimum and that a significant change in the network is required to achieve an overall improvement. For example, adding a new breakdown requires a substantial amount of freight to be moved through it before it has the volume to start loading economical directly. A human being can easily identify these spatial patterns and test out promising configurations.

The second use of the interactive feature, which proved critical to the adoption of the system, was the user's ability to accept and reject suggestions made by the computer. In contrast to a block-box approach, SYNSNET displays suggested changes and allows the user to evaluate each one in terms of difficult-to-quantify factors. For example, Yellow provides special services for individual customers that may require freight routing that run counter to SYNSNET's suggestions. Also, local considerations, such as work rules or special operating practices that are not incor-

Developed into the model, can be accounted for by a knowledgeable user. We devoted considerable research to developing and tuning these algorithms [Powell 1986; and Powell and Sheffi 1983]. For example, we studied the solution of the shipment-routing subproblem extensively [Powell and Kousonidas forthcoming]. We tested and compared several different primal and primal-dual algorithms. The primary contribution of this research was a set of primal heuristics which could be shown to provide very accurate solutions. We also researched exact algorithms for network design problems [Lamar, Sheffi, and Powell 1990] to help evaluate the effectiveness of the local search heuristics. Research into exact solutions of the network design problem for less-than-truckload applications [Balakrishnan, Magnanti, and Wong 1989; Balakrishnan and Graves 1989; Magnanti and Wong 1981] has been limited to networks that are considerably smaller than the problem presented by Yellow Freight. Reflecting this limitation of optimal approaches, other researchers have developed heuristics for solving the service network design problem, most commonly using a black-box search technique [Crainic and Roy 1987; Leuz, Magnanti, and Sanghal 1990].

**Systems Support**

A major part of the project was to integrate SYNSNET into the corporate MIS system. SYNSNET requires extensive information about freight flows and forecasts, transportation and handling costs, and a variety of productivity and performance measures. To remain current, this data must be periodically updated, which requires access to a broad range of files. We developed a set of production programs that can be used to scan all the raw data files and compile the necessary statistics, which range from a count of the number of doors in a breakdown to an estimate of the average density of freight originating in Boston to a calculation of the average cost per mile for trailers moving from Maybrook to Cleveland.

For strategic planning, the outputs from SYNSNET are a set of reports used to prepare management summaries on different options. However, SYNSNET is also used on an operational basis to perform load planning. In this role, SYNSNET is used to maintain a file that determines the actual routing of shipments through the service network. This file, which contains the load plan, is accessed directly by systems that are used by virtually every terminal manager in the field. SYNSNET's control of the load plan and its ability to communicate these instructions to the field is the single most significant accomplishment of the project. Over the course of the project, numerous requests were forwarded through information services, which is responsible for all production programming on the mainframe. These requests were given priority over 2-2 year backlog of data requests from other departments.

**Implementation**

The primary objective of SYNSNET was to take over and manage the flow of shipments through the network. Several members of the operations planning department became proficient in the use of SYNSNET. In their hands, SYNSNET became the principal tool for managing the controlled direct program. The implementation of this program represents one of the single larg-
est changes in the basic operating strategy implemented since Yellow’s emergence as a national LTL carrier. At the heart of the program was the transition from a policy that encouraged terminal managers at origin end-of-lines to load direct past the origin breakbulk. The controlled direct program required terminal managers to make the transition from managing based on a set of (outdated) operating strategies (load whenever possible) to managing according to a computerized load plan. This plan would specify which directs should be run on a daily basis and which should not. The computer would also specify directions controlling where directs could be run if on a given day there was sufficient freight to fill a trailer. Furthermore, the load plan even specifies which shipments are to be loaded on each trailer. Thus, the load plan might instruct the Boston terminal manager to load a Chicago direct but to put the shipments to Milwaukee on the trailer to Maybrook (allowing the Maybrook terminal manager to fill a trailer to Milwaukee). The load plan must be followed rigorously on a daily basis, thereby providing even, predictable flows through the network. Exceptions are allowed but only under tightly controlled circumstances that are explicitly handled within the load plan.

There are four key elements to the implementation process: (1) selling the concept to upper management; (2) developing an implementational strategy; (3) implementing the system in the field (which included selling it to people in operations); and (4) providing management incentives and enforcement.

