An Information System for Simultaneous Consolidation of Inbound and Outbound Shipments

The day-to-day operations of a modern business are becoming more and more dependent on computers and information systems. Available information must be efficiently and effectively managed in order for a company to survive. Information systems, databases, and fourth-generation computer and simulation languages have all played an integral part in the utilization and control of information.

The transportation and logistics fields are no exception. A logistics information system is a veritable necessity for competent materials management and distribution. A large number of organizations implementing such systems have noted significant cost savings by the logistics departments. One area with great potential for cost savings is the consolidation of inbound and outbound shipments. A system that can accommodate pickups and deliveries simultaneously could produce substantial market advantage for the company.

This article discusses the nature and capabilities of a conceptual system, denoted by LIS, whose main thrust is the consolidation of inbound/outbound shipments. The article will present a history of information systems in the logistics field, review the logistic cycle, set the basis for this LIS model, and consider the requirements for simultaneous consolidation, outlining the capabilities available through this LIS.

The evolution of just-in-time manufacturing is rapidly becoming a way of doing business for many organizations. The article presents a brief description of that methodology, and the various unique requirements for LIS in such an environment. The introduction of electronic data interchange and its impact on logistics functions is examined, and an illustrative example is given which demonstrates how LIS would work. Later sections compare the joint consolidation schedule, i.e., that resulting from LIS, to the performance under separate consolidation, discuss potential future enhancements, and offer conclusions.

LOGISTICS INFORMATION SYSTEMS: PAST AND PRESENT

Much research has been done concerning the opportunities, techniques, and advantages of shipment consolidation. For example, Buffa has written a series of articles detailing various approaches to inbound consolidation methods. A number of other authors have treated outbound consolidation. Vollmann, Berry, and Whybark have discussed Distribution Requirements Planning (DRP), a modification of Materials Requirements Planning to handle distribution planning. Tyworth, Cavinato, and Langley describe general forms and frameworks for outbound shipment consolidation. However, at the time of writing, only one paper could be found which considered a simultaneous consolidation of inbound and outbound shipments. In that work, consolidation occurs at a transportation terminal, rather than on routes which mix inbound and outbound movements of goods.

Various authors have examined the growing uses of information systems and computer applications in logistics. Bushnell, Low, and Wiley summarize examples of network models. Gustin studies implementation trends of U.S. manufacturing and merchandising companies in transportation and distribution management.

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discovering numerous areas of increased computer utilization. Such systems, besides bringing efficient and effective methods of information control, can provide financial benefits. Calantine and Morris, through examination of companies implementing decision support systems, report 43 percent of companies realized decreased costs and 78 percent realized increased cash flow due to computer technology.

Other authors have recognized the need for and potential advantages of logistics information systems. Forrester, Cavinato, and Langley acknowledge information systems as an integral part of the control process, presenting a comprehensive view of the requirements of such systems for transportation. Langley considers how the logistics area can make use of the information available through the latest technology. Halsey and Krishnamoorthy propose a system approach which integrates all aspects of the logistics cycle from marketing to customer service. Langevin and Saint-Meux describe an interactive decision support system for physical distribution planning through which the user designs delivery routes based on personal knowledge.

The majority of these systems contain modules which perform some form of consolidation, either inbound or outbound, using standard operations research techniques and methods. Cascio, Golden, and Wasiolka, on the other hand, examine vehicle routing with backhauls. The algorithms and case studies presented concentrate on adding backhaul shipments to a predetermined "delivery route." These methods either attempt to delay pickups as much as possible, placing them at the end of the route, or consider deliveries a higher priority than pickups. No system or methodology could be found which treated inbound and outbound shipments as equally important for vehicle routing.

**Problem Definition and Assumptions**

Many businesses have utilized consolidation opportunities to their advantage. Since consolidation of inbound or outbound shipments can result in significant savings, a company that effectively combined both types of shipments on a common vehicle could potentially save money through greater efficiency in routing trucks.

