Simulation Analysis of Just-in-Time Distribution

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Introduction

Just-in-time (JIT) production has been a subject of considerable research in the past few years. The Japanese were the first to actually use JIT systems rather than the traditional economic order quantity inventory system or the more recent method of Material Requirements Planning (MRP). Considerable savings in inventory-holding costs, faster spotting of defective producing stations and improved quality control have been observed using just-in-time production.

The purpose of this article is to determine if JIT distribution is a feasible alternative to traditional distribution. Just-in-time distribution would supposedly reduce finished goods inventory at the factory, warehouses, distributors and retailers. Such inventory reductions would be accompanied by decreases in required storage area, storage containers, shelving units and moving apparatus such as fork lifts and conveyor belts. Can all this be accomplished at no degradation in the service furnished by each echelon to the next lower level in the distribution system? That is one question to which the present study is directed.

Some of the references discussed in the next section do consider transportation aspects of JIT production, but solely on the inbound side, i.e., daily deliveries of raw materials and components. As far as the authors are aware, the present article is the first treatment of outbound JIT transportation or distribution.

Our article begins with a review of the literature on JIT production and related concepts, following which we then formulate our first model, that of a factory-warehouse-retailer distribution system. A second model formulation, requiring no warehouses, has stock moving from the factory directly to retailers. More frequent deliveries, shipment scheduling and longer lead times are then discussed. The measures of performance of these models are the service levels, turnover and variation of production quantities. These measures are described and evaluated using computer simulation.

Our conclusions are then presented. These include the problems of implementing JIT distribution and suggestions for further research. Finally, an Appendix discusses the materials-handling changes appropriate to JIT distribution. These concern reduction of distribution set-up costs; modifications of trailers and loading docks to support daily deliveries; and the sharing of distribution costs with other organisations.

Literature Review

The original article on just-in-time production appeared in 1977: Sugimori et al. [1] discussed the production system implemented at Toyota by a vice-president. This was designed to attain low cost with minimum amounts of equipment, materials, parts and

Rice and Yoshikawa [8] review the Kanban system and relate Kanban to MRP. (Their Kanban system is what other authors call the just-in-time system.) Both Kanban and MRP depend upon bottom-up participative management within each company. MRP uses time-horizon planning, while Kanban features shopfloor control. Most Japanese industries applying the Kanban system are set up on a general one-year master schedule, a one-to-two month horizon for the detailed production schedule, a 99 per cent-fixed ten-day production schedule and a daily schedule.

Martin [9] has applied Material Requirements Planning to distribution, resulting in Distribution Requirements Planning (DRP). This approach, and that of the present article, regards distribution as a continuation of the production functions. Martin [9] and Stenger and Cavinato [10] discuss the benefits of extending MRP to the “outbound side”. Other references pertaining to co-ordination of DRP with decisions on inventory replenishment and transportation include Bookbinder and Heath [11] and Bookbinder and Lynn [12].

The Distribution Models

The simplest concept of a just-in-time distribution system might be as follows. Each time \( X \) units of a product are removed from the retailer’s shelf, another \( X \) units are requested from the warehouse. This order arrives and the retail shelf is restocked. The warehouse then orders from the factory to replace its lost units. The factory ships \( X \) units to the warehouse, which now has a stock of \( X \) units, and the factory then produces \( X \) units to replace the quantity shipped out.

“Lot-for-lot” shipping may not be practical when \( X \) is small. Nevertheless, the preceding concept appears feasible if implemented on a daily basis. The viability of JIT distribution would also be enhanced by combining shipments of several products and by “sharing” distribution with other firms (see the Appendix). We now develop two models of JIT distribution.

With daily deliveries in a factory-warehouse-retailer system, each retailer should have an amount of stock appropriate to that day’s demand. Whatever is sold is re-ordered from the warehouse to be delivered before the next day. Then the warehouse orders from the factory to replace what has been shipped to the retailer. There is one delivery from the factory to each warehouse every day and similarly from each warehouse to its retailers. Delivery routes may, of course, go to more than one warehouse or to more than one retailer per circuit, but considerations of vehicle routing are beyond the scope of the present article.

For both of our models of daily distribution, the configuration is as given in Figure 1, namely a factory, two warehouses, and three retailers served by each warehouse. We denote by \( R_{ij} \) the \( j \)th retailer served by warehouse \( i \), where \( i = 1,2 \) and \( j = 1,2,3 \).
In model 1, the warehouses hold some inventory, while for model 2, the warehouses carry no stock at all and serve only a "break-bulk" function.