Adoption by Upper Management
Implementing this major change in operation required the involvement and support of all levels of the company. This process began with the acceptance of the system within the operations planning department. Operations planning was responsible for guiding the project and managing, with close cooperation from the information services department, all aspects of the implementation. The system’s acceptance was largely due to the use of interactive optimization, which gave users the support required to optimize such a large network while also keeping them in close control of the entire process. Users could analyze suggested changes to the network basing the linehaul simulation package developed at Yellow in the late 1970s. The interactive reports and features that convinced operations planning also played an important role in gaining top management support. We can interact session for upper management to demonstrate how SYSNET made suggestions and generated supporting reports to back up the numbers. We demonstrated how standard operating practices could be detrimental and why coordinating the entire network was important. By doing this, we gained the confidence from upper management that we needed to support a field implementation.

Developing an Implementation Strategy
With the support of upper management, we were able to develop an implementation strategy. This step involved much more than simply convincing field operations that the new concept would improve operations. The controlled direct program changed operating philosophy so drastically that a single, corporate-wide transition was viewed as simply too dangerous. Managing 10,000 dispatches and 60,000 shipments efficiently each day depends on a basic predictability in the freight flows. The allocation of drivers around the network is closely controlled by union contracts that can seriously penalize the company if flows are shifted from one part of the network to another. Breakbulk managers need to plan their dock schedules for loading and unloading trailers. In implementing SYSNET, Yellow made a systematic change in the way it loaded direct. Specifically, SYSNET encourages a greater proportion of directs to be loaded out of breakbulks than out of end-of-lines compared to Yellow’s standard method of operation. It was impossible to change this method of operation over the entire network simultaneously. However, it was also difficult to do it in a piecemeal fashion. For example, implementing the new strategy at the Maybrook breakbulk and its satellites would increase the amount of freight coming into Maybrook from its satellites. Maybrook would then do its utmost to load directs past the other breakbulks in the system to reduce their handling costs. However, Maybrook would not have the capacity to handle this additional freight if the other breakbulks in the system did not simultaneously try to load directs past Maybrook.

To deal with this problem, we developed a phased implementation strategy that began with the smallest breakbulks in the system and worked up to the larger ones. Careful planning insured that no breakbulk would be over capacity during the intermediate stages of the process. Yellow implemented SYSNET between November 1988 and May 1989, with the summer of
1989 representing the first major transition period. We planned the entire implementa-
tion to ensure that re-breakbulk would find itself over capacity during the transi-
tion period.

Field Implementation
Once we had developed the complete strategy, we had to commmunicate the new concept to terminal managers in the field. This stage involved three steps: (1) design-
ing new support tools so that the SYSNET routing instructions were easy to follow; (2) training terminal managers and dock personnel to use these new systems; and most important (3) convincing terminal managers that the new approach was a good idea.

We developed two new support tools to assist field operations. The first was a set of reports that managers or dock supervisors could access from their local computer ter-
minals, giving them immediate access to the SYSNET load pattern. The second tool was a revised shipment movement bill. (A movement bill is a document that accom-
panies each shipment.) The new document includes the SYSNET routing instructions for that shipment, telling the dock worker exactly what trailer to load the shipment into along its entire path from origin to destina-
tion. This movement bill provides a very high level of control over the routing of individual shipments. Since the bill is used by thousands of employees, its modi-
fication represented a major implementa-
tion challenge.

The operations planning department handled training by organizing a series of visits to all 25 breakbulks. Each week, a team from operations planning visited a new breakbulk to handle the transition for

that terminal. In some weeks, the team converted several breakbulks at once. Dur-
ing each visit, staff members explained the principles behind the controlled direct pro-
gram, the new reports, and the use of the new routing instructions. Furthermore, this training continued long after the initial visit. A member of operations planning with extensive experience in line opera-
tions made countless phone calls to termi-
nal managers to review their use of the system, discuss problems, suggest alterna-
tives, and generally help them through the process.

Our most important task was to con-
vince terminal managers of the logic be-
hind the new operating strategy. Ten years of incentives to load direct at will are not easily replaced. Especially difficult to change was their intuition that they should put shipments on trailers going the longest possible distance. The idea that a shipment should be loaded on a trailer going to the nearest breakbulk, when it could be put on a trailer going to the destination breakbulk, is a paradigm in the industry. Terminal managers needed to understand that they had to follow the load plan be-
cause it was designed to coordinate differ-
ent parts of the system. We used examples to illustrate the effect their decisions could have on other terminals. Generally, people in the field accepted the principle that their decisions should be coordinated with those in the rest of the system.

