Distribution Planning and Control:

An Experimental Comparison of DRP and Order Point Replenishment Strategies

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Abstract:

The increased globalization of trade has resulted in greater emphasis on Supply Chain Management. The planning and control strategy used to regulate the flow of goods is important in determining performance. Objectives are often stated in terms of meeting delivery requirements while minimizing distribution chain inventory. Distribution Requirements Planning (DRP) and Order Point replenishment systems are two commonly used strategies with very different information requirements. This research examines the performance within networks involving manufacturing, distribution and retail facilities. Multiple products with non-stationary demand are considered. Simulation results are used in identifying strengths and performance characteristics of each strategy.

Key Words:

Supply Chain Management, Inventory Replenishment, Logistics, Distribution Requirements Planning (DRP).

Introduction

Supply Chain Management (SCM) issues have recently been of intense interest to both researchers and industrial practitioners. Benefits of better management include improved delivery performance, reduced inventory, and increased flexibility and responsiveness to customer demand (see 1997 Benchmarking Study, 1997). Handfield and Nichols (1999) give the definition of Supply Chain Management as "the management of information systems, sourcing and procurement, production scheduling, order processing, inventory management, warehousing, custom service, and after-market disposition of packaging and materials". Obviously, a major part of Supply Chain Management is the integration of information from business organizations whose activities are related to the provision of raw materials, production, and distribution of final products. This paper presents a preliminary investigation of integrated performance within a stochastic demand environment. Distribution Requirements Planning (DRP) and Order Point planning and control systems are compared.

Distribution Requirements Planning (DRP) is a time-phased replenishment approach in which inventory status is reviewed and new shipment plans are generated periodically. The concepts and logic used are similar to those used in Material Requirements Planning (MRP). However, the approach is applied toward the distribution of goods separated geographically rather than the flow of parts within one manufacturing facility. The demand at the stage most closely linked to the end user is treated as independent demand, while demand at upstream stages is treated as dependent demand. Forecasting is used to anticipate requirements at the independent demand level (or echelon), while time-phased logic is use to anticipate requirements for upstream inventory echelons. Inventory status and planned lead times are therefore used to time order releases so inventory is minimized while still preventing excessive shortages. Since inventory is planned throughout the supply chain, based on anticipated demand, DRP systems are considered to be proactive. Advantages of DRP include inventory reduction, better customer service, and compatibility with other systems within the supply chain (e.g. MRP, transportation planning, etc.). Martin (1983), How DRP Helps (1984), Maskell (1988), Ross (1988), or Ho (1990) provide further information. However, DRP also has disadvantages. Data throughout the supply chain must be accessible (Weiler, 1998), implementation costs are relatively high, and system nervousness can result in highly uncertain environments (Ho, 1992).

Order Point systems, on the other hand, treat demand at all echelons in the supply chain as independent demand. Control is decentralized and inventory is reviewed at each stage independently. Under continuous review, orders are placed when the inventory falls below the reorder point. If inventory falls to zero, backorders are also taken into account in placing new orders. Reorder points are calculated on the basis of expected demand during expected replenishment times (actual lead times). Order Point systems are considered to be reactive, since they often use average information for replenishment decision and do not have mechanisms to anticipate the changes in demand. This tends to lead to poor performance in environments where demand fluctuation is high.

DRP has been proven to work well where supply chain integration is feasible, especially when compared to traditional Order Point systems (Cooke (1983), Smith (1985), and Madia (1990)). However, there has been little research that compares DRP performance to Order Point performance under similar conditions. In this research, the two planning and control systems are modelled and compared experimentally, using discrete-event simulation. The objective is to gain further insights into the behaviour, performance and applicability of these systems.

In this research, delivery performance and inventory requirements are examined with respect to lot sizes, planned lead times (in DRP systems) and reorder points (in Order Point systems). The hypothesis is that DRP will perform better than Order Point systems in a supply chain network with stochastic, uncertain demand. The reason is that DRP is proactive and uses forecast information to anticpate time-phased requirements throughout the supply chain.