With increasing frequency, recognized techniques and heuristics for complex operations research methodologies are being programmed for computer manipulation. Consolidation is no exception. The vast amounts of information, multiple routes, and number of shipments can be handled more efficiently by a computer. Therefore, when considering simultaneous inbound and outbound shipment consolidation, a computer algorithm is the natural way to go. This article attempts to determine the various steps and modules that would be needed to perform this unique form of consolidation. Throughout, we emphasize the business aspects and omit the mathematical details.

**Overview of the Logistics Cycle**

Contrary to what may be popular opinion in general management circles, logistics covers more than the physical distribution of goods from point of origin to point of destination. Logistics has been defined as:

the process of planning, implementing and controlling the efficient flow and storage of raw materials, in-process inventory, finished goods, and information from the point of origin to point of consumption, for the purpose of meeting customer-service goals of the organization at acceptable cost.

Other authors have given comparable definitions, covering a large number of business functions, most outside of what is traditionally considered to be distribution.

The logistics cycle begins with the marketing department, which advertises the goods available. This, triggers an order from a potential customer, perhaps through contact with a salesperson. In order to fill this request, purchases of raw materials must be made, the production process started, and transportation of the goods arranged. This, hopefully, puts in motion a cycle which never ends until the business ceases to exist. The effectiveness of the cycle is measured primarily by a customer service goal set by the company. Each of the various functions plays an important part of the logistics efforts of the firm. Each must therefore be integrated to achieve a productive system.

**LIS Requirements**

The above-mentioned functions can all be adapted to a computer environment through the use of information systems. Order processing, production planning, and inventory control have all been transferred to computer systems by successful companies. Today, many vehicle routing programs are available to aid in determining distribution paths and networks. Unfortunately, all of these modules are, for all intents and purposes, designed independently of one another. Interface between the various components is essentially a last-minute consideration instead of an initial element in the design. Development of an efficient logistics information system requires a coordinated effort among all areas.

Although a thorough system definition would include specifications for all elements in the cycle, their inclusion would exceed the scope of this article. Therefore, all future references to this information system will concern those functions directly related to shipment consolidation. It will be assumed that this system is simply a sub-module of a larger system.

**Model Assumptions**

In order to determine the specifications for our information system, certain assumptions are made to keep the system manageable:

1. The company is a manufacturing firm. The terminology used in the remainder of this article will be that of a manufacturing firm.
2. Transportation is by truck. Shipments requiring other types of transportation will be excluded from consideration.
3. The company manages its own truck fleet, which is large enough to handle the flow. In order to consider joint consolidation, the company must have control over a reasonable number of pickups and deliveries, and therefore must be able to perform these duties on its own.
4. All trucks (trailers) are identical in size, shape, and capacity, and contain multiple doors. Multiple doors are required to allow easier access to the interior of the trailer, increasing the flexibility to mix pickups and deliveries.
5. There is sufficient compatibility between products that they can be shipped together. These goods have identical storage requirements, such as those concerning temperature. Incompatible items will be eliminated from consideration.
6. All suppliers and customers are within a given radius of the plant. This is to facilitate the assignment module.
7. Access to vehicle-routing software is assumed.
8. The objective is to minimize cost while maintaining a desired customer service level. Note that in most cases, these assumptions will not appreciably limit the applicability of our system to a manufacturing firm which operates a private fleet.

**LIS**

The proposed system, denoted by LIS, will require certain facilities and capabilities in order to provide meaningful and reliable data. The following presents a description of the various modules and their respective components.

**General Overview**

LIS is a conceptual model intended for use by organizations with inbound and outbound shipment requirements. It is designed to coordinate a company’s pickups and deliveries in order to exploit potential savings due to consolidation: fewer trucks and drivers, improved customer service, and more reliable receipt of raw materials. LIS maintains and controls data that is relevant and up-to-date, invoking a sort algorithm to assign shipments to trucks and provide improved routing schemes. The system also allows overriders where and when the user deems necessary. Post-analysis capabilities and performance measurements are provided.