Management Incentives and Enforcement
Prior to SYSNET, Yellow evaluated termi-
nal managers in part based on the num-
ber of trailers they were able to load direct. Immediately following the implementation

of SYSNET, we developed a target that represented the anticipated number of di-
rects that they should be loading based on the SYSNET plan. Yellow then measured terminal managers' performance based on how closely they met this target. After a period of time, it seemed compliance with the plan so good that today it does not formally measure terminal managers' perfor-
mancc on the basis of the directs they load. They are measured on other activities and Yellow continues to monitor compli-
ance with the load plan informally. It then contacts terminals that appear to be out of compliance to determine the reason. In short, SYSNET has changed load planning from a decentralized process that de-
pend on local management incentives to a centralized process that relies on moni-
toring and enforcement.

The Tactical Planning Room
Our need to communicate the logic be-
hind SYSNET has proved to be ongoing, even beyond the problem of obtaining ini-
tial acceptance. For everything from direct loading decisions to changes in the align-
ment of satellites to breakbulks, operations planning must explain and justify each recommendation. To assist with this pro-
cess, Yellow uses a special room equipped with graphical display tools that allow meet-
ings to be conducted around SYSNET. In
one common use of the facility, Yellow brings regional managers in from the field to run through a series of what-if scena-
rions, allowing them to pose their own questions. During such meetings, an opera-
tor runs SYSNET from a computer termi-
nal, displaying the results on a large screen. The operator can show different re-
ports, along with detailed analysis summa-
ries, allowing participants to appreciate the issues and trade-offs that arise during an analysis. If an idea does not work, the par-
ticipants can propose and test alternative scenarios. The tactical planning room has proved invaluable in involving a much larger part of the organization in the planning process than was possible before, pro-
ducing a high level of acceptance for the system that extends down to field opera-
tions.

Ongoing Planning Applications
Without question, the major visible ap-
plication of SYSNET was the implementa-
tion and management of the controlled di-
rect program. In addition, SYSNET contin-
ues to play a major role in a range of other tactical and strategic planning areas. One example is the original application of Yel-
low's old line-haul simulator, breakbulk
capacity planning. With SYSNET, Yellow can forecast flows five years into the fu-
ture, but instead of simply simulating ac-
tivities, it can use SYSNET to optimize the load plan with these new flows. Thus, a 20-percent increase in average volumes does not necessarily mean a 20-percent in-
crease in flows moving through the break-
bulk. Yellow can use SYSNET to identify new directs that can be run with the higher flow levels, thereby reducing the demands placed on the handling facilities. The result is a much more accurate estimation of what will actually happen in five years.

Other applications range from far-reach-
ing studies of the fundamental structure of Yellow's network to such operational ques-
tions as the alignment of satellites to
breakbulks. The LTL industry tends to be dominated by different "philosophies": di-
rects should be loaded out of origin end-of-lines; large breakbulks are better than small breakbulks (these facilities can range from 60 or 80 doors to over 400 doors, with clear implications with regard to network consolidation); regions should be served by a lot of small end-of-lines or by a few large ones. Due primarily to the sheer size of the networks, these philosophies can be difficult or impossible to analyze in a formal, quantitative manner. Existing operating practices tend to persist because of the difficulty in proving that a different strategy is better. SYSNET allowed Yellow to replace philosophy, intuition, and gut feel with formal analytical tools.

The Impacts of the System

SYSNET’s impact can be seen in four areas: in the quality of planning practices and management culture; in the cost savings resulting directly from improvements in load planning; in analyzing projects; and in improved service to customers from more reliable transportation.

