IMPACT ON A TRUCKING COMPANY OF A CUSTOMERS USE OF DISTRIBUTION REQUIREMENTS PLANNING

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and

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HEADNOTE

In distribution requirements planning (DRP), demand for a product at the final distribution point determines demand at intermediate distribution centres. Previous work in this area has examined the impact of DRP on the company using it, but never considered how it might affect the provider of transportation services. Through a simulation model, we examine the impact on a trucking company when one of its major customers uses DRP and hence can eliminate buffer inventories at the intermediate centres. We compare the trucking company's performance with DRP to that with a non-DRP system; we also investigate the effect of fleet size, demand rate from other customers and changes in lead time for the non-DRP system.

INTRODUCTION

Distribution Requirements Planning (DRP) is a method of controlling inventory by the systematic distribution of finished goods from the factory to the warehouses and retailers. One major aim of DRP is increased efficiency in the planning and scheduling of production, storage and distribution. The second objective of DRP is better management of surpluses (inventories and truck capacities).

The benefits of DRP are increased efficiencies and better management. These results are possible because DRP recognizes a situation that is known as "dependent demand": demand for a product at the factory F (Figure 1) is dependent on the demands at the warehouses (W₁, W₂). Similarly, demand at each warehouse is dependent on the demands at the retailers (R₁, R₂,...) served by this warehouse.
In other words, the amount of product that each warehouse must furnish is basically the sum of the requirements ordered by these retailers it supplies. If this warehouse can anticipate when and how much each retailer will order, very little inventory need be carried between orders. Similar remarks apply to the anticipation by the factory of orders from the warehouses, these orders stemming in turn from the above anticipation by the warehouse of the retailer demands.

Before the recent development of DRP, the only decentralized way to manage inventories of a product held at several levels or "echelons" was a method proven successful for a single echelon, the usual "order-point" system. Consider a particular product whose on-hand stock at retailer $R_1$ is below its reorder point. $R_1$ then places an order with the warehouse $W_1$, which may in turn have to place an order on the factory $F$, if $W_1$ does not have enough stock on hand to fill the order. In the extra time needed to ship from $F$ to $W_1$ to $R_1$ (compared to shipping only from $W_1$ to $R_1$), $R_1$ may suffer a stockout before the goods arrive.

Naturally, an order-point system can be made less vulnerable to stockouts at a retailer or warehouse, at the expense of higher safety stocks at each echelon. DRP, on the other hand, eliminates these extra inventory carrying costs, by recognizing that demand at each echelon is dependent on the demand at the next lower echelon. As previously mentioned, demand at $W_1$ is known once demands at $R_1$, $R_2$ are known. Similarly, demand at $F$ is determined by that at $W_1$ (and $W_2$).

DRP safety stocks need only be carried at the retailer’s $R_1$ and $R_2$, to protect against fluctuations in the "independent" final demand. Warehouse $W_1$ need not carry a safety stock, provided it has advanced knowledge of each retailer's inventory status and the approximate demand rates. (This enables the "anticipation" referred to above.) $W_1$, and analogously $W_2$, can then roughly tell when orders will be placed with it, hence the factory can know ahead of time when each warehouse is likely to order from $F$. The factory can more smoothly coordinate the production schedule of the given item with that of other products.

In summary, DRP should allow the factory to be more efficient in serving its warehouses and retailers. That increased efficiency, we suspect, can be shared by the trucking company which carries the shipments between echelons.

The focus of this article is the impact on a trucking company when a major customer uses DRP.

We have designed and programmed a computer simulation model of a factory warehouse system served by a trucking company (see Figure 2). Through this model we examine the impact on the trucking firm when the factory-warehouse uses DRP compared to when it does not. We study whether these impacts increase or decrease as we vary the lead time for customer shipments, the demand rate, and the size of the truck fleet.

DRP AND RELATED WORK

DRP is a recent outgrowth of a method for managing inventories in a manufacturing system, Material Requirements Planning (MRP). In fact, DRP may be thought of as an extension of MRP to the "outbound" side. A sample DRP plan, related to the model which we discuss in this article, is shown in Table 1.