Figure 1. Distribution Layout

The warehouses for model 1, and the factory and retailers for both models, manage their inventories according to an "order-up-to-level" or "base stock", which is the target stock at the echelon for the end of each day. Retailer \( R_{ij} \), for example, experiences a daily demand for a given product which is a random variable \( D_{ij} \). This is assumed to have a normal distribution with mean \( \mu_{ij} \) and standard deviation \( \sigma_{ij} \). That retailer must therefore have available an amount \( S_{ij} = D_{ij} + k_1 \sigma_{ij} \), where \( k_1 \) denotes the (identical) safety factor for buffer stock at any retailer, and \( S_{ij} \) is thus the base stock for retailer \( R_{ij} \). The order placed by that retailer, at the end of each business day is the difference between its stock on hand and \( S_{ij} \).

That order is placed through a telex or a data communication network to the warehouse (or to the factory in model 2). Overnight delivery takes place and the level of product available at the start of the following day is again the quantity \( S_{ij} \), assuming there was not a stockout at the warehouse (or at the factory in model 2).
Similar remarks concerning base stock levels pertain in model 1 to the warehouses ordering stock from the factory, where we let $k_2$ denote the safety factor at each warehouse. The factory as well is managed according to a "produce-up-to" level. We use the notation $k_3$ for the safety factor at the factory in model 1, and $K_4$ for this safety factor in model 2.

In the event that a warehouse in model 1 cannot satisfy the aggregate demand from its retailers, the amounts shipped to each are apportioned so that service levels are identical among the retailers. (This identical service level occurs whether or not there is a stock-out at the warehouse). Each retailer is to receive its "fair share" in order to maximise the percentage of total demand satisfied from stock. There is a similar distribution policy between the factory and warehouses.

Zero inventory at the warehouses is possible in model 2 because modern communication methods make it easy for the factory to receive sales information from retailers. Replenishments may then be shipped directly to retailers, with each warehouse serving only a "break-bulk" function. The order-up-to levels at retailers remain the same as in model 1, with a similar distribution policy in which service levels are equalised each day among the retailers in the event of a stock-out at the factory.

For inventory control, there are generally two types of service measures [13]. The $P_1$ measure is the fraction of replenishment occasions for which inventory satisfied the demand completely. For example, a 95 per cent $P_1$ service level for a retailer would imply that on 95 out of 100 days, this retailer completely satisfied demand. The other measure, the $P_2$ service level, is the fraction of demand satisfied from on-hand inventory or from the shelf. A 95 per cent $P_2$ service level for a retailer means that 95 per cent of the quantity demanded was satisfied directly from store inventory. If separate demands of 1,000 units and 10 units were each unfulfilled by one unit, the $P_1$ measure would count both as stock-out occasions, but the $P_2$ measure would reflect the greater seriousness of one unit short on a demand of 10 units. The choice of service measure should, of course, reflect the importance of a stock-out. For example, in a spare parts inventory of expensive machinery, the $P_1$ measure may be more important. The measure $P_2$ may be more useful for the case of a large-volume consumer product.

The "service-equalisation" policy in the event of a stock-out is based on the $P_2$ service measure. From now on in this article, however, the term "service level" refers to $P_1$ unless otherwise stated.

In our simulations, we use the fact that normally distributed demands on retailers will also create normally distributed demands on warehouses which in turn create normally distributed demands on the factory. The base stock values at the retailers, warehouses and factory are set at the beginning of the simulation before any demands are realised. When these (normally distributed) demands occur, however, the eventually-observed service levels will differ from the service levels initially used in setting base stocks throughout the system. These differences occur because of system interactions between retailers, warehouses and the factory.

When a retailer does not receive the entire amount requested because of a warehouse stock-out, e.g., the order quantity for the next day is still the conventional one, equal to the retailer base inventory minus the current stock on hand. Thus, although there is no back ordering as such, the system of daily deliveries ensures that the total amount
desired will eventually be received.

In the simulations, all demands at the retailers are assumed to be independent and identically distributed. Three retailers are served by each warehouse. Any stock-out at a warehouse is divided among its retailers and an adjustment is made to ensure integer shipments. As mentioned, the amounts shipped are determined so each retailer will achieve the same $P_2$ measure, which can be shown to maximise $P_2$ for the total system.