The remainder of the paper is organized as follows. The next section describes the supply chain network and general methodology used in this research. Following this, the two planning and control systems are described. Next, the experimental design is presented. Results and analysis follow this. Finally, the conclusions are stated and future research opportunities are identified.

The Supply Chain Network

The supply chain modelled consisted of four echelons configured in the network shown in Figure 1. This network involved eight nodes from which inventory could be shipped or received; two Suppliers, two Manufacturers, two Distributors and two Retailers. Material flowing between each of the nodes was designated by a unique part number, shown as Parts 1 through 8 in the diagram. Only one part type was held at each of the nodes, except at the Retail nodes. These each stocked two part types. Raw material at the Supplier nodes was assumed to be infinite so that no shortages or back orders occurred at this inventory echelon.

A discrete-event simulation model of this network was developed using ARENA 3.0 (1994). This "supply chain simulator" was interfaced with an Excel spreadsheet program through the use of Visual Basic for Applications (VBA). The Excel spreadsheet was used to specify all model and experimental control inputs, including whether DRP or the Order Point system was being used. As well, the Excel spreadsheet contained extensive Visual Basic macros for creating order release schedules under Distribution Requirements Planning (DRP). These plans were communicated to the supply chain simulator on a weekly basis during experimental runs.

Customer orders for P1 through P4 were assumed to be accumulated during each week and shipped at the end of the week. Forecasts of demand were also made on the basis of weekly intervals. The forecast weekly demand patterns at the Retail level are illustrated in Figure 2. The average forecasts values were set to 2000, 1500, 2000 and 2500 units per week for P1 through P4, respectively. The forecast patterns were sinusiodal with a cycle length of 52 weeks and amplitudes of 360, 360, 180 and 180 units. The forecast patterns were also offset so that peak demand resulted at 13, 39, 26 and 0 weeks for Parts 1 through 4, respectively. The actual weekly demands were normally distributed around the forecast. The coefficient of variation for actual weekly demand relative to the forecast weekly demand was 0.1.

