SIMULATING AN INTERNET PRODUCT DELIVERY SUPPLY CHAIN WITH MULTI-ITEM ORDERS

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ABSTRACT
The increase of e-commerce has developed new challenges for online retailing companies delivering product orders to customers. With this challenge, a new type of supply chains have been developed aiming to cope with a strict control of lead time and associated costs. In this paper a model of an internet product delivery supply chain with multi-item orders is simulated. We address specifically the mismatch between supply and demand when retailers for any reason are unable to estimate the configuration of multi-item orders or single item orders. Three scenarios of demand configuration are simulated (demand as expected, lower than expected and higher than expected) using discrete-event simulation to look at the effect on lead time. A detailed numerical analysis is used to draw conclusions.

Keywords: internet retailing, product delivery, merge-in-transit, discrete event simulation

1. INTRODUCTION

Distribution channels in many industries have experienced major changes in recent years in terms of their structure, collaborative partnership, operational practices and performance requirements. These channel transformations arise from several factors that have altered the rules for providing competitive delivery services. Changes in product delivery management can be attributed to three main driving forces:

Customers are raising their service expectations. Customer demands for quick response and customized products are propagating along supply networks. Changes in life style of people require manufacturers and service providers to adjust to the new circumstances.

Information technologies are providing more timely and detailed supply chain data. Advances in information technologies in both connectivity and reach increase the potential for information sharing and enable tighter integration among supply chain partners.

Partnerships with logistics service providers allow manufacturers to focus on their core competences while taking advantage of the distribution efficiency and expertise of dedicated distributors. In turn, distributors are offering their services beyond the traditional warehousing and transportation functions to include value-added activities e.g., repackaging, labeling, light assembly, and non-inventory distribution services of which cross-docking and merge-in-transit distribution are examples.

Merge-in-transit distribution (MiT) is a logistics process introduced in practice in the late 1990s.

Merge-in-transit is defined as a distribution process that brings together at a consolidation centre multi-product order components, coming from different origins, consolidates them into a single order, and then ships it for final delivery to the end customers.

Some of the advantages obtained with MiT are:

Higher customer satisfaction is obtained by delivering multi-product orders in one event instead of making more than one delivery, one for each component or partial group of them.

Savings are achieved by not keeping inventories in the distribution process; since merge-in-transit centers just hold order components for a short time (usually less than 24 hours) so the order is all the way in transit to its final delivery point. Holding costs associated with warehousing operations are avoided or at least minimized.

Savings also arise by avoiding the risk of keeping obsolete inventories. MiT is normally applied to distribute orders where sometimes one component has been made-to-order. Those tailored components have been made for a specific need and are never kept in stock so there is no risk of keeping obsolete components (Ala-Risku, Karkkaainen and Holmstrom 2003).

2. SUPPPLY CHIAN DESCRIPTION

In this section it is described a prototypical supply chain that will represent a generalization of normal operation of MiT supply chains. It is considered a customer that is online at home or office and makes the selection of items that he wants to buy in the same transaction. The information is sent to the retailer and the retailer sends the multi-item purchase order to the order consolidation center. The order consolidation center collects the items needed and a single multi-item package is assembled for the specific customer order. It may happen that some items required are not in stock because they are in transit to the consolidation center. Having products out of stock obviously causes delay in the delivery process.

A graphic explanation of the supply chain can be seen in Figure 1.

The stock of items at the consolidation center is replenished by a continuous review policy. The following logic is applied: if the stock level at the consolidation center goes below the reorder point, then place an order that replenishes the stock at the consolidation center. The replenishment shipments have an implicit transportation time. Finally, when all the items required for a multi-item order are available, a single shipment is transported and delivered at the customer location.

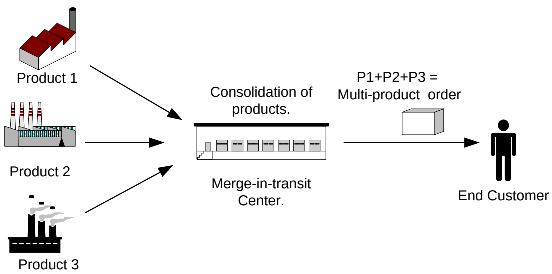

Figure 1: Supply Chain Model

3. CONCEPTUAL MODEL

The supply chain described in section 3 can be translated in a conceptual model (Pidd 1998) to approach the construction of the simulation model required for the analysis. Figure 2 shows a conceptual model with four basic operations:

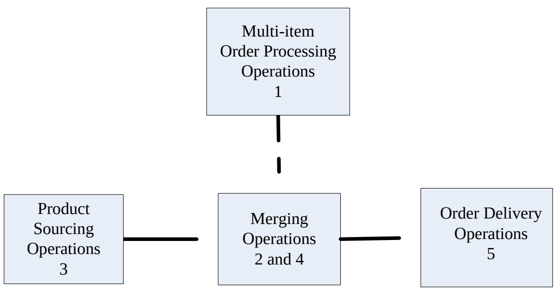

Figure 2: Conceptual model of the MiT supply chain

3.1. Multi-item Order Processing Operations

Multi-item order processing operations include the activities involved in the communication and initial information processing of the order placed by the customer. Communication of the order placed by the customer means how the MiT Supply Chain gets the preferences of the customer into their system. It can be a website portal in which the customer selects from a catalogue of products. Web internet ordering systems have the advantage of communicating the information instantaneously.

