Exploring Duplicate Orders in a Single-Manufacturer Multi-Distributor Supply Chain

Sebastián Villa Betancur
University of Lugano, Switzerland
Via Buffi 13, CH-6904 Lugano, Switzerland.
e-mail: villabes@usi.ch

Gloria Urrea Castaño
University of Lugano, Switzerland
Via Buffi 13, CH-6904 Lugano, Switzerland.
e-mail: urreacag@usi.ch

Paulo Gonçalves
University of Lugano, Switzerland
Via Buffi 13, CH-6904 Lugano, Switzerland.
e-mail: paulo.goncalves@usi.ch

ABSTRACT:
This paper seeks to better understand how duplicate orders may dynamically influence the general performance in a single-manufacturer multi-distributor supply chain. We analyze a system where manufacturer sells her products through two distributors and the distributors sell the products to final customers. If a distributor is not able to satisfy his final customer demand, the unsatisfied demand will be backlogged and the customer will also place the order to the other distributor with certain probability. When the customer demand is satisfied by any of the distributors, the customer will cancel the duplicated order to the other distributor. Finally, when final customer demand exceeds available distributors supply, distributors often hedge against shortages by inflating orders to the manufacturers.
Our results allow us to characterize the supply chain performance according to different probabilities to duplicate orders, different times to build manufacturer's capacity and the well-known anchoring and adjustment heuristic to model distributor orders and manufacturer capacity investment.

KEYWORDS:
Duplicate Orders, Supply Chain Management, Capacity Management, System Dynamics.

1. INTRODUCTION

Distributor order amplification often takes place when supply shortages – due to insufficient production capacity, uncertain production yields, or supply chain glitches – lead to fierce distributor competition. The resulting distributor order amplification can lead to problems such as excessive manufacturer capital investment, inventory gluts, low capacity utilization, and poor service, among others (Armony and Plambeck, 2005; Gonçalves, 2003; Lee et al., 1997a; Sterman, 2000). Lee et al. (1997a, 1997b) characterize the mechanisms leading to distributor order amplification. Under scarce supply, the manufacturer rations the allocation of available supply to satisfy distributors' orders, while at the same time distributors amplify orders in an attempt to secure more units (Lee et al., 1997a, 1997b). Customers also play an important role in these dynamics. Anupindi and Bassok (1999) study the stocking decisions of two distributors during several periods with stationary demand and find that in every period, when a customer realizes that his distributor is out of stock, he may buy from the other distributor. In other cases, customers could also decide to duplicate the order to several distributors, in order to increase the probability to receive the product. Then, when supply finally normalizes, customers cancel duplicated orders to distributors and return to previous ordering levels (Lee et al., 1997a, 1997b). As mentioned before, such retailer ordering behavior can pressure manufacturers to make unnecessary investments in capacity, build excess inventory, experience low capacity utilization, leading to large financial losses.

Cisco System's 2001 US$ 2.2 billion inventory write-off (Byrne and Elgin, 2002) provides an instructive example. In the summer of 2000, Cisco began to experience shortages of several key components. As delivery delays to customers increased, they started to place orders with multiple distributors to improve their chances of receiving their orders. Because Cisco failed to recognize the magnitude of customers' order amplification, it maintained its ambitious sales forecast and engaged in strong capacity expansion through long term contracts with its OEMs. When additional capacity became available and delivery delays went back to normal levels, customers began to cancel duplicated orders with distributors, leaving Cisco with significant excess capacity, rigid long-term contracts and a remarkable amount of inventory. Armony and Plambeck's (2005) suggest that Cisco's write-off was caused by estimation errors and cannot be blamed entirely on the economic downturn.