The decision variables are the safety factors $k_i$ for the factory, warehouses and retailers, with the objective of reaching a desired retailer service level at low system holding costs. These inventory-holding costs are inversely related to the annual turnover $T$ of total system stock. For JIT distribution with daily deliveries, the turnover ration may be defined as:

$$T = \frac{(B \cdot D_a)}{S}$$

where $B$ is number of business days per year, $D_a$ is the average satisfied demand per day, and $S$ is the average system stock at the beginning of each day.

Simulation Results, Analysis and Discussion

We conducted three simulation studies. The first pertained to the JIT system described by model 2, while the second and third studies concerned comparisons of model 1 and model 2. Following the presentation of these results we discuss the costs involved in using a JIT system and the possible savings that can be realised. (See Locke [14] for further technical details of both the models and the simulation studies.)

The Model 2 System

For the just-in-time distribution system described by model 2, stock is delivered daily to the retailers from the factory. This distribution system consists of a factory supplying stock to two warehouses which in turn each supply three retailers. Demand at each retailer is normally distributed with a mean of 100 units and a standard deviation of 20.

There were two primary decision variables: $k_1$, the safety factor at the retailers and $k_4$, that for safety stock at the factory. We set $k_1$ at 2.33, giving the retailers an initial $P_1$ service level of 99 per cent, and varied $k_4$ to simulate initial factory service levels of 60, 70, 80, 90, 95 and 99 per cent. The six runs each had the same input demands. The simulation was for a 100 day period in all cases.

The results of this study can be seen in Figure 2 to Figure 5. In Figure 2, as the factory initial service level $k_4$ increases, there is an increase in the observed retailer service level $P_1$, i.e., in the percentage of days there was no stock-out at the retailers. As expected, there are diminishing marginal returns in $P_1$ as $k_4$ is increased. This figure also shows, however, that there is no need for a high safety stock at the factory, since $P_1 = 95$ per cent even for a value of $k_4$ corresponding to an initial factory service level of only 60 per cent.
Figure 2. Observed retailer service level $P_1$ versus factory safety factor $k_4$ (model 2)

With this reduction in factory safety stock, i.e., in the base stock there, one naturally improves the annual total system turnover. Figure 3, consistent with Figure 2, shows the corresponding decrease in observed retailer service level. It should be noted that an increase in system turnover can only be attained by reducing the factory base stock, since we have fixed $k_1$, corresponding to the retailer safety stock (or initial service level).
Figure 3. Observed retailer service level versus annual turnover of system stock (model 2)

To discuss Figure 4, we remark that a factory base stock of 600 units corresponds to no safety stock at that echelon. As the factory base stock is increased, the average total order to the factory decreases. (The decrease is quite rapid until the base stock is at least 640 units.) This result may be understood by distinguishing between an order to the factory and the amount shipped. An increase in base stock makes it more likely that a given order will be satisfied, hence the next order to the factory needn't be as large.
Figure 4. Average total order made to factory versus factory base stock (model 2)

We observe in Figure 5 that as the standard deviation of production quantities increases, the observed retailer service level increases. This can be explained by combining the results of Figures 2 and 4. An increase in the factory base stock implies both an increase in the observed retailer service level $P_1$ and a decrease in the average order to factory. With this increase in base stock, however, comes the possibility of some higher production quantities, and since the average factory order is lower, the standard deviation of production quantities increases.
Figure 5. Observed retailer service level $P_1$ versus standard deviation of production quantities (model 2)

We associate increasing standard deviation of production quantities with higher manufacturing cost and greater difficulty in using just-in-time production in the factory. (The JIT system requires low variance of production quantities.) Unfortunately, this is the price which must be paid if a greater retailer service level $P_1$ is desired.

Comparison of Models 1 and 2
In our second study we compare model 1 with model 2. Both distribution systems still consist of a factory supplying two warehouses, each supplying three retailers. As before, demand at all retailers is normally distributed with a mean of 100 units and a standard deviation of 20.
For model 1 we set \( k_1 = 1.64, k_2 = 0.52, \) and \( k_3 = 1.64, \) corresponding to initial service levels at the retailers, warehouses and factory of \( P_1 = 95, 70 \) and \( 95 \) per cent respectively. For the model 2 system, we set \( k_1 \) and \( k_4 \) each equal to 1.64.

This in turn sets the initial service levels at the retailers and factory at 95 per cent. Lower values for each \( k \) were chosen for this study because of the nature of the \( P_1 \) service measure. Daily deliveries ensure that an extremely high value of \( P_1 \) is not necessary. Once customers know about the daily deliveries, they realise that even when a stock-out occurs, replenishment stock will be arriving the next day.