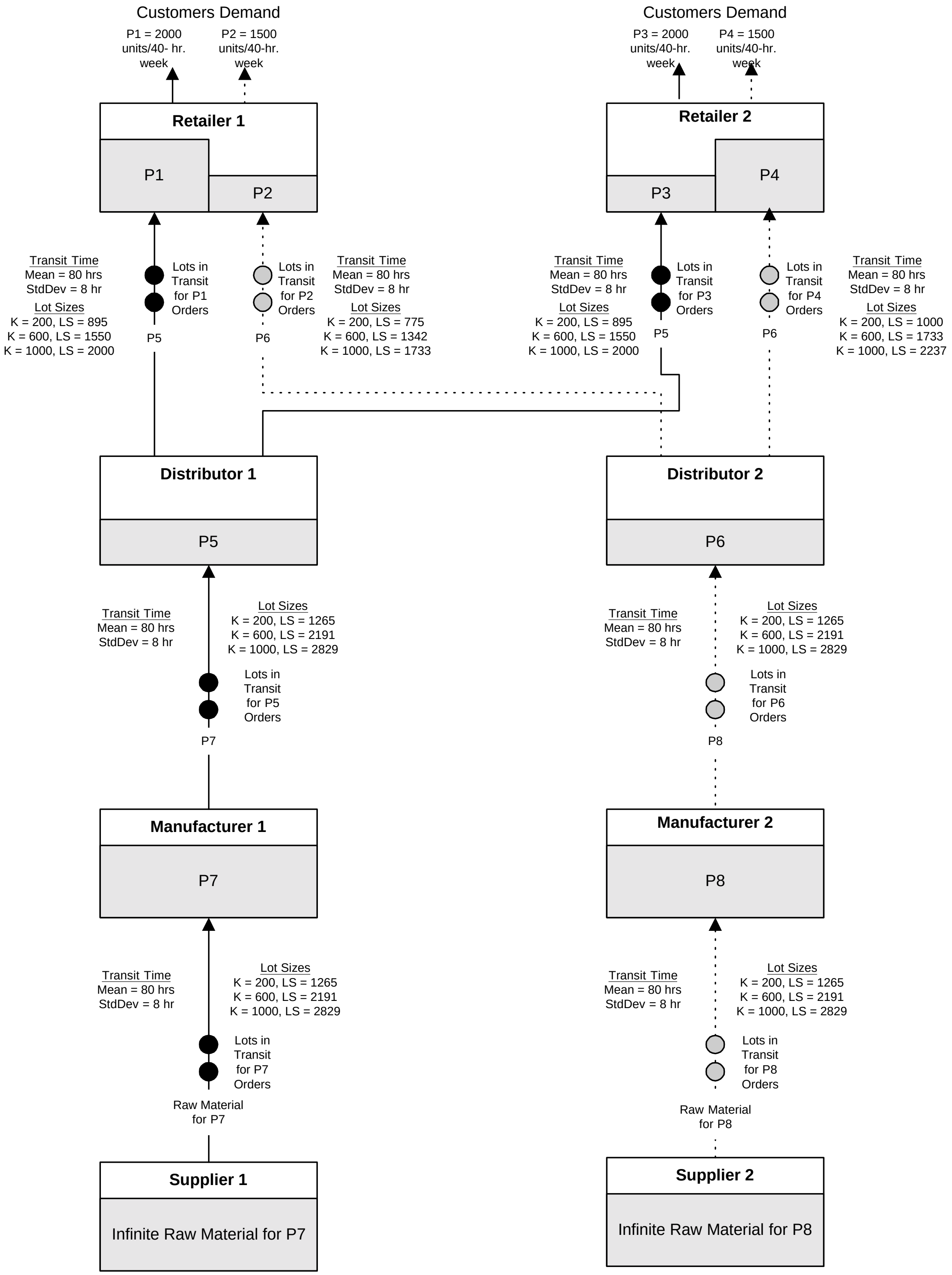

Fig. 1 - Supply Chain Network

The mean, or expected, transit times between all nodes was 80 hours. This was equivalent to 2 weeks under the time unit assumptions made in this research. Actual transit times were normally distributed, with a coefficient of variation of 0.10. These transit times applied to the shipment of lots of material, with no lot splitting allowed. The nodes in Figure 1 were assumed to be unconstrained with respect to capacity, except for the Manufacturing nodes. The two manufacturing facilities were each modelled as a single resource. The time spent going through each resource was assumed to represent the aggregate of all operation flowtimes. The utilization of the manufacturing facilities was in the range of 90% and the flowtimes were approximately 24 hours. Therefore, a manufacturing time allowance of 24 hours was added to the replenishment time for P5 and P6. In other words, the expected replenishment time at the Distributor nodes was based on an expected transit time of 80 hours plus an expected manufacturing time of 24 hours.