A number of additional examples illustrate the important role played by retailers in the dynamics of order duplications. In the 1980s, the computer industry perceived a shortage of DRAM chips in several occasions. Orders surged, not because of increased consumption, but because of anticipation (Li, 1992). Similarly, a surge in orders for Hewlett-Packard's LaserJet printers caused it to ration the product. HP could not discern whether the orders were simply phantom orders from resellers trying to get better allocation of the product and lifted its constraints on the resupply of the printers. By that time, many resellers cancelled their orders to HP, making it incurring in costs in excess inventory and unnecessary capacity increases in the millions of dollars (Lee et al., 1997a). Along the same lines, facing shortages of Pentium III processors, Intel planned to introduce a new production plant (Foremski, 1999). Later, due to large order cancellations and economic slowdowns, Intel warned that its revenues would fall short of projections and that sales would be flat (Gaither, 2001).

Despite the fact that distributor order amplification has been identified in the literature for almost a century, when Mitchell (1924) described the case of distributors inflating their orders to manufacturers when competing with other distributors for scarce supply, there has been little research analyzing it systematically. For instance, Sterman (1989a, 1989b) studies the individual decision rules for ordering through the Beer Game, obtaining results that show costly oscillations and instabilities in the system. Lee et al. (1997a, 1997b) show that when supply shortages occur, they lead the manufacturer to ration the allocation of available supply to meet distributors' orders. In order to compensate for this strategy, distributors inflate orders to try to meet final customers' needs. Gonçalves (2003) captures distributors' order amplification when competing for scarce supply using an anchoring and adjustment rule and Villa et al. (2013) experimentally test distributor ordering decisions. However, these studies neither account for distributors in competition for resources nor allow for customer order cancellations. An exception to this gap in the literature is the analytical work of Armony and Plambeck (2005). They show that any manufacturer that fails to account for duplicate orders will overestimate the demand rate and the reneging rate, leading to errors in capacity planning.

In general, the available research does not explain (a) how different factors may independently or in combination influence distributor order amplification in single-manufacturer multi-distributor supply chains, or (b) the impact that such factors may have on the upstream manufacturer demand estimation or capacity investment. To start addressing these gaps, this paper builds on Armony and Plambeck's (2005) analytical work on the impact of duplicate orders on upstream suppliers' demand estimation and capacity investment by developing a System Dynamics (SD) simulation model encompassing more realistic (and endogenous) decision policies for (i) manufacturer's capacity investment, (ii) distributors' inventory management, and (iii) customers' order cancellations. Nevertheless, our model has also some differences with the one proposed by Armony and Plambeck (2005). For instance, in their model, when two customers order to the same distributor, the latter will ship the order according to first in first out (FIFO) or priority; while in our model this allocation is proportional to the backlog and orders. A second important difference is that our model does not consider cancellations due to long waiting times.

Our results show that the increase of the amount of orders being duplicated affect the extent to which the manufacturer's capacity will be amplified. However, the time to build capacity can help to soften the effect of the duplications. This way, we improve our understanding of the endogenous dynamics leading to distributors' order amplification decisions, which directly affect manufacturer's capacity, providing practical implications that may be useful for supply chain managers.

This paper proceeds as follows. Section 2 describes the proposed system dynamics model. Section 3 shows our analyses and main results. Section 4 presents our discussions about the main findings and future research.

2. MODEL DESCRIPTION

We build upon a model proposed by Armony and Plambeck (2005). As Figure 1 shows, the model considers a supply chain structure composed of a manufacturer with two distributors facing demand from customers. Final customer demand is independent and deterministic; however, distributor demand is not, since distributors may compete for scarce supply. If a customer finds that his distributor is out of stock, he will then duplicate the order with the other distributor in the next period with a given probability (r). In addition, the distributor may inflate his order to the manufacturer, according to the expected demand and the desired inventory. As soon as one distributor supplies the customer with his desired amount, the customer cancels the duplicated order with the other distributor. The manufacturer's production capacity determines her ability to deliver products to distributors (and, therefore, to customers). Finally, the manufacturer's estimation of demand serves as a basis for her decision on production capacity investment.