Initial information processing means the initial classification of information that MiT Supply Chains may do to batch orders with similarities that represent an advantage to the system. It also includes setting priorities to special orders or customers as another example. Three main issues can be found to be relevant in Multi-item Order Processing Operations: first is the order size. How many items are included in the order? Large order sizes may have implicit long consolidation times due to the number of items required to have available to have a complete order. Second is the mix of products Assemble-to-Order (ATO) and Make-to-Stock (MTS). Coordination of items with different natures (ATO versus MTS) represents a challenge as usually they have different holding costs and processing times. ATO items are assembled just as an order has been placed, so its assembly time and transportation is critical to have lead time under control. Making right decisions in the sourcing of items needed in order to have the required mix of items can be a challenge with implications on performance and cost. Third are the order processing decisions.

3.2. Product Sourcing Operations

Product sourcing operations include the activities required to have available at the consolidation point the items to be merged to integrate a multi-item order. In the case of MiT Supply Chains that merge items ATO and MTS, the Sourcing Policy decisions and the Transportation are relevant decisions. Sourcing Policy means what type of Inventory Management logic will be used to bring in the required items to the consolidation centre. It cannot be said that a MiT Supply Chain holds inventory as this would be contradictory to its principle but it certainly can hold items that are waiting to be merged. The more desynchronized is the merge of multi-item orders, the more the process turns from merging operations to holding inventory operations. Sourcing Policies can operate under periodic review logic where time is the variable that triggers the transportation process or it can be reorder point systems where the level of in hand items triggers the transportation of items. Transportation is another significant decision in the Product Sourcing Operation. Distance of Transportation and Speed of the transportation media can be important factors in the costing and service levels reached in the operation. In the case of ATO items, Postponement can be a relevant strategic decision to be included. If the assembly time of ATO items is one of the critical elements in the whole order lead time, then it can be understood that if is possible to pre-assemble some parts of the ATO items before the order is placed into the system, then some time can be saved to cut lead times.

3.3. Merging Operations

The orders taken online are transferred in the sequence they arrive to the point of consolidation of items. There is no order batching. Based on the items' availability, customer orders are scheduled for consolidation following a first-in-first-out rule. The point of consolidation maintains a minimum level of stock and every time the stock level goes below the level a replenishment order is scheduled following a fixed replenishment point/fixed replenishment quantity inventory policy (Q, R). The replenishment batch size is fixed. Customer orders that require items out of stock at a given time are put away temporarily and as soon as the item required is available in the consolidation point, the waiting order is scheduled to be processed. The consolidation process is modelled as a quick operation, very similar to the sortation in material handling systems. Once an order is consolidated, a delivery truck delivers a batch of orders. The time taken for the delivery truck to complete its deliveries may vary according to a given probability distribution. The delivery truck is dispatched regularly regardless of the number of orders to be loaded but having a maximum capacity. The base model includes the consolidation of up to 3 items, each of them being sourced from different origins. Figure 3 shows the flowchart that describes the logic for the model.

3.4. Order Delivery Operations

Order delivery operations include the transportation of the MiT order once it leaves the merge centre. Order Delivery Operations is what Boyer, Frohlich and Hult 2005; Bowersox, Closs and Cooper, 2007) discuss in the extended supply chain concept. From the operations perspective, Order Delivery includes two typical decisions to consider. One is the consideration of Time Windows on the final delivery trip. It can happen that delivery staff arrives to drop off the order and customers are just unable to receive it. It can be also the case that companies are offering a higher service level to customers by allowing customers to set a day and time range for their delivery operations. A second issue to consider is the design of an Optimal Delivery Network. This means looking at finding the best delivery network for the MiT supply chain that as example can set as its objective to minimize the cost of operations given a set of constraints. Alternatively, the objective may be to minimise the delivery time given a set of constraints.

4. PROBLEM DESCRIPTION

The supply chain model utilized is able to deliver up to three items for the same customer order and the supply chain structure and operating principles remain the same.