The variance-reduction technique of “common random numbers” [15] (for the demand data) was employed to compare model 1 to model 2. Each simulation was again for a 100-day period.

The observed \( P_1 \) retailer service levels were obtained for five replications of both models. Each pair of service levels was based upon a common set of random demands and a paired \( t \)-test was used to determine a confidence interval for the difference in service levels, i.e., for (service level of model 1 − service level of model 2). At both the 95 and 98 per cent levels of statistical significance, model 2 furnishes better service than model 1, typically several percentages better in absolute terms. Similar results were also observed at the 95 and 98 per cent levels for the \( P_2 \) service measure at the retailers. Since inventory in the model 2 system is much less than that of model 1, the model 2 system is a clearly better method of distribution, with the above \( k_1 \) values.

With different safety factors, however, model 1 need not have inferior service. The next test used \( k_1 = k_2 = k_3 = 1.64 \) in model 1. Initial service levels at all echelons in both models were thus 95 per cent. We again used common random numbers for the demand data to compare model one to model two, simulating for a 100-day period. The 95 and 98 per cent confidence intervals for the paired \( t \)-test for \( P_1 \), and for \( P_2 \) as well, showed no significant difference between the two systems in service furnished at the retailers. However, model 2 is still likely to be preferred because of its lower system inventory. In fact, with these values of \( k \) and the normally distributed retailer demands as above, it can be shown that total system inventory in model 2 is approximately two thirds that of model 1. That is, the total multi-echelon inventory is reduced by about one-third.

**Effect of Lower Factory Inventories**

In the next study we again compare the model 1 system to the model 2 system, and choose lower values of \( k_3 \) and \( k_4 \) to study the effect of moving forward the system inventory. The model 1 system constants were set at \( k_1 = 1.64, k_2 = 1.64 \) and \( k_3 = 0.84 \) to give initial \( P_1 \) service levels at the retailers, warehouses, and factory of 95, 95 and 80 per cent respectively. The model 2 system constants were set at \( k_1 = 1.64 \) and \( k_4 = 0.84 \) to give initial \( P_1 \) service levels at the retailers and factory of 95 and 80 per cent respectively.

As before, demands at retailers were normally distributed with a mean of 100 units and a standard deviation of 20. Both models were simulated ten times each for a 200-day period. We found that even with an initial service level at the factory of 80 per cent, the observed retailer service levels were still very high: \( P_1 = 95 \) per cent and \( P_2 > 99 \) per cent. The respective values of \( P_1 \) and \( P_2 \) were essentially the same in either model, at both the 95 and 98 per cent levels of statistical significance.
It is not surprising that the model 2 system uses much less inventory, since it has one less echelon of stock to carry. (For the preceding $k_1$, the inventory reduction is now greater than one-third relative to model 1.) The real point, of course, is that this inventory reduction is not accompanied by a decrease in customer service at the retailers. When system inventory is moved forward, we can again conclude that the model 2 system is a better method of just-in-time distribution.

**Discussion of Costs**

Let us now elaborate on the cost or inventory reduction for JIT distribution, first in general and then for model 2 versus model 1. To discuss the potential savings when an organization uses JIT distribution, recall that JIT production permits considerable decrease in work-in-process inventory, the direct saving from which is lower financing cost. The same result holds for JIT distribution.

Suppose an organization has a mean inventory over its entire distribution system of 10,000 units. If this company switches from shipments every two weeks to every day, the average stock on hand is much less. Indeed, ten smaller deliveries would be used whenever there had been one delivery before. Because there are safety stocks in either case, however, the total cost will be greater than one-tenth its former value. Consider JIT shipments for which average daily demand at a retailer is 100 and a safety stock of 50 is carried. The average on-hand inventory is $50 + 0.5 \times 100 = 100$. If deliveries were every two weeks, the corresponding safety stock would be $\sqrt{10 \times 50}$ or about 160 units, resulting in a mean inventory of $160 + 0.5 \times 1000 = 660$. In this example, daily deliveries thus use an average inventory of approximately one-seventh the previous inventory, still a significant savings.

It is important to note that this impact of daily JIT deliveries, relative to shipments every two weeks, is more pronounced than the difference between model 2 and model 1 inventories. That is, a company would significantly benefit from either of these multi-echelon systems with daily deliveries. Unfortunately, transportation systems at present inhibit the use of small lot sizes; the cost structures of both private and common-carrier trucking still argue in favour of full outbound loads.