LIS is a menu-driven system which facilitates access to the various modules, each module is self-contained while maintaining overall system consistency and integration. The following sections present more detailed descriptions of the relevant components.

**Inbound Shipments**

Inbound shipments refer to those items considered as inputs to manufacturing, such as raw materials and components. These items, normally ordered by the purchasing department, will be required at specific times and locations and in exact quantities throughout the production process. More timely receipt of goods will enhance the reliability of manufacturing, and should help improve customer service. However, to achieve this goal, certain elements of information will be required:
Outbound Shipments

The company's *outbound* shipments are of its finished goods. These items, generally sold through the joint efforts of marketing and sales, will be required at specific times and locations, and in the quantities ordered, either as goods for resale or as inputs to another production process. Similar to the inbound case, new information will be needed to facilitate this endeavor:
1) Date and time that goods are available for pickup
2) Date and time that goods are required for production
3) Time window within a given day for pickup at the supplier
4) Type and location of the supplier's loading facility

Sort Algorithm

The sort algorithm is employed to develop a merged list of pickups and deliveries, thereby setting priorities for vehicle routing. A sort could be invoked whenever desired. However, a regular time interval would be most efficient, with emergency runs performed as necessary. The default interval for sorting is one week. This is reasonable since the company will continually accumulate information and should have detailed knowledge of required inbound and outbound shipments for the coming week. That initial plan, although subject to future changes, provides the company with a basis for personnel and maintenance scheduling and the like. It can also alert the user to possible problems or anomalies which, if remedied, could potentially result in additional savings.

Using this weekly schedule as a base, new runs of the algorithm would be initiated on a two- to three-day cycle for further refinement as new data are made available. The last step would be a final daily schedule, kept firm except in situations deemed emergencies by the logistics department.

Initiation information is required before the actual algorithm is invoked. These data concern any environmental changes related to trucks and road conditions. Examples include:
1) New truck acquisition
2) Truck disposal
3) Scheduled truck maintenance
   (These elements could appear on the sort-runtime screen as modifiable inputs concerning the number of available vehicles and maintenance. Any changes made at this time could automatically update the data for future runs if appropriate.)
4) Scheduled road work by city repair crews, where this would affect travel time
5) Scheduled new road construction and expected completion dates
   (The vehicle-routing software would accommodate the above elements in some fashion, assuming a geographical database were available. Should such a database be unavailable, the above information would have to be incorporated through projected travel times for given routes.)

The sort algorithm can be divided into unique phases as outlined below.

**Phase I: Elimination Phase**

This phase deletes those shipments which cannot be handled under the stated assumptions:
1) Shipments for which there already exists alternative transportation, determined through contracts and the other previous arrangements
2) Shipments which require different modes of transportation, such as air freight
3) Shipments to or from destinations outside the given radius of consideration
4) Shipments which cannot be carried on the trucks due to differing storage and/or transportation requirements

Elimination of the above will yield a list of shipments suitable for assignment and routing.

**Phase II: Sort Procedure**

This list resulting from Phase I will now be sorted. The user can determine which relative priorities are to be applied for routing. Sorting can thus be based on any of the following:
1) Preferred vendors/customers. Certain vendors or customers may be deemed more important than others, and therefore deserve initial consideration in order to maintain desired service parameters.
2) Vendor/customer location
3) Date and time of pickup or delivery
4) Size of shipment (dimensions)
5) Weight of shipment
6) Shape of shipment
7) Time window for delivery or pickup

**Phase III: Vehicle-Routing**

The sorted list from Phase II is used as input to the vehicle-routing software. Output will be the recommended routing. That output should also report any problems such as unassigned shipments. This routing can be saved and retrieved at a later date, if desired, for study or evaluation of user-determined changes.