For this case we use three demand scenarios, each of them having different proportions of dependent orders. The three scenarios are: a) Demand with a high proportion of dependent orders, this type of demand will be called higher than expected, b) Demand with a medium proportion of dependent orders, we will call this type of demand as expected, c) Demand with a low proportion of dependent orders and this will be called lower than expected.

The key concept to explore in this simulation scenario is whether the supply chain operation is set to supply and cope with the delivery of orders to customers with an expected level of demand per individual item, which may be different to the demand actually received. Based on the fact that orders are not single-item and that the multi-item orders depend on customer choice, the real demand per item may be different from what was expected and consequently the capability of the supply chain to fulfil the delivery orders on time may be affected. By order configuration based on customer choice we mean the group of items requested per multi item order.

Three order types will be defined: type A represents an order for item 3 only, type B represents an order for items 2 and 3 and type C represents an order for items 1, 2 and 3. We assume a situation where we expect an equal proportion of orders from customers of types A, B and C.

In this paper, we simulate three customer demand configurations, each one representing levels of demand: higher than expected, as expected, and lower than expected. In the higher than expected configuration, we assume that a higher proportion of orders are of type C and a lower proportion are for type A. In the lower than expected configuration, we assume that a lower proportion of orders are of type C and a higher proportion are for type A. In this condition it is expected that the system will operate with excess of capacity.

The objective of this three scenario experiment is to quantify the implications in the delivery supply chain when the demand for some items is significantly more or less than expected, due to different proportions of orders combining orders for different items.

The values used to generate each of the demand scenarios are in tables 1,2 and 3:

Table 1: a) Demand higher than expected

Order Type	Item 1	Item 2	Item 3	% of orders per type
A	0	0	1	15.00%
B	0	1	1	30.00%
C	1	1	1	55.00 %

Table 2: b) Demand as expected

Order Type	Item 1	Item 2	Item 3	% of orders per type
A	0	0	1	33.33%
B	0	1	1	33.33%
C	1	1	1	33.33 %

Table 3: c) Demand lower than expected

Order Type	Item 1	Item 2	Item 3	% of orders per type
A	0	0	1	55.00%
B	0	1	1	30.00%
C	1	1	1	15.00 %

5. DATA AND INPUT PARAMETERS

The simulation model was run for 50 replications of 3 months of continuous operation, each 2196 hr. The conditions of the model were: 50 % of stock out risk, inbound and outbound transportation times were modelled following a Normal distribution with means of 24 hrs and 72 hrs respectively. Standard deviations for the transportation times were 2.4 hr and 7.2 respectively. Table 4 summarize data and input parameters used for the simulation runs.

Table 4: Input parameters, control variables and experimental variables.

Section of the model	Variable name	Variable value
Order taking	Order inter arrival time	Exp (0.15)
	Maximum number of different type of products	3
	Order configuration (independent & dependent)	2
Inventory	Excess of Supply factor	1.25
	Reorder policy	(R, Q)
	Induced stock-out probability	30%
	Inbound transportation time	N(24, 2.4)
	Inbound transportation vehicle size	2MLTD
Consolidation	Consolidation operation time	0.005/item
Outbound transportation	Outbound transportation time	N(72, 7.2)

6. METHODOLOGY

Discrete event simulation (DES) was used as the modeling methodology for the analysis of the supply chains under study. DES is a well-established technique for the study of operational scenarios in real world situations (Banks, Carson, Nelsona and Nicol 1995; Pidd, 1998; Law and Kelton 2000). DES is a suitable analysis tool for the research objectives set for this thesis because of the following advantages:

- DES allows a high level of detail to be modeled for the operating scenarios under study while mathematic analytic models would only allow the simplified representations of real world scenarios (low level of detail).
- Using DES can easily model alternative scenarios of operation (experimentation) of the supply chains under study and allow practical conclusions to be drawn.
- One of the main research aims in this thesis is the study of the composition of customers' multi-item orders when buying using the Internet. This order composition is a behavioral element that can be nicely modeled and experimented upon with DES. Supply chain problems involving behavioral issues use predominantly simulation over analytical methods as the primary research tool, since the complexity of human interaction with complex systems precludes analytical methods for examining customer election issues (McCreery, Krajewski, Leong, G. K. and Ward, P. T. 2004 (McCreey et al, 2004).
- DES is a methodology that allows the dynamic analysis of operations. As the name suggests, a simulation run is a sequence of events for which the model can be can be stopped at any event in the run. This feature is very useful in the verification of the model, as it allows to carefully checking that the operating conditions in the computer model are accurately executed as in the conceptual model.

RESULT AND ANALYSIS

Table 5 shows the results for the three scenarios of demand being higher than expected, as expected and lower than expected. The table includes the segregated values for orders delayed and non-delayed as well as all the orders

Table 5: Input parameters, control variables and experimental variables.