The original implementation of DRP was by André Martin, to coordinate the manufacturing and distribution activities at a pharmaceutical company. He cited the following benefits: improved inventory turnover, increased service levels, decreased distribution costs, reduction in write-offs due to obsolescence and increased manufacturing productivity. Martin also described how DRP can deal with special situations such as seasonality, stock buildup and depletions and re-arranging the distribution network. Collins and Whybark, in a case study on this same pharmaceutical firm's use of DRP, stressed the role of the Master Production Scheduler if a company is to obtain low total costs of ordering, inventory carrying, transportation, expediting and stockouts. Stenger and Cavinato, using data from a state liquor control board, found that good demand forecasting is essential if use of DRP is to result in lower safety stocks.

It should be noted that the DRP system interfaces with physical distribution management responsibilities in at least two ways. One clearly is inventory, the decision at a given echelon to place an order with the next higher echelon. The second is timeliness for receipt of that order, concerning not only when it should be placed but also how it should be delivered (on which vehicle should it be scheduled) to best assure timeliness. DRP thus impacts on both inventories
and transportation. To help establish the context of our model, we briefly discuss some work concerning combined transportation/inventory decisions, as well as coordination between other line responsibilities in operations management.

### Table 1

**Sample DRP Plan**

<table>
<thead>
<tr>
<th>Day</th>
<th>Number On Hand</th>
<th>Order Quantity</th>
<th>Planned Delivery</th>
<th>Number On Hand</th>
<th>Order Quantity</th>
<th>Planned Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
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<tr>
<td>2</td>
<td>350</td>
<td>650</td>
<td></td>
<td>550</td>
<td>1450</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>230</td>
<td></td>
<td></td>
<td>300</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>700</td>
<td>650</td>
<td>1500</td>
<td>1450</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>550</td>
<td></td>
<td></td>
<td>1250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>400</td>
<td></td>
<td></td>
<td>1000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

------ Above information communicated to the Carrier ------

<table>
<thead>
<tr>
<th>Day</th>
<th>Number On Hand</th>
<th>Order Quantity</th>
<th>Planned Delivery</th>
<th>Number On Hand</th>
<th>Order Quantity</th>
<th>Planned Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>250</td>
<td>750</td>
<td>750</td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>100</td>
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<td>9</td>
<td>700</td>
<td>750</td>
<td>250</td>
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<tr>
<td>10</td>
<td>550</td>
<td>1500</td>
<td>1500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>400</td>
<td></td>
<td>1250</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>12</td>
<td>250</td>
<td>750</td>
<td>1000</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Maxwell and Muckstadt\(^6\) have developed an approach to coordinate production schedules with shipping schedules. Van Roy and Gelders\(^5\) consider a 3-stage logistics system, incorporating truck-scheduling constraints in solving their overall distribution problem. Tancheo, et al.,\(^10\) Constable and Whybark,\(^11\) and Gaither\(^12\) have looked at extensions of the economic order quantity to include considerations of transportation. Tancheo considers volume and weight restric-
tions on unit-loads, as well as space for storage-in-process. Both Constable and Whybark and Gaither study joint transportation-inventory decisions, with Gaither including quantity discounts in both the transportation alternatives and in the purchasing lot-size.

Another informative article is by Stenger, Coyle and Price\textsuperscript{13} whose transportation/inventory technique may be useful to carriers in determining how much they must change their rates, speed or reliability in order to attract more business. Lastly, before presenting the details of our model, we make one further comment. DRP shares the same philosophy as MRP, but it should be noted that an alternative approach to manufacturing is furnished by the Japanese Kanban system.\textsuperscript{14} Based upon Kanban, one may well be able to develop an extension to distribution planning quite different from DRP.

**OPERATIONAL ASSUMPTIONS**

To keep our calculations manageable, we had to make several modelling assumptions. These are consistent with our goal of estimating the maximum savings possible to the trucking firm.

The trucking company \( T \) does the shipping from \( F \) to \( \{W_1, W_2\} \) (Figure 2). The factory was assumed to be always able to satisfy demands by the warehouses. Although no retailers have been included, we have taken into account other customers \( \{0\} \) of the trucking company. The system \( \{F, \{W_1, W_2\}\} \) is given priority by the carrier. It was run under DRP for some of our experiments, and as a non-DRP system ("NDRP") for the remainder of our simulation runs. In either case, the trucking company gave the factory-warehouse system priority over "other" customers \( \{0\} \). That is, all factory-warehouse orders are committed by the trucking company to be delivered exactly on time. In the event of a shortage of trucks, some factory-warehouse orders may be sub-contracted to ensure on-time delivery. However, deliveries for \( T \)'s "other" customers could be made as much as 2 days early or 6 days later, or else cancelled if these deliveries are not possible within the allowable time-frame. In fact, cancellations almost never occurred during our simulation runs.