The inventory reductions from JIT distribution could more probably be realized if materials-handling changes such as those of the Appendix were carried out. The fixed costs/delivery would then be reduced, making the small lot sizes of LTL or shared distribution just as "economic" as full truck loads are today. We remark that for JIT *production*, Porteus [16] has discovered the economic justification of analogous capital investments to decrease the manufacturing set-up costs.

**Conclusions**

Current ideas on JIT production systems were described in this article and applied to the outbound distribution system. We investigated the behaviour of two formulated just-in-time distribution models, one in which the warehouses hold stock and the second in which they serve only a "break-bulk" function. The models were compared using statistical tests and model 2 was determined to be the superior distribution system, since
it furnished essentially the same service level to retailers while carrying one less echelon of stock. We suggest that research be done in freight forwarding and related information systems to allow joint ventures of distributing products. Implementation problems are those of information, order picking, and side-opening truck trailers and other set-up/reduction techniques. The information problem refers to the necessity of keeping track of stock levels at all times, calculating the order sizes and distributing these orders in time to the factory or warehouse.

Order picking requires employees to assemble small amounts of a large variety of products on a daily basis within a limited time frame. Setup changes, such as the truck loading changes described in the Appendix, are difficult to implement because of the current standardisation of transportation equipment and loading areas in organisations. Further studies in this area should be carried out in conjunction with suppliers of transport equipment.

Appendix

Materials Handling for JIT Distribution
We now discuss some materials-handling modifications which, if made, would lower the fixed set-up cost per delivery or per order. The small size of a JIT shipment would then be closer to the "optimal" distribution quantity (see [5]). Recall that our first model has a factory, warehouses and retailers in the chain of distribution. Suppose all shipments from the factory to the warehouses and to the retailers are by the company's trucks, and that the daily usage or requirement for a given product is too small to justify (conventional) daily shipments to warehouses and retailers. The delivery vehicle can then be filled each day with many different products from the same company or different firms. The truck trailer can be divided into sections for use in a joint venture with several companies, as illustrated in Figure 6. Notice that door openings are on the side and rear for easier access and quicker loading and unloading. These door openings should be on the appropriate side of the vehicle to allow for curb-side unloading at retailers.

Figure 6. Top view of trailer

Companies can co-operate to share distribution costs by alternating truck deliveries as follows. Assume that companies A and B each have a factory in Toronto and distributors in Vancouver. Company A fills a truck, 50 per cent with its products and 50 per cent with those of company B, and transports it to each firm's distributor. Company B's truck repeats the procedure the following day. The products of both organisations are being delivered daily, but each firm only has to make a trip every second day. If five companies were involved in shared distribution, daily deliveries would require that each firm use its own truck once per week. Naturally,
these trucks would serve different warehouses and/or products during the other days. Such a system of shared distribution is similar to the “round-tour, mixed loading” approach of Toyota (2) in which sub-contractors transport each other's products to the main company, allowing very frequent but small deliveries.

For daily deliveries of this type, loading docks could be arranged as in Figures 7 or 8. Either scheme would allow a truck to load and unload much faster by using side doors of the trailer. In addition, trucks would never have to back up. Three sliding doors on the trailer (see Figure 9) would allow three individual sections of the trailer to be accessed.

Figure 7. Loading dock, layout one

An alternative method would employ standardised interchangeable containers which could be placed on or removed from a flatbed trailer in a small period of time. These containers would be filled and sealed before the truck arrives at the loading dock, as is the present practice in “inter-modal” shipping of containers on flat beds. The remainder of our discussion, however, assumes that containers are not used.

To reduce set-up costs, quick loading and unloading of trucks is necessary. This can be accomplished by having all products assembled and on pallets before a truck arrives. When a vehicle comes to the loading dock, it is loaded in a few movements of the fork lift and continues onward. If a trailer were divided into three sections and had special doors that rolled upwards, three fork-lifts could work simultaneously to load or unload the truck, substantially reducing turnaround time.

Paper work can be lessened by using computers for all ordering, scheduling of stock shipments and timing of stock placements at loading docks. Long-term contracts for daily deliveries would allow continued use of quantity discount buying. These contracts should be used when factories, warehouses and retailers are separately owned. We mention in closing that just-in-time distribution by rail or air freight may also be appropriate and worthy of some analysis.
Figure 8. Loading dock, layout two

Figure 9. Three-door trailer
References