	Demand Pattern Condition		
	Higher	As expected	Lower
% orders of type A, B and C	15,30,55	33,33,33	55,30,15
Avg. Time in System (1)	279.00	110.41	110.17
Minimum Time in System (1)	66.99	66.06	70.57
Max. Time in System (1)	1660.09	157.97	152.12
St Dev of (1)	214.64	21.94	21.01
CV (1)	0.77	0.20	0.19
Items Entered (delayed)	6727.66	804.14	390.26
Avg. Time in System (2)	108.81	108.53	108.52
Min. Time in System (2)	57.67	57.36	57.36
Max. Time in System (2)	164.07	164.38	164.39
St Dev of (2)	22.59	22.59	22.59
CV	0.21	0.21	0.21

The average time in system for the case of orders with demand higher than expected is almost double (195.50) that for the as expected (108.63) and lower than expected (108.56) cases. The reason for this is the higher number of out of stocks registered under the higher than expected demand. The high coefficient of variation (CV) of time in system for orders with higher demand than expected (0.90) compared to the ones from as expected (0.21) and lower than expected (0.21) confirms the higher variability in delivery time of the system with higher demand than expected caused by the lack of stock. As orders with demand as expected or lower than expected have the same CV, we can argue that they expect the same degree of variation in the delivery time. The percentage of orders delayed for higher than expected, as expected and lower than expected demand is 52.8%, 5.5%, 2.7% respectively.

More than half of the orders are delayed when demand is higher than expected. This value is ten times higher than when demand is as expected and almost twenty times higher than when demand is lower than expected. So this proportion can be very high and implies a potential high impact on the delivery time of the order and customer satisfaction. Again, the high proportion of orders delayed when demand is higher than expected is related to the lack of items to fulfill orders.

The average difference in lead time between delayed and non-delayed orders for the different scenarios show that when demand is higher than expected, the orders (170.19 hr) have around a 100 % longer delays compared to when demand is as expected (1.88 hr) and lower than expected (1.64 hr). This means that delays registered when demand is higher than expected are hundred percent longer on average than for the other types of demand.

The percentage of difference in lead time between delayed and non-delayed orders for runs with the same demand values show that when the demand is higher than expected a delayed order takes 156.4% more time to be fulfilled than a corresponding order that did not register delay. In the case when demand is as expected, the difference between delayed and non-delayed is only 1.7 % more time, while when the demand is lower than expected, the delay is 1.5% time in excess.

Table 5: Cont. input parameters, control variables and experimental variables

	Demand Pattern Condition		
	Higher	As expected	Lower
% orders of type A, B and C	15,30,55	33,33,33	55,30,15
Items Entered (non-delayed)	6019.84	13847.4	14260.64
Avg. Time in System	195.5	108.63	108.56
Min. Time in System	57.67	57.36	57.36
Max. Time in System	1660.09	164.68	164.43
St.Dev(1+2)	175.95	22.58	22.57
CV	0.9	0.21	0.21
Number Completed (all)	12763.8	14552.9	14553.4
% of orders delayed	52.8%	5.5%	2.7%
Ave. Diff. in LT(Delayed vs. Non-delayed)	170.19	1.88	1.64
% of Diff in LT(Delayed vs. Non-delayed)	156.4%	1.7%	1.5%

For orders non-delayed the lead time in systems is the same for the three types of demand (108.53, 108.81, and 108.52). This data confirms the correct operation of the simulation model including that the model is not blocking at the merge operation. The standard deviations for delayed orders are 214.64, 21.94, 21.01 for high, medium and low mix respectively. We can understand from this that orders delayed in when demand is higher than expected have a 10 times larger standard deviation in the delivery time.

7. CONCLUSIONS

The higher value on average time in system for the demand pattern defined as higher than expected is not counterintuitive. However, it can help managers to quantify the delay on the delivery systems with consolidation if there is mismatch between supply and demand on at least one item of the order. Figures for the scenario evaluated show that the delivery time can go from 4.58 to 11.62 days. The proportion is considerable and having a delivery system with delays double than base delivery time can have considerable implication on customer satisfaction. The system can have a better performance if the stock-out probability or reorder policy for items is adjusted for products likely to be ordered in a consolidated order. The average difference in lead time between orders delayed and not-delayed with figures of (170.19, 1.88 and 1.64) can provide mangers an idea on how “ long or deep” is the delay of an order. This figure is also linked to the inbound transportation time. The smaller the inbound transportation time is the smaller the impact on the delivery of items consolidated will be. An alternative for managers is sourcing from suppliers that offer shorter lead time.

The systems evaluated in this paper help to profile the expected behavior of the logistic system with implications with customer satisfaction and indirectly the cost of running the logistics system if improvements on the system want to be realized.

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