Only for the DRP model was a plan of shipments such as that of Table 1 communicated in advance to the carrier. Thus, our simulation experiments allow estimation of the benefits to a trucking company \( T \) when a major customer employs Distribution Requirements Planning and shares this information with \( T \). These benefits of DRP include regular business, shipments delivered to the factory-warehouse system on routes which are essentially pre-planned and scheduled.

Most of our simulation runs treated warehouse stock as a standard product mix. However, we did implement a 2-product version of the model and verified that the product-mix assumption did not oversimplify the situation (see Table 4).

The simulated shipments involve Toronto, Ottawa, Windsor, Sudbury and Thunder Bay, all of which are major cities in the province of Ontario. Toronto is also the site of the factory, while the warehouses \( W_1, W_2 \) are located in Ottawa and Thunder Bay. Flows on the various arcs were randomly drawn from probability distributions corresponding to recent Ontario patterns of shipments by truck.\textsuperscript{15} All trucks were assumed to be the same size.

Finally, all delivery trips required the same length of time (1 day), quite appropriate for the five cities involved. In the DRP model, the total lead time before delivery of an order to the warehouse is fixed at 2 days. We analyzed separate cases for the non-DRP model of total lead time \( k \) of 2, 3 and 4 days.

**DETAILS OF THE SIMULATION MODEL**

Demands at warehouses 1 and 2 were simulated from a Poisson distribution with respective mean daily demands of 150 and 250 units. There were thus high fluctuations in actual demands, since the Poisson distribution has a variance equal to the mean demand rate.

Each NDRP system was managed as an (s,s) or order point, order-up-to system. The parameters \( s \) and \( S \) for lead times \( k = 2, 3, 4 \) were set so that the number of Factory-Warehouse orders during the course of the simulation remained approximately the same for each of these three cases.

The simulated DRP and NDRP systems are both subjected to the same realized demands at each warehouse and to the identical stream of orders from "other" customers. After a 6-day startup period, each case is simulated 40 times in batches of 100 days each. Appropriate statistical procedures are used to compare the 40 runs of one case (say a DRP system) with those of another (e.g., a non-DRP system) to determine mean differences between pairs of cases.


The DRP simulation model has slightly more complicated logic because of its 2-week planning horizon. For both models, the first step each day is to generate demand at the two warehouses. In the non-DRP case, if inventory on hand falls below the re-order point, a delivery order is issued immediately. In the DRP case, the number on hand is updated in the 2-week plan. This may change the size of an order or the day on which a delivery is required. In both systems, any new factory-warehouse orders are then inserted into the carrier's delivery schedule. If there is no vacant truck, the order is sub-contracted.

The next step is to schedule the "other" delivery orders. A major scheduling is done once every 3 days. On the other days, new orders received are compared to see if any can fit into the already existing schedule, say in a truck that is deadheading to pick up its next load.

Daily output statistics are tabulated, the counter for number of days is updated, and the above process is repeated 100 times. This constitutes one run.

RESULTS

In this study, we have considered the \( [F, (W_1, W_2)] \) system using two approaches. The first is one in which \([F, (W_1, W_2)]\) uses DRP to plan its shipments; in the other approach, an order point system is used so that a delivery is ordered only when the inventory level at either warehouse falls below its re-order point. To refer to the two systems we use the notation DRP and NDRP ("Non-DRP") respectively.

Other variables that have been included in the model are the daily demand rate for deliveries by "other" customers of the trucking company and the number of trucks available for making deliveries. Thus we refer to the DRP system with i "other" orders per day and j trucks available as DRP(i,j). The total lead time for receipt of a factory-warehouse order was fixed at 2 days for the DRP cases. This committed lead time was a parameter, \( k \) days, in the non-DRP systems, and denoted as LkNDRP.

Using this notation, the cases that we examined are:
- DRP(i,j) with \( i = 3,4,5,6 \) and \( j = i + 1, i + 2 \)
- LkNDRP(i,j) with \( i = 3,4,5,6; j = i + 1, i + 2 \) and \( k = 2,3,4 \).

For example, DRP(3,7) means the factory-warehouse system is operated under DRP and there are 7 trucks available to serve it and an average of 5 "other" orders per day. Similarly, L2NDRP(6,8) shows that \([F, (W_1, W_2)]\) is not run under DRP but has been guaranteed a total lead time of 3 days before delivery. The average of 6 "other" orders/day, plus the demands of the factory-warehouse system, will be delivered by 8 trucks.