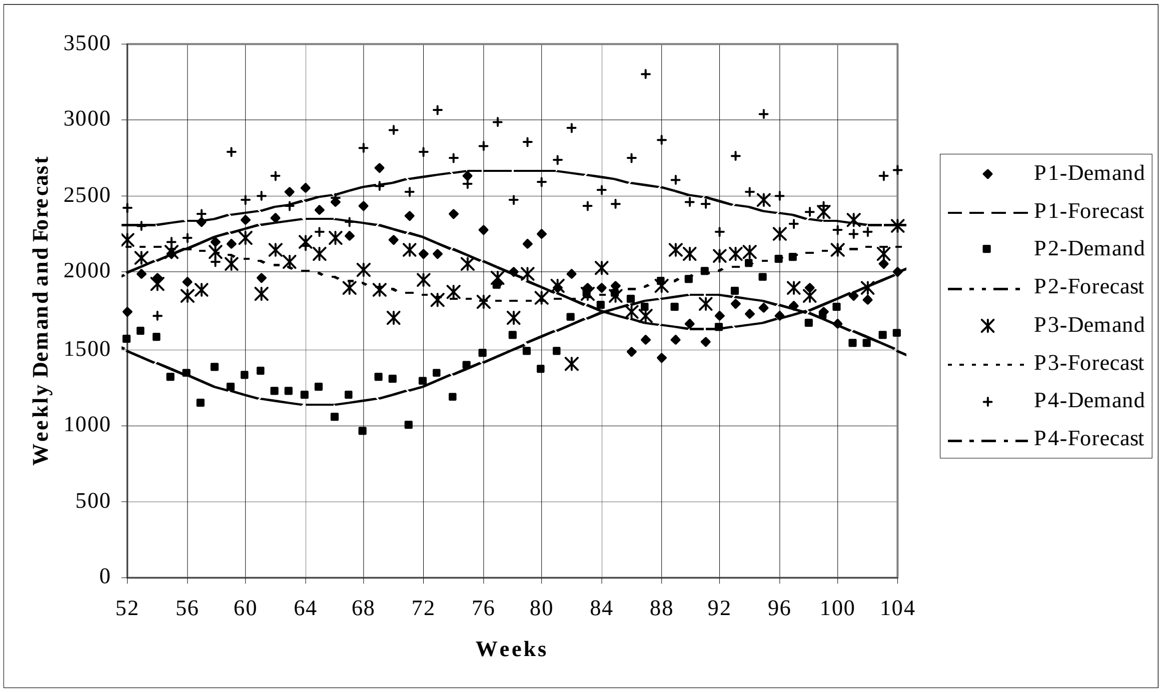

Fig. 2 – Forecast and Demand Patterns

Planning and Control Systems

The DRP system requires planned lead times and lot sizes to be set, while the Order Point system requires the reorder point and lot sizes to be set. The inventory-delivery performance tradeoff of interest in this type of research can be evaluated by adjusting these system decision parameters. The Fixed Order Quantity (FOQ) lot-sizing rule was used since it is applicable to each of the planning and control systems. It is desirable to use the same lot-sizing policy, as well as actual lot sizes, since this eliminates lot sizing as an experimental factor and facilitates making comparisons. Therefore, performance is controlled on the basis of adjusting planned lead times for DRP and adjusting the reorder point for Order Point systems.

It should be noted that DRP can be run with a variety of other lot-sizing policies and it is not being claimed that FOQ is best. Bookbinder and Heath (1988) analyze and compare several other lot-sizing policies under DRP assumptions. The logic used in FOQ lot-size setting is explained next. Following this, the order release logic for each of the systems is described.

Calculation of Lot Sizes (Q):

Economic Order Quantity (EOQ) assumptions were used in determining appropriate lot sizes. Relevant costs include the fixed cost of placing a new shipment order and the holding costs for inventory stocked at the nodes in the supply chain network. Holding costs for inventory in transit are not relevant since the expected amount of inventory in transit is constant. As well, transportation costs are assumed to be a linear function of the shipment size. Therefore, total transportation costs are also constant, regardless of shipment lot sizes. The following EOQ relationship then applies.

$$Q_i^* = \sqrt{\frac{(2 S_i D_i)}{h v_i}}$$

where:

Q_i^* - optimal lot size for Part *i* based on EOQ assumptions.
S_i - order cost, or setup cost, for shipments of Part *i*.
D_i - average demand per time unit for Part *i*
h - inventory holding cost rate per unit time.
v_i - value, or cost, of part *i*.

Now if the order cost is assumed to be equivalent to the cost of holding some amount of inventory for a given amount of time, then we can set S_i equal to the following:

$$S_i = k\ (h\, v_i\ )$$

Therefore,

$$Q_i^* = \sqrt{(2\, k\, D_i\ )}$$

As an example, assume the demand for Part *i* is 2000 units per week and k is set at 1000 unit-weeks. In this case $Q_i^* = \sqrt{\ 2\ (1000\ )\, 2000\ } = 2000$.

Logic for DRP order release:

The Distribution Requirements Planning logic was based on a time-bucketed system. Forecasts for independent demand parts were based on expected demand during intervals of one week. The planning horizon was set at 10 weeks and unbiased forecasts were generated for each week in the planning horizon. The distribution plan was regenerated weekly and forecasts were updated on the basis of a rolling horizon.