Performance Measures

Key to the evaluation of any system is the analysis of performance. Feedback on day-to-day operations, as well as on the extent to which company goals and objectives are being met, is essential if an organization is to exploit all areas with potential benefits. To this end, LIS will provide the ability to analyze and evaluate many aspects of the logistics system.

The main ingredient to successful implementation is meeting the company's service levels. Care must be taken to determine if these prespecified levels are being attained. Rushion and Oakley discuss customer service and enumerate some of the more popular elements which could be available through LIS. Distribution managers provides many other areas where measurement of performance is advantageous. Tyworth, Cuvino, and Langley furnish a list of control measures which could be used to monitor traffic. Continual evaluation of service levels will aid in early detection of any decrease in effectiveness, and hence lead to more timely correction.

Private carriage requires attention to certain performance aspects to ensure efficient operation. Parameters such as fleet utilization and load factor are important indicators regarding truck usage. Driver performance can be evaluated through route sheets or tachographs. LIS will contain methods for analyzing such data.

Because of the unique shipping consolidation performed by LIS, a valuable measure would be the comparison of these costs to those that would have been incurred using the previous system. This will provide concrete evidence of savings incurred.

**Post-Analysis Module**

Several opportunities, such as those outlined by Firth et al., although detectable through basic methods, may be quite difficult to incorporate. For example, suppose stops were too concentrated in one portion of the day. Although LIS could help in recognizing this problem, its resolution would require a more in-depth approach. Specific action by the user will be required, but LIS can help a great deal in this regard.

LIS will thus provide a somewhat innovative graphical analysis for those organizations who wish it. Each suggested routing will be available for terminal display via the geographic database. The user will be allowed to input changes to evaluate their impacts on mileage, service levels, and times from origin to destination. The magnitude of these changes will determine the difficulty of estimating the effects; certain differences will require invoking the sort algorithm for a test run, while others will simply need a few minor calculations. This facility can be used as well to input last-minute alterations when time does not permit a run of the entire system.

By employing the graphical output, the user can also evaluate various routings for robustness although modification of a modification. This is particularly valuable if the week-to-week or day-to-day shipping requirements are fairly consistent. The organization may be able to select an alternate route which on the surface may cost more, but may be robust enough to handle changes at lower cost than the suggested routing.

**JIT-LIS Integration**

Pioneered in Japan, just-in-time (JIT) manufacturing ideology has progressively been adopted by many North American firms. An increasing number of companies are recognizing the benefits of lower inventory and more timely delivery of higher-quality goods. The stringent demands of the methodology are more easily and accurately met by computer utilization and information system development. For the company implementing JIT principles, LIS
will prove a valuable investment.

**JIT Overview**

Over the past twenty years, the Japanese have developed a system designed to meet two major goals: reduction of inventory and 100 percent quality of all parts, subassemblies, and products. At each stage in the manufacturing process, each component or subassembly arrives just in time for addition or assembly, the final product being completed just in time to be sold. Consequently, each shipment, inbound and outbound, must be of the highest quality; no defects or missing items can be tolerated. However, such stringent demands cannot be met absolutely; they merely represent an ideal which one strives to attain. Schonberger has defined this ideal as:

all materials [being] in active use as elements of work in process, never at rest collecting carrying charges. [JIT] is a hand-to-mouth mode of operation, with production and delivery quantities approaching one single unit — piece-by-piece production and material movement.

Each refinement of a production process leads a company one step closer to achieving this ideal. The effectiveness of the JIT methodology has been documented by many companies and authors. For instance, Toyota has shown great success through JIT. As described by Monden, firm's goal is to "produce the necessary units in the necessary quantities at the necessary time." Toyota's phenomenal success has prompted other organizations to investigate the principles and to change their perception of the manufacturing process. North American companies are attempting to emulate their Japanese counterparts in the hope of reducing costs and hence increasing profits.