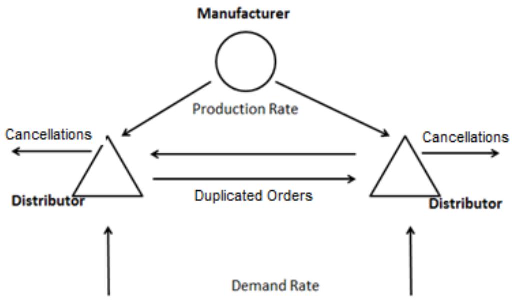

Figure1. Supply Chain Structure

Figure 2 provides an overview of the system dynamic model built for Distributor 1 (the model for Distributor 2 has the same structure). The Distributor 1 (D1) receives orders from Customer 1 (C1) and from Customer 2 (C2). The demand followed by Customer 1 is determined by a step function (starts in 50units and then in period 4 increases from 50 to 70 units), while the demand received by Customer 2 corresponds only to duplicated orders (unbeknown for Distributor 1), generated with a probability **r** when Distributor 2 (D2) is out of stock.

If D1 has enough inventories, he will be able to supply the orders to both customers. Otherwise, he will ship the available product to customers in proportion to the backlog and orders received from each one of them. The orders that could not be supplied accumulate in the respective backlog (D1 Backlog C1, D1 Backlog C2), i.e. the backlog represents the customers' orders that are waiting to be delivered by the distributor.

Our model, however, allows for customer cancellations which help reduce backlog. Let us consider the case of Customer 1 when Distributor 1 is not able to supply the placed orders. The first step is that C1 will duplicate the missing orders to D2 the next period with a probability **r**. Then, C1 will wait until he receives the missing order. If the order was sent by D2, C1 will immediately cancel that order to D1. However, if C1 received the order from D1 (as C1 duplicate the order to D2 only with a probability **r**), he will only cancel a proportion of the backlog to D2, according to the total backlog C1 has in D1 and D2.

In the meanwhile, D1 has also to place his orders to the manufacturer. In our model, the orders placed by D1 follow a heuristic of anchoring and adjustment (Sterman, 1989a, 1989b; Gonçalves 2003) considering the supply line, the inventory and the expected new orders from C1 and C2.