The planning bucket for determining order releases was set equal to 0.05 weeks. Therefore, order releases for any Part *i* could occur at any one of 20 different times during a week. Many examples of DRP logic use a planning bucket equal to the plan regeneration interval. However, the DRP planning bucket can be much smaller than the replanning interval, just as in MRP systems. The smaller time bucket improves performance as well as making it possible to develop much better inventory-delivery performance tradeoff curves.

The logic used in DRP is similar to that used in Materials Requirements Planning (MRP). Forecasts are made at the echelon furthest downstream (or closest to customer demand). This is often the retail echelon. Orders are planned at this level in a similar manner to how order releases for independent demand items are planned in an MRP system. Assuming the plan is being generated at the current time, *tp*, the following relationship is used to determine the schedule of order releases, $Q_{i,t}$, at discrete future times, *T*.

$$Q_{i,T} = \max\left(0,\ IntRndUp\left[\frac{\sum_{t=tp}^{T+PLT_i} Forecast_{i,t} - \sum_{t=tp}^{T+PLT_i} SR_{i,t} - \sum_{t=tp}^{T+PLT_i} PR_{i,t} - Inv_{i,tp} + BO_{i,tp}}{Q_i^*} \right] Q_i^* \right)$$

where:

$Q_{i,T}$ - order quantity scheduled for release at time T.
Q_i^* - optimal lot size, based on EOQ assumptions.
$Forecast_{i,t}$ - forecast of weekly demand for Part i at time t.
$SR_{i,t}$ - scheduled receipts at time t of Part i released orders.
$PR_{i,t}$ - planned receipts at time t of Part i planned orders.
$Inv_{i,tp}$ - quantity of Part i, WIP or finished goods, in stock at time tp.
$BO_{i,tp}$ - quantity of Part i, WIP or finished goods, back ordered at time tp.
PLT_i - planned lead time, equal to a multiple of the size of the planning bucket, for replenishment of Part i.
T - time at the beginning of a discrete planning bucket.
tp - current time, when the plan is generated.

The quantity in square brackets is rounded up to the nearest integer, as indicated by *IntRndUp*.

The order releases for upstream echelons are derived from gross requirements, based on the order releases from the downstream echelon which they supply. Orders are planned in a similar manner to planning dependent demand items in an MRP system. However, the process is sometimes referred to as one of implosion, rather than explosion. Since there is no Bill of Materials specifying assembly requirements, as in MRP, the planning process is simply one of moving upstream through each inventory echelon sequentially. All downstream requirements are aggregated and then the quantity and timing of orders are calculated using the following relationship.

$$Q_{i,T} = \max \left(0,\ IntRndUp \left[\frac{\sum_{t=tp}^{T+PLT_i} GR_{i,t} - \sum_{t=tp}^{T+PLT_i} SR_{i,t} - \sum_{t=tp}^{T+PLT_i} PR_{i,t} - Inv_{i,tp} + BO_{i,tp}}{Q_i^*} \right] Q_i^* \right)$$

where:

$GR_{i,t}$ - gross requirements for Part i at time t.

The gross requirements for Part i at time t are equal to the sum of all orders for this part at downstream echelons.

The planned lead times for Part i, PLT_i, were set equal to the expected replenishment time, rounded up to the next planning time bucket, multiplied by a safety factor.

$$PLT_i = IntRndUp \left[\frac{RT_i}{p} SF_i \right] p$$

where:

PLT_t - planned lead time for part i

RT_t - expected time units for replenishment of part i

SF_t - safety factor for part i

p - length of time in planning bucket

The safety factor, SF_i, was used to control the tradeoff between the inventory levels and the delivery performance observed. Increasing SF_i increases inventory holding costs but reduces tardy deliveries. It should be noted that DRP systems also lend themselves to the use of safety stock, as opposed to using this approach of inflating planned lead times. However, safety stock was not considered in this study since this would introduce an extra experimental control factor applicable to DRP alone.