Qualitative changes include the following:

- Management gained greater control over network operations. SYSNET allowed Yellow to convert from being a carrier that relied on operating policies to manage trailer loading and dispatching to one that has direct management control. The new load pattern closely controls the loading of directs, and management can quickly change the load pattern in response to changing needs. Yellow felt this new level of control was an important tool for managing future growth of the company.
- It could set realistic performance standards. Prior to SYSNET, Yellow evaluated terminal managers on how many trailers they could load direct, relative to goals based on past performance. SYSNET allowed Yellow to set direct-loading standards based on anticipated freight levels, creating more realistic performance expectations.
- Planners can better understand the total system. Yellow can now evaluate new projects and ideas based on their impact on the entire system. Prior to SYSNET, it was difficult or impossible to calculate system impacts. Now, staff at all levels appreciate the need to coordinate the entire system.
- Managers can base decisions on analysis. Managers found it difficult to analyze complex new options in the past, often doing nothing or managing by philosophy. SYSNET allows them to analyze many of these projects formally.
- Managers plan and respond more quickly. With SYSNET managers can analyze new options quickly in response to changing situations. The departure of a competitor (which happened frequently during the last decade) can create sudden new business that may be difficult to handle in the short run. A sharp economic recession can leave trucks waiting for freight. Yellow can now analyze such new scenarios and quickly send new instructions to the field.
- Analysts are better able to try new ideas. They can test new operating strategies quickly and easily. They try new ideas on the computer, which ultimately leads to new ideas in the field.
- Yellow is introducing new technologies. Because of SYSNET, Yellow is more open to the use of new information technologies. Originally a mainframe application,
NET. The result is an increase in the average number of pounds on trailers moving direct by approximately 380 pounds. This shift in the load average alone produced savings in transportation costs of approximately $1.42 million per year.

Ongoing Projects

Operations planning uses SYSNET principally to analyze a variety of projects ranging from relocating breakbulks to re-aligning satellites with breakbulks. Senior management, operations planning, or managers in the field may initiate projects. Using SYSNET, operations planning now completes over 200 projects per year, mostly on an informal, exploratory basis. Often groups of people work with SYSNET as the tactical planning room, testing ideas and generating new ones. SYSNET’s speed in evaluating different ideas is critical to this process.

Of these projects, about 75 eventually become formal recommendations. Each of these requires a series of signatures before final field implementation. Examples of such projects follow:

—SYSNET was used to evaluate moving a breakbulk to a new location. Operations planning tested various satellite configurations and the ability of the new break to load directly to the rest of the system. With SYSNET they could evaluate different configurations quickly and accurately. The total savings from moving the breakbulk were $800,000 per year.

—A manager in the field suggested aligning a large end-of-line with more than one breakbulk. Using SYSNET, planners tested simultaneous alignments with three different breakbulks. Under each scenario, they evaluated the impact on direct loads out of each of these breakbulks and the impact of changes in flows throughout the system. Total savings were $720,000 per year.

—After expanding a breakbulk, Yellow used SYSNET to analyze the impact of all operations into and out of the new facility, to optimize the loading of direct, and to determine the impact of the change on other breakbulks within the system. The total savings were $825,000 per year.

Some projects are based on suggestions from the field. In the past, Yellow often implemented such projects believing that field personnel had a better understanding of actual activities. With SYSNET, it can quickly and accurately evaluate these suggestions. In some cases, suggestions from the field were shown to produce substantial cost increases as a result of network effects.

In 1990, Yellow used SYSNET to identify over $10 million in annual savings from projects such as these. SYSNET improved the speed with which such analyses could be completed and expanded the scope of each project, allowing Yellow to study system impacts with far greater precision than before. While it is difficult to estimate how much of these savings could have been realized without the system, SYSNET has played a central role in the identification, design, and evaluation of these projects.

Improved Service

The savings resulting from SYSNET are substantial compared to its development and implementation cost, producing a payback period that can be measured in weeks. At the same time, trucking is an industry dominated by such basic costs as fuel and driver wages, and productivity improvements are measured in small fractions of a percent. Such savings can easily be lost on the way to the bottom line if fuel costs change or the economy shifts. It is perhaps not surprising then that following the implementation of SYSNET, management tended to focus on a single statistic that could be traced to the project.

In LTL trucking, service is measured by the percent of shipments that are not delivered within a specified number of days, referred to as the service standard. From 1988 to 1990, the number of shipments delivered over standard fell by 27 percent, reducing by over 400,000 shipments the number of late deliveries.

The value of improved service is difficult to quantify for a motor carrier. Over time, better service will translate to higher market share and higher revenues. However, such changes occur gradually and are difficult to attribute to any single activity. At the same time, during the ’80s, service and quality proved to be the most important dimension of any business. Many companies have adopted just-in-time concepts as part of broad quality-control programs for reducing inventories and eliminating hidden problems in quality control. Yellow contributes to these programs by providing its customers with timely, reliable service that reduces their need for safety stocks.

Yellow Freight plays an important role in manufacturing, supplying parts and materials for assembly processes and delivering finished goods to market. It is a partner in the extensive quality-control programs introduced by many manufacturers. This involvement has been recognized by several major manufacturers: in 1990, 3M Corporation presented Yellow with their Quality Achievement Award; Yellow was the only long-haul carrier to receive the Ford Excellence Award; and Motorola, a winner of the prestigious Malcolm Baldrige National Quality Award, gave Yellow its highest service rating.

Closure

Continuing development of SYSNET helps it to meet Yellow’s changing needs. Following the initial implementation of SYSNET at Yellow in 1988, a software consulting firm, Princeton Transportation Consulting Group, Inc., was founded to take over development of SYSNET and to support other applications of optimization software. PTCG has enhanced the original system and supported Yellow’s transition to a work-station environment.

Internally, Yellow continues to use SYSNET for a variety of planning projects and to continuously monitor and improve the load plan. SYSNET is now used directly within the linehaul operations group responsible for the day-to-day management of flows through the system. In addition, Yellow is using SYSNET as a foundation to expand the use of optimization methods for other aspects of its operation.

SYSNET is now widely accepted and respected within the company for its ability to carry out accurate, comprehensive network planning projects. In fact, often the first question posed regarding a new idea is, “Has it been run through SYSNET?” A final testament to the importance of SYSNET is contained in the following passage quoted from Yellow’s 1990 Annual Report:

—Other operations advances came from our progress with SYSNET. This computer model of our entire company structure allows us to ob-
tained information about the best load patterns, capacity planning, and most cost-effective linehaul routes system-wide. Some five years in development, SYNET incorporates continuous programming capabilities to keep precise pace with requested information and reports.

References
Cranie, T. G. and Roy, J. 1987. "OR tools for the tactical planning of freight transport," Publication no. 198, Centre de recherche sur les transports, Université de Montréal, Montreal, Canada.

Notes
SYNET is a registered trademark of Yellow Freight System, Inc. The FORTRAN programs are proprietary to Princeton Transportation Consulting Group, Inc., Burlington, Massachusetts and are used under license by Yellow Freight System, Inc.

George E. Powell, III, President, Yellow Freight System, Inc. of Delaware, 10990 Roe Avenue, Overland Park, Kansas 66207, writes "More and more of our customers are responding to a competitive global market place by enlisting our help in their efforts to improve quality. SYNET® has enabled us to meet this challenge, and in the process, not only enhanced our service offerings, but sharpened our customer competitive edge as well. For Yellow Freight management, and especially the operations planning, department, SYNET means greater management control and effectiveness. It is an important tool in our own total quality management efforts; and for our customers, SYNET means a real difference in service and reliability."

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The range of books reviewed is wide, covering theory and applications in operations research, statistics, econometrics, mathematics, computers, and information systems (so no software is reviewed). In addition, we include books in other fields that emphasize technical applications. Publishers who wish to have their books and proceedings reviewed should send them to Professor Benjamin Lev, School of Management, The University of Michigan-Dearborn, 4901 Evergreen Road, Dearborn, Michigan 48128-1491. We list the books and proceedings received; not all books received can be reviewed because space and time are limited. Those who would like to review books are urged to send me their names, addresses, and specific areas of expertise. We commission all reviews and do not accept unsolicited book reviews. Readers are encouraged to suggest books that might be reviewed or to ask publishers to send me copies of such books.


In operations research’s early days, it was not uncommon for an analyst to fight with a potential client who knew exactly what the problem was and merely wanted a technician to devise the right solution to it. Experience had shown that the client’s diagnosis was usually far enough off the mark to make work centered on it unproductive. Rather, analysts preferred to respond to vaguely stated problems situations for which clients were willing to help with the early explorations and problem structuring. Sometimes the early inquiries yielded enough information and data to identify remediable causes and suggest courses of beneficial action, but often the difficulties lay deeper and needed the sort of model building and calculation that later