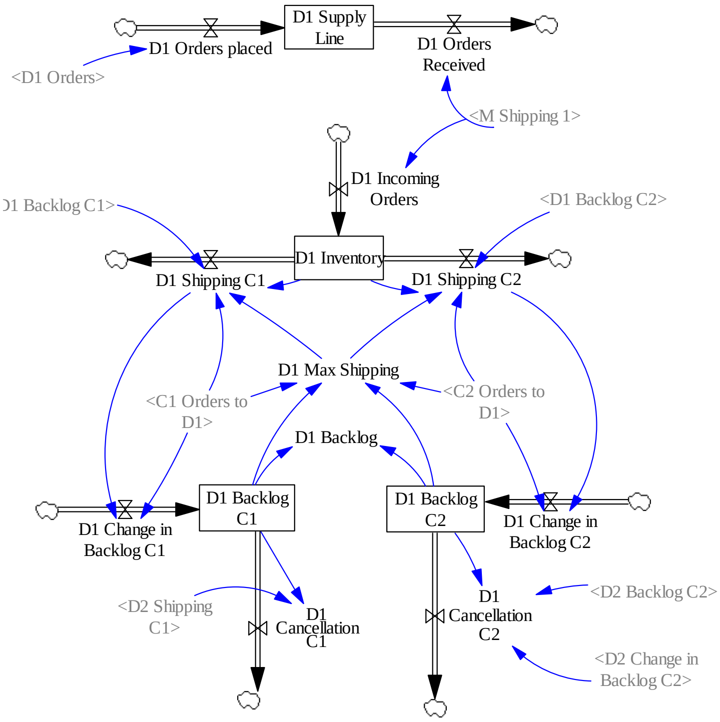

Figure2. Overview of model for Distributor 1

The Manufacturer (M) receives orders from D1 and D2 following a model similar to the one shown in Figure 2, with the main difference that distributors are not allowed to make cancellations to M. The Manufacturer follows a heuristic considering expected new orders and inventory to define her desired capacity. Then, M will compare this desired capacity with the capacity under construction and the actual manufacturer capacity (see Figure 3) to determine the capacity gap and the subsequent capacity to be built. However, if the capacity gap is negative (a signal of a possible reduction of the demand), it is also possible to decrease manufacturer capacity. For both situations, increase and reduction of capacity, there is also a time (time to build capacity) that will delay the moment in which the capacity will be definitely adjusted.

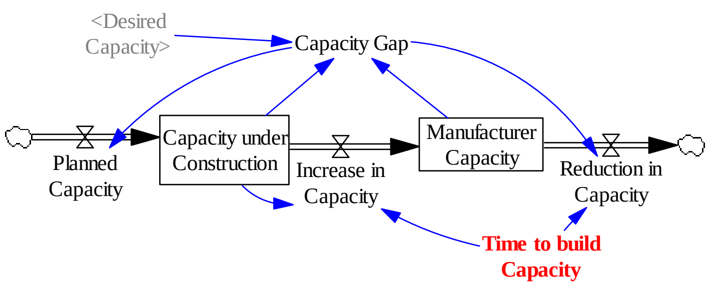

Figure3. Overview of model for Manufacturer

For further details about the model, Appendix A shows the main equations from Vensim.

3. ANALYSES AND RESULTS

In this section we present the overall results of the study using the model described above as a basis of our analysis. Our simulation explores two characteristics previously discussed by Armony and Plambeck (2005) and Gonçalves (2003) affecting supply chain performance: probability of customer order duplications (**r**= 0, 0.3, 0.7 and 1) and supplier capacity acquisition delay (**Tk**=1 and 4 periods). Table 1 specifies the cases used in this paper.

Table1. Cases of study

	C1	C2	C3	C4	C5
P. Duplication (r)	0.0	0.3	0.7	1.0	0.3
Time to build Capacity (Tk)	4	4	4	4	1

We run the model for 33 periods (weeks) using Vensim and overall results show clear effects regarding the effect of duplications in inventory and capacity management. Figure 4 shows manufacturer capacity as a function of time. During the first periods the system is in equilibrium, given that the manufacturer is able to satisfy distributors' orders and also distributors are able to satisfy customers' demand on time. However, once the step in D1 demand increases from 50 to 70, D1 will face a backlog and D2 will increase his probabilities of receiving duplicated orders. The presence of backlog and possible final customer demand inflations (due to the duplications) lead to an increase in the demand that the manufacturer perceives. Over time, the manufacturer builds capacity to meet the increase in the perceive demand. Capacity continues increasing, even surpassing final customer demand (120units/wk). When the manufacturer capacity is large enough, she will be able to satisfy her demand but also will face a reduction in her perceived demand due to the cancellations that customers will make to the distributors. At this point, the manufacturer capacity meets its maximum and capacity investment turns to divestment.

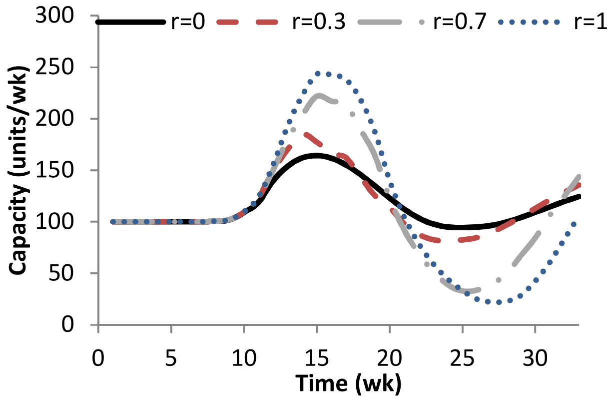

Figure4. Manufacturer Capacity under different duplication probabilities (r) and with Tk=4