JIT requires cooperation between supplier and customer. Each must be committed if the implementation is to be a profitable success. An effective JIT approach requires delivery of smaller but more frequent shipments, and these shipments are to be of high-quality merchandise. More accurate and timely information must be exchanged the system is to benefit both parties. Suppliers and customers must be in constant contact to ensure the production process does not stop because of incorrect shipments.

**LIS Requirements**

The integration of JIT principles into this LIS requires special considerations. Bookbinder and Dilts describe a conceptual model of a JIT logistics information system which outlines some of these issues. Although their model is limited to inbound shipments, the ideas are still relevant to the LIS presented in this article. While discussion of these concepts is tangential to the present subject, namely inbound/outbound coordination, the following is a brief examination of the changes necessary to adapt the LIS of the previous section to a JIT environment. We note that not all shipments need to be on a just-in-time basis.

As the first JIT modification to LIS, data requirements for inbound shipments will now be more precise. Particular dates and times that items are needed for production will be specified. An exact drop-off location at the manufacturing plant must be given for each incoming item. The time necessary to move items from the unloading facility to this location should be taken into consideration.

Changes to outbound shipment information will concern the date and time that goods are available for delivery; JIT should be more accurately pinpoint this time. It should be noted that, due to the nature of JIT, it may be advisable to invoke the sort procedure with relaxed pickup time constraints prior to contractual negotiations with prospective suppliers. This less-constrained schedule may aid in determining desirable times for pickups at the suppliers, so as to improve the vehicle routing as much as possible.

Because JIT operates on a more stringent schedule, the sort procedure will have to be carried out at shorter time periods. The default interval is two or three days, to allow the scheduling of trucks, personnel, and maintenance. However, as last-minute information concerning the quantities and exact time requirements for each item are relayed to the supplier, the sort program can be invoked by the organization at moments closer to the deadline. Performance measures and post-analysis capabilities will still be available, and will contain those elements mentioned earlier. The graphical analysis may prove invaluable. The ability of this module to consider alterations to the schedule could be perfectly suited to a JIT environment, where last-minute changes and emergencies could be detrimental or fatal to the production process.

**EDI-LIS Integration**

Electronic Data Interchange (EDI) is modifying the way many companies do business, by eliminating verbal and written communication. EDI allows a direct communication link between different computer systems, thus increasing the speed and accuracy of information transmitted between companies. Data transferred by a person takes time to reach the interested party and hence can be out-of-date and irrelevant. By lessening the need for human intervention, organizations can exchange important information on a more timely basis, making it both accurate and up-to-date.

The logistics and transportation fields have led the way in introducing EDI to the everyday business world. The vast amount of data transferred between organizations involved in the logistics cycle made EDI a virtual necessity for success. Lambert and Stock present a list of EDI usages which demonstrates the degree to which it has been applied in the transportation area.

EDI provides many benefits beyond the increased speed and accuracy of information, such as decreased transit times and the lower chance of human error. The grocery business has estimated direct cost savings of $68 million, indirect savings of up to $250 million, and efficiencies in areas such as purchasing and invoicing in excess of $50 million per year. Figures of this magnitude warrant consideration of the use of EDI in all areas of business where data must be relayed between two or more computer systems.

The joint consolidation of inbound and outbound shipments requires immense cooperation between the firms involved. Data must flow freely and on a timely basis. EDI is therefore the perfect companion to LIS. With EDI the flow of information is automatic and up-to-date. Parties can be notified immediately of any changes in arrival patterns, shipment quantities, or other relevant matters. If these changes warrant new routings, logistics personnel would be notified immediately.

The demanding time requirements of JIT provide a perfect environment for the implementation of EDI. Purchase orders placed within hours of the deadline require quick and accur-

<table>
<thead>
<tr>
<th>Table 1a: Shipment List for Routing</th>
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</thead>
<tbody>
<tr>
<td>Customer/Supplier</td>
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<tr>
<td>--------------------</td>
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<tr>
<td>C</td>
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rate communication between supplier and customer. The constant contact and on-line communication available through EDI is suited to such an environment. EDI can enhance the benefits of JIT through proper integration.