Logic for Order Point order release:

The inventory position in the Order Point system was reviewed on a continuous basis. Any event affecting the system inventory could trigger a new order release. At each change in the inventory position, the following relationship was evaluated to determine whether a new order should be placed and how large this order should be.

$$Q_{i,t} = \max \left(0,\ IntRndUp \left[\frac{OP_i - (\ Inv_{i,t} + OR_{i,t} + OT_{i,t} - BO_{i,t}\ )}{Q_i^*} \right] * Q_i^* \right)$$

where:

$Inv_{i,t}$ - quantity of Part *i*, WIP or finished goods, in stock at time *t*.

OP_i - reorder point for Part *i*

$OR_{i,t}$ - quantity of Part *i* in orders released to the supplier but not filled, at time *t*, due to lack of upstream inventory.

$OT_{i,t}$ - quantity of Part *i* in transit to the destination, at time *t*, where they are required.

$BO_{i,t}$ - quantity of Part *i*, WIP or finished goods, back ordered at the destination at time *t*.

Q_i^* - optimal lot size determined on the basis of EOQ assumptions.

The order quantity must always be 0, Q_i^* or a multiple of Q_i^* .

The reorder point, OP_i, was set equal to the expected part demand during the expected replenishment time, multiplied by a safety factor. This relationship can be stated as follows:

$$OP_i = D_i\ (\ RT_i\ )\ SF_i$$

where:

D_i - average demand per time unit for Part *i*

RT_i - expected time units for replenishment of Part *i*

SF_i - safety factor for Part *i*

The expected replenishment time, RT_i, was set equal to the average transit time for shipments placed between non-manufacturing destinations. If the order was placed to a manufacturing facility, the expected production time was also taken into account. The safety factors, SF_i, are used to adjust the reorder point and vary what is commonly referred to as the safety stock level.

Experimental Design

The experimental design consisted of three factors. The first factor was the distribution planning and control system. The settings for this factor were DRP and Order Point. The second factor was the lot-sizing parameter k. This parameter controls the relationship between inventory holding costs and order or setup costs. The higher the value of k is, the more important order costs become relative to inventory holding costs. This affects the optimal lot sizes, Q_i^*, calculated. Higher values of k result in larger lot sizes. The values of k used in this research were 200, 600 and 1000 unit-weeks. The resulting lot sizes with $k = 200$ were 895, 775, 895, 1000, 1265, 1265, 1265 and 1265 for Parts 1 through 8, respectively. For $k = 600$ they were 1550, 1342, 1550, 1733, 2191, 2191, 2191 and 2191, while for $k = 1000$ they were 2000, 1733, 2000, 2237, 2829, 2829, 2829 and 2829.

The final experimental factor was the safety factor, SF_i ,used to control delivery performance. This factor was run at 20 levels for each combination of other factor settings so that inventory-delivery performance curves could be generated. The safety factor for the DRP system adjusted planned lead times. It was set at increments of 0.05, between 1.0 and 1.95, and was applied equally to all parts. The safety factor for the Order Point system was used to adjust the reorder point. In other words, the safety stock level was being adjusted. This value was also adjusted by increments of 0.05, between 1.0 and1.95.

This experimental design resulted in 120 simulation settings. One replication was run at each setting for these preliminary results. However, tests indicated there was little variance in results when multiple replications were run. Each replication was five years in length, with data from the first year being discarded to avoid initialization effects.

The primary measures in this research were delivery mean tardiness and inventory part counts. Tardiness is defined to equal zero if a part is delivered early or on time, and to equal the lateness otherwise. Delivery tardiness was measured on the basis of deliveries to end-user customers only, not deliveries at upstream echelons. Therefore, only the delivery performance of Parts 1 through 4 were considered relevant. Inventory part counts were based on the total quantity of parts in the distribution system. This did not include Supplier inventory, assumed to be unlimited with respect to replenishment availability, but did include parts in transit from the Supplier echelon.

Results and Analysis

The customer delivery performance results, based on mean tardiness, versus total system inventory are summarized in Figures 3 to 7. The points along each line, moving toward the right, represent increasing safety factor, SF_i, settings. Therefore, these curves indicate increasing planned lead times for DRP and increasing reorder points for Order Point systems.