The performance measures which were considered include truck utilization and percentage of factory-warehouse orders sub-contracted and, for "other" customers, the percentage of late deliveries and the average lateness.

Comparisons were made between many pairs of output data to determine the effects of fleet size, demand rate by other customers, DRP vs NDRP systems and extra lead time for the NDRP system. Symbolically these comparisons are:
- DRP(i,j) vs DRP(i,j+1)
- LkNDRP(i,j) vs LkNDRP(i,j+1)
- DRP(i,j) vs LkNDRP(i,j)
- LkNDRP(i,j) vs LkNDRP(i,j) (\( k_1 \neq k_2 \))

A convenient measure of the carrier's overall level of activity is the ratio of \( j/l_i \), i.e., the ratio of number of trucks available to the number of "other" orders per day. The carrier is more and more "busy" as the ratio \( j/l \) increases. As this ratio increases, the following quantities exhibit a decreasing trend:
- truck utilization
- sub-contracting
- percentage of late deliveries for "other" customers
- average lateness (see Figure 3)

**Truck Utilization**

Truck utilization (Table 2) ranges from a low of 67% for L2NDRP(3,5) to a high of 82% for DRP(6,7). There was usually little difference between the utilization levels of DRP(i,j) and L4NDRP(i,j). As \( k \) increased, utilization in the non-DRP system got closer to that of the DRP system. The DRP system
TABLE 2

TRUCK UTILIZATION (%)

<table>
<thead>
<tr>
<th>i (orders per day)</th>
<th>j (trucks)</th>
<th>DRP</th>
<th>NDRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L2</td>
<td>L3</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>76.4</td>
<td>75.1</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>77.6</td>
<td>76.7</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>78.2</td>
<td>77.7</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>72.8</td>
<td>71.8</td>
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<td>80.5</td>
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<tr>
<td></td>
<td>8</td>
<td>78.6</td>
<td>78.0</td>
</tr>
</tbody>
</table>

Lk: Lead time of k days for non-DRP case.

generally gave better utilization performance. This is because fewer factory-warehouse jobs were sub-contracted and the "other" orders were fit into the schedule around these factory-warehouse orders.

Percentage of Factory-Warehouse Orders Sub-contracted

As the trucking company reached capacity (indicated by a low value of the ratio j/i), more factory-warehouse jobs are sub-contracted. However, the DRP system does consistently and noticeably better than any of the non-DRP systems for j = i + 1. This happens because the advanced knowledge of orders by the DRP system allows them to be scheduled earlier than in the non-DRP system. This is particularly important when the trucking company is very busy. Again we found that as the lead time for the non-DRP cases is increased, the results approach those of DRP.

Lateness

Recall our modelling assumption that all factory-warehouse orders are delivered exactly on time. Whether the factory-warehouse system is operated
under DRP or non-DRP, late deliveries is thus an issue only for "other" customers.

Percentage lateness was generally highest in the DRP cases. Because there are fewer factory-warehouse jobs sub-contracted, more late deliveries are made to "other" customers under the DRP system. Consistent with this, Figure 3 shows that in all cases, DRP also has the highest average lateness for "other" customers.

**Impact of Changing Fleet Size**

For various levels of demand, Table 3 indicates the effect on truck utilization when the number of trucks available in each system is decreased by one. The final entry in column A, as an example, shows that truck utilization was about 3.0% higher for the system DRP(6,7) than for DRP(6,8). The differences in truck utilization are positive, as expected, since decreasing the number of trucks by one means the company is working nearer to its capacity. For each of the four systems investigated, it seems that the increase in utilization when a truck is removed is much the same for each level of daily demand.

**TABLE 3**

Differences in Truck Utilization (%): Effect of One Less Truck

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>i (orders per day)</td>
<td>j (trucks)</td>
<td>8.7</td>
<td>8.4</td>
<td>8.4</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
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<tr>
<td>6</td>
<td>7</td>
<td>3.0</td>
<td>2.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>

*Utilization of DRP(i,j) − Utilization of DRP(i,j+1), % Similarly for other entries

The effect of adding a truck on percentage of late deliveries is dramatic, of the order of 50%. It also appears that having an extra truck can reduce lateness quite significantly, especially for the DRP system. Because it has the highest average lateness, adding another truck to the fleet will give the greatest reduction in lateness in the DRP system.

**CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH**

The objective of this study was to determine the gains and losses to a trucking company when one of its major customers uses DRP. To this end, we have examined several performance measures and have found that while DRP generally benefitted the trucking company, the level of service was then reduced to its other (non-priority) customers. Specifically, truck utilization was higher and percentage of factory-warehouse jobs sub-contracted was lower in the DRP system than in any of the non-DRP systems, regardless of length of lead time for the latter. However, there was increased lateness to "other" customers when DRP was used by the Factory-Warehouse system. Table 4 summarizes our results, including the extension to a 2-product model.

One way to take advantage of the higher utilization of DRP is in giving lower rates to the trucking company's customers. This may result in more business and thus maintain or increase the company's profits despite lower prices. Such a move depends on the company's ability to handle additional business and certainly should not be done in cases where sub-contracting and/or lateness is already high. Extrapolating from our model results, such a move would require the number of trucks in the fleet to be more than marginally greater than the number of "other" delivery orders per day.

Another important finding was that as the lead time in the non-DRP cases was increased, the performance of these systems became more like that of the DRP system. When the lead time was four days, the results for the non-DRP cases were very close to those of the DRP cases. This is significant. It suggests that use of DRP by the factory-warehouse system has given the trucking company the equivalent of two extra days of lead time in making its deliveries. This in turn implies that the trucking company has managed its scheduling of deliveries more efficiently. This was one of the benefits (of DRP to the trucking company) that we had hoped to discover.
The truck scheduling algorithm was by far the most complicated portion of our computer program. It required keeping track of truck status (empty, committed, en route) and origin/destination, and matching current or anticipated truck locations with origins or destinations of shipments still to be scheduled. More advanced versions of our problem, involving multiple products and vehicle capacity constraints, form the basis of on-going research. Based on this and the work reported in the present article, it is our feeling that a trucking company cannot enjoy the benefits of a customer's DRP unless the carrier's vehicle scheduling procedures are at least partially computerized.

A very important point to note in determining the effect of DRP on the trucking company is that the estimates of daily demand at the two warehouses must be fairly accurate. This was so in our model and therefore there was little expediting and de-expediting of planned deliveries. Such changes in orders would mean constant re-scheduling of factory-warehouse deliveries and this would probably result in lower utilization and higher sub-contracting levels. The trucking company would lose the two-day advantage mentioned previously and may well be worse off than in the non-DRP case with a lead time of two days.

Because the findings from any model-based analysis may be limited by the assumptions made, it is worth pointing out several improvements that could be made to our model. Each would require further research, but would bring the study environment closer to the realistic conditions under which logistics managers work.

Our analysis of truck utilization generally considered only whether a truck was idle or busy. Sub-division of the busy category into truckload and less-than-truckload would be a desirable enhancement, both in terms of the scheduling environment and in permitting transport charges to be incorporated in a future version of the model.

Another possible extension is to consider cyclical demand patterns at the warehouses, with a daily demand rate that varies according to day of the week. We anticipate the impact on the trucking company to be much the same as in this article, but the bunching of factory-warehouse deliveries at times of high demand may affect service to the carrier's "other" customers.

Finally, one could include the factory production process and employ longer lead times for the DRP plans. After implementing this modification, it would make sense to consider shipments between the two warehouses if a stockout occurs at the factory.

Nevertheless, given our assumptions, the DRP and NDRP systems were compared systematically through the use of a simulation model. Our conclusions may be summarized as follows. This article has shown that a trucking company will achieve better truck utilization, lower sub-contracting and more efficient scheduling if one of its major customers uses DRP. A negative effect is that the carrier will have more difficulty meeting the due dates for its "other" business under DRP than in a non-DRP situation.

DRP may in the future become as popular as MRP is today. If so, there may be a much higher demand for contract trucking rather than LTL, and the strict conditions imposed by (P, W<sub>1</sub>, W<sub>2</sub>) may become more common. Perhaps a trucking company which collaborates with a major shipper, persuading the latter to use DRP, may be able to reduce its rate and still achieve the same level of
profitability. By the same token, a carrier might be reluctant to make a delivery commitment to a firm that does not use DRP.

ENDNOTES


4. Same reference as Endnote 1.


ACKNOWLEDGEMENTS

We are grateful to the Ontario Ministry of Transportation and Communications, and especially to Mr. Murray Lister of the Truck Transportation Office, for encouragement and generous support of this work. Thanks are also due to Mr. Donald Heath for assistance with some of the calculations.

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