**ILLUSTRATIVE EXAMPLE**

This section presents a numerical illustration of LPS and its capabilities. The example is simple in nature, to allow understanding of the various aspects and nuances of the system. The application is structured as a base problem with sub-problems designed to cover special circumstances. Certain assumptions were made:

1. The manufacturing environment is non-JIT.
2. The shipments to be processed span a two-day interval.
3. If more than one route is feasible, the one having the earliest completion time is chosen.
4. There are two products - Prod1 is a finished good, weighing 20 pounds per unit and measuring 4\(\times\)4\(\times\)4\(\mathrm{in}^3\), while Prod2 is a raw material, of weight 25 pounds per unit and size 4\(\times\)4\(\times\)4\(\mathrm{in}^3\).
5. There is one truck available for use, measuring 9\(\times\)9\(\times\)40\(\mathrm{ft}^3\), with a weight capacity of 48,000 pounds. Therefore, it can accommodate 180 units of Prod1 and Prod2 collectively, assuming 2 units across, 2 units high, and 9 units long.
6. The truck driver is allotted a one-hour lunch break.
7. The vehicle leaves the plant at 9 a.m., having pre-loaded the goods to be delivered in that trip.
8. The list of shipments has already been processed through Phases I and II. Therefore the list is ready to be routed in Phase III.

### Table 1b. Day1: Shipment List

<table>
<thead>
<tr>
<th>Customer/Supplier</th>
<th>Date for Pickup/Delivery</th>
<th>Time Window</th>
<th>Stop Time (in mins)</th>
<th>Product</th>
<th># of Units</th>
<th>Shipment Weight (in lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Day1</td>
<td>9:00-10:15</td>
<td>51</td>
<td>Prod1</td>
<td>70</td>
<td>1400</td>
</tr>
<tr>
<td>S1</td>
<td>Day1</td>
<td>9:00-11:00</td>
<td>30</td>
<td>Prod1</td>
<td>45</td>
<td>1125</td>
</tr>
<tr>
<td>C2</td>
<td>Day1</td>
<td>9:00-12:00</td>
<td>52</td>
<td>Prod1</td>
<td>75</td>
<td>1500</td>
</tr>
<tr>
<td>S1</td>
<td>Day1</td>
<td>11:00-1:00</td>
<td>32</td>
<td>Prod1</td>
<td>50</td>
<td>1250</td>
</tr>
<tr>
<td>S2</td>
<td>Day1</td>
<td>2:00-3:30</td>
<td>20</td>
<td>Prod1</td>
<td>20</td>
<td>500</td>
</tr>
<tr>
<td>C3</td>
<td>Day1</td>
<td>2:30-5:00</td>
<td>30</td>
<td>Prod1</td>
<td>25</td>
<td>500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer/Supplier</th>
<th>Date for Pickup/Delivery</th>
<th>Time Window</th>
<th>Stop Time (in mins)</th>
<th>Product</th>
<th># of Units</th>
<th>Shipment Weight (in lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5</td>
<td>Day1</td>
<td>9:00-11:00</td>
<td>51</td>
<td>Prod1</td>
<td>70</td>
<td>1400</td>
</tr>
<tr>
<td>C3</td>
<td>Day3</td>
<td>10:30-12:30</td>
<td>47</td>
<td>Prod1</td>
<td>60</td>
<td>1200</td>
</tr>
<tr>
<td>C1</td>
<td>Day1</td>
<td>11:00-1:00</td>
<td>42</td>
<td>Prod1</td>
<td>50</td>
<td>1000</td>
</tr>
<tr>
<td>S1</td>
<td>Day1</td>
<td>3:00-5:00</td>
<td>32</td>
<td>Prod1</td>
<td>50</td>
<td>1250</td>
</tr>
</tbody>
</table>

9. All sub-problems are independent unless otherwise stated.
10. Prior to implementing LPS, consolidation of inbound and outbound shipments were considered independently of one another.
11. Times for loading and unloading, by forklift, can be derived using Deming's relationship between handling time and shipment weight. With times in minutes and weight in pounds, Deming's result is shipment-handling time \(= a + b \times \text{weight}\) where \(a, b, \text{and } c\) are regression coefficients. Values for these parameters are \(b = 0.66\) for loading, \(b = 1.0\) for unloading, and \(a = 0.6\) and \(c = 0.54\) in either case. Note that in the following calculations, times have been rounded to the nearest minute.