Taking in to account the different duplication probabilities, Table 4 shows that the higher the duplication probability, the worse the pattern perceived in manufacturer capacity. For example, the black-straight line shows the behavior when the probability of duplication is zero. In this case, the perceived underperformance of the supply chain and specifically of the manufacturer will be explained by the specific unsatisfied demand that D1 faced. Case 1 shows a clear instability of the system; however, this instability will be small and will disappear early over time. On the other hand, as the probability of duplications increases, the amplitude of the manufacturer capacity also increases, leading to a highly unstable system. Indeed, manufacturer capacity will be difficult to stabilize, in the long term, when there is high probability of duplications.

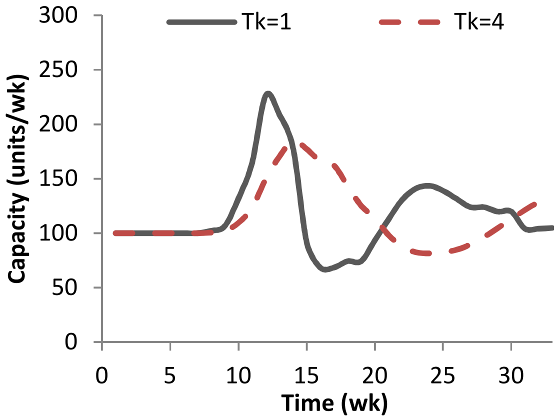

Figure5. Manufacturer's and Distributors' Backlog

One of the common alternatives strategies for dealing with changes in demand is trying to change the average time needed to change capacity. Figure5 show the general manufacturer capacity when the time to build capacity is both 1 and 4. As it was expected from the literature, the system with lower Tk presents a sharper and more variable pattern and the system with higher Tk smooth better the instabilities of the system. However, having systems with high delays could difficult management due to it would be more difficult to understand the general dynamics and causalities of the system.

Extending our analysis to the distributor, whose decisions are modeled using the anchoring and adjustment heuristic, Figure6 shows how D1 inventory evolves over time under different duplication probabilities. As a general result, we can see that in all cases the inventory is higher than the desired inventory level (60 units). Analyzing the case when there is not possibility of duplication, we can see that there is a conservative rise in the inventory level and the system stabilizes in the long term. However, as described before for the manufacturer, as the probability of duplication increases, the distributors' perceived demand increases. Hence, distributors place a higher order to the manufacturer. Once enough inventories are available to satisfy final customer demand, duplicated orders are canceled and distributor end up with high inventory levels. This pattern can be specially observed in the case where there is a 100% of orders' duplication probability (dotted line – Figure 6).

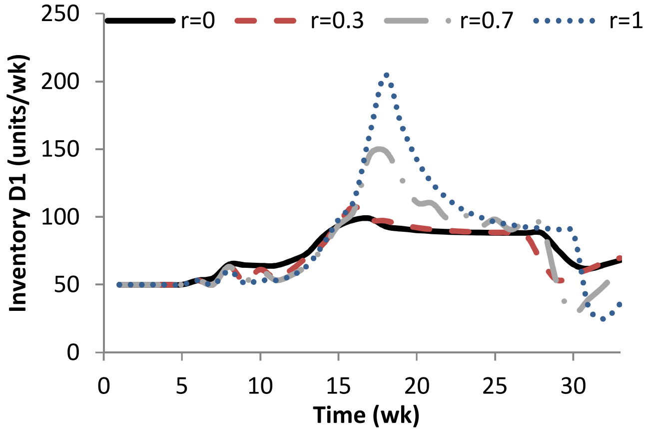

Figure6. Distributor 1 inventory under different duplication probabilities

Distributors' cancellations allow us to measure the effect of duplications in distributors and manufacturer performance. Existence of cancellations in this system represents a clear contamination of the information shared. This approach could