Figures 3 and 4 show the effect of increasing lot sizes for DRP and Order Point systems respectively. Lot sizes, Q_i^*, increase as the value of k, which indicates the tradeoff between order costs and holding costs, increases. In all cases, increasing lot sizes shifts the performance curves to the right. This is consistent with expectations. As order costs increase relative to holding costs, larger lot sizes are justified. This means delivery performance will be worse for a given inventory level or, alternately, inventory will be higher for a given level of delivery performance.

Of more interest is the relative performance of DRP and Order Point systems. These results are compared in Figures 5 through 7. The graphs show that DRP consistently performs better than the Order Point system. These results support the hypothesis that centralized planning and control, based on global inventory and order information, performs best when demands vary through time and when there is significant uncertainty with respect to demand and replenishment times. This superior performance is believed to be due to the ability of DRP to anticipate changes, based on forecast information, in demand along the supply chain and release time-phased orders in anticipation of future requirements.

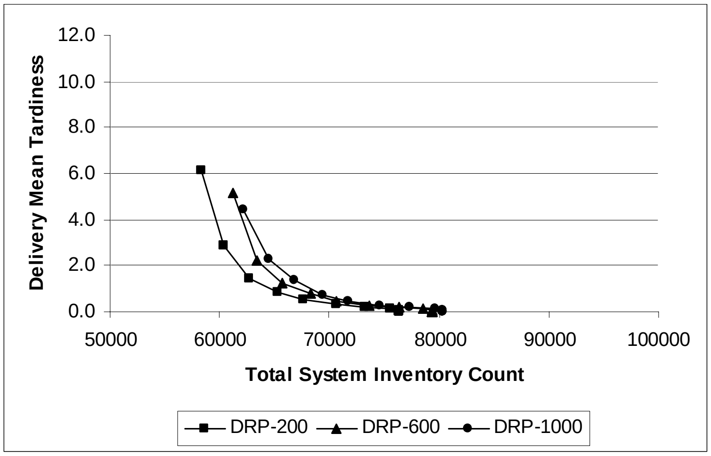

Fig. 3 - Planned Lead Time and Lot Sizes Effect for DRP

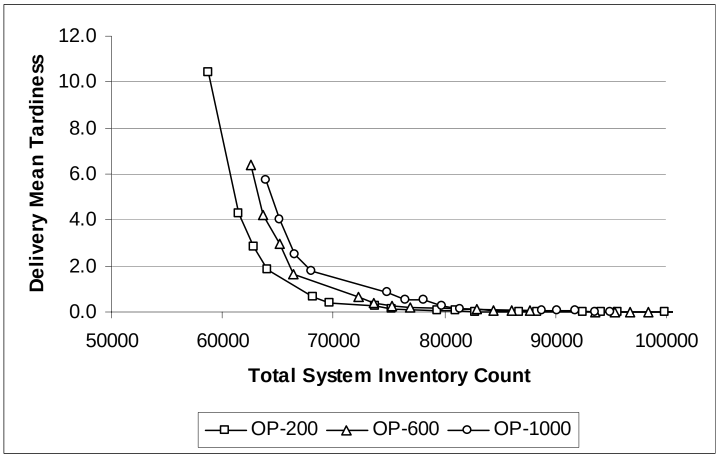

Fig. 4 - Reorder Point and Lot Sizes Effect for Order Point

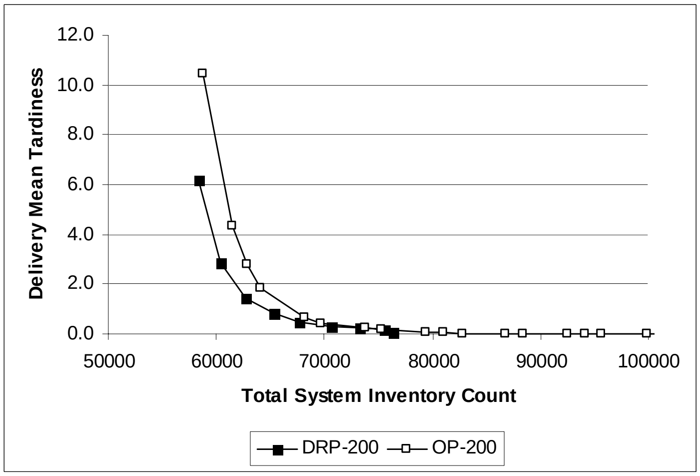

Fig. 5 - Comparison with Lot Size Parameter k = 200

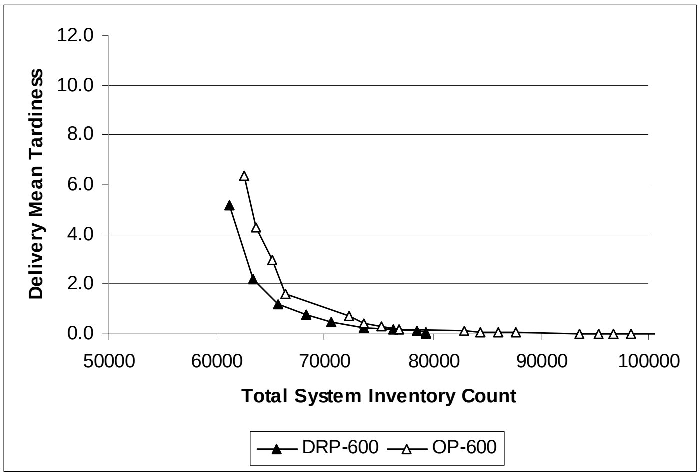

Fig. 6 - Comparison with Lot Size Parameter k = 600

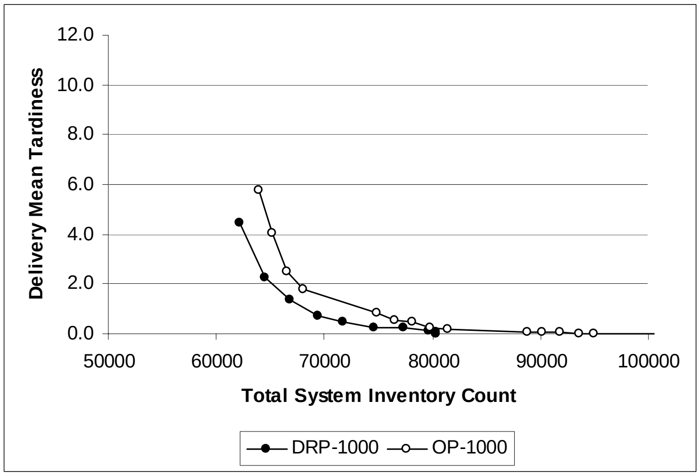

Fig. 7 - Comparison with Lot Size Parameter k = 1000

Conclusions

A direct comparison of two common distribution planning and control systems, based on the logic used to move material through supply chains, has been presented. Although there has been a lot of conjecture regarding the relative merits of such systems, the current study is a step towards understanding the true underlying behaviour and tradeoffs in each system. Results indicate that centralized planning and control, as implemented under Distribution Requirements Planning (DRP), is beneficial under realistic situations of time-varying demand and replenishment time uncertainty.

Further research is required to determine how different levels of variability and uncertainty affect the relative performance of these systems. This research also does not address the selection of proper planned lead times or reorder points on an a priori basis. It is also of interest to examine analytical relationships which could guide in the selection of planning and control parameters based on the uncertainty present and the desired level of delivery performance.

This research has focused on comparing the relative performance of systems based only on the logic implemented. In practical terms, there are a number of additional issues related to implementation. DRP systems require relatively complex and extensive software information systems. As well, the various nodes in the supply chain or distribution network must all be able to communicate with the central planning function. This may not be feasible if the network nodes are controlled by independent enterprises. Less coordination of information is required when Order Point systems are used. The use of only inventory and order information local to the upstream replenishment loop makes implementation significantly easier. Such issues such concerning implementation and operation may act to offset the advantages of systems when evaluated purely on the basis of planning and control logic.

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