Table 1a shows the list of shipments to be considered for routing during the two-day period; Tables 1b and 1c divide the list into Day1 and Day2 shipments respectively. The delivery/pickup network is illustrated in Figure 1. Numbers associated with arcs represent the average time in minutes that it takes to travel from one stop to the other. Because a detailed network showing all paths would be complicated, only those arcs used in the example are exhibited.
Consider Day 1 scheduling first, referring to Table 1b and Figure 1. Notice that there are three stops with time-windows beginning at 9:00. These must be routed so as to allow reaching all three within the allotted windows. Consider stopping at C1 first. Expected delivery time is 52 minutes; thus, there is not a sufficient interval to make it to C1 and unload, and hence C1 cannot be the first stop. Now consider S1 as the first stop. It is apparent that this pickup cannot be accommodated until a delivery is made; customer shipments make up 170 units, so there would be room for only part of the 45 units from S1. That leaves C3 as the first stop. Using travel and pickup/delivery times as given, the resulting schedule is:
1) 9:10 - 10:01 at C3
2) 10:06 - 10:36 at S1

Figure 2. Day 1 Routing

3) 10:41 - 11:23 at C1
The next stop will be S2; this is the only interval during which that stop can be accommodated:
4) 12:13 - 12:45 at S2
5) 12:45 - 1:45 driver takes lunch
All that remains is to sort C1 and S2. Consider going to C2 next. This would require waiting 25 minutes after arrival until the time-window opens. Following drop-off of the goods and departure at 3:00, arrival at S3 would occur too late for the 3:30 close. Therefore, the concluding schedule will be as follows:
6) 2:15 - 2:35 at S3
7) 3:20 - 3:50 at C2
8) 4:00 - 5:14 at plant (unloading of the 115 units of ProdC takes 74 minutes).
Similarly, routing for Day 2 (Table 1c) can be done to arrive at the following schedule:

Figure 3. Day 2 Routing

1) 9:15 - 10:06 at C6
2) 10:41 - 11:28 at C5
3) 11:43 - 12:25 at C3
4) 12:25 - 1:25 driver takes lunch
5) idle time from 1:23 to 2:29
6) 3:00 - 3:32 at S4
7) 3:52 - 4:40 at plant (it takes 48 minutes to unload the 50 units).

Figures 2 and 3 show the routes for Day 1 and Day 2, respectively.
There are other situations which could occur after the routing is decided, requiring alterations to the schedule. A sample of ad hoc occurrences will now be considered.

CASE 1: A Change in Delivery Date
Suppose that supplier S1 calls, saying that the shipment of raw materials must be picked up on Day 1, as opposed to Day 2, but in the same time-window. There are two ways in which this change of Day 1 could be accommodated:

a) 1) original routing up to and including S2 remains the same
2) 3:05 - 3:37 at S2
3) 3:57 - 4:27 at C3
4) 4:37 - 6:07 at plant (unloading takes 90 minutes - have 165 units)
b) 1) original routing up to and including C5 remains the same
2) 4:10 - 4:40 at S5
3) 5:12 - 6:42 at plant (unloading again takes 90 minutes).

Option (a) would be the better choice, since it requires 35 less minutes than option (b). However, this routing still requires an additional 53 minutes over the base case for Day 1. The schedule for Day 2 would also be affected; the truck could proceed to the plant after stopping.
at C and before the driver’s lunch. Work for the day would finish at 12:45 with no unloading required, approximately 4 hours earlier than the original Day schedule. (Note that this change leaves the driver and vehicle available for several hours of additional work not included in this consolidation scheme.) Figures 4a and 4b show the altered routings for Day 1 and 2, respectively.

CASE 2: Post-Analysis Evaluation of Efficiency

Examination of the final routing in Figure 2 reveals a backtracking from S to S. Crossing of routes such as this usually indicates a suboptimal solution, but here the crossing is needed to accommodate the time-windows. Now suppose, only for a moment, that the respective time-windows constraints were eliminated. This would alter the schedule to:

1) 11:58 – 12:18 at S
2) 12:18 – 1:18 driver takes lunch
3) 1:48 – 2:20 at S
4) 2:40 – 3:10 at C
5) 3:20 – 4:34 at plant (unloading of the 115 units takes 74 minutes).

This would result in a savings of 40 minutes over the original case. Therefore, negotiations with these suppliers should be initiated in order to change the time windows to include 11:58 – 12:18 at S and 1:48 – 2:20 at S. The optimal routing, assuming these changes are possible, is given in Figure 5.

COMPARISON TO PREVIOUS SYSTEM

It is important to compare the performance of the joint consolidation schedule to that of the prior system. Consider the routings required for separate consolidation:

Day: Outbound
1) 9:10 – 10:01 at C
2) 10:11 – 11:03 at C
3) 11:03 – 2:15 idle (with one hour lunch for driver)
4) 2:30 – 3:00 at C
5) 3:10 back at plant (no unloading required)

Inbound
1) 9:15 – 9:45 at S
2) 9:45 – 10:15 idle
3) 11:00 – 11:32 at S
4) 11:32 – 1:30 idle (with one hour lunch for driver)
5) 2:00 – 2:20 at S
6) 2:55 – 4:09 at plant (unloading again takes 74 minutes)

Day: Outbound
1) 9:15 – 10:06 at C
2) 10:41 – 11:28 at C
3) 11:43 – 12:25 at C
4) 12:45 back at plant (no unloading required)

Inbound
1) 3:00 – 3:32 at S
2) 3:52 – 4:40 at plant (unloading of the 50 units takes 48 minutes).

The primary difference between the routings is the need for a second truck prior to implementing joint consolidation. Day 2 requires two vehicles or a contract with another company to cover those shipments that cannot be accommodated on the single truck. This necessitates an additional capital expenditure for another vehicle, and the salary of an extra driver (or an outlay of cash if the shipment is contracted out).
The second major difference is the extra idle time present before using LIS. Days inbound and outbound schedules both show idle time for the truck and driver. Idle time is wasted time and results in unnecessary expenses as the driver must still be paid. Some idle time may be desirable, but too much is detrimental to company operations.

Both difficulties can be avoided through simultaneous inbound/outbound consolidation, as shown above. One vehicle can more efficiently handle the shipment requirements through application of LIS. Idle time can also be reduced, improving performance.

Figure 5. Case 2: Day 1 Routing After Change

CONCLUSIONS

Simultaneous consolidation of inbound and outbound shipments is a promising area for further research. As illustrated earlier, this methodology could result in significant savings and improved efficiency. Future endeavors could be directed to developing heuristics to handle simultaneous consolidation. This may be more efficient than using current versions of vehicle routing software, which were not designed to accommodate such a scenario. Algorithms which may serve as a base for this type of study could include those mentioned by Casco, Golden, and Wasil and by Min, Current, and Schilling.

It is true that introduction of a system such as LIS would require extensive coding and coordination of various aspects of the company. However, for an organization considering a joint inbound/outbound consolidation program, LIS will prove beneficial. The system will streamline the consolidation process, and should also result in improved efficiency and cost savings as well as major reductions in capital expenditures.

ENDNOTES


13 C. John Langley, Jr., op. cit., p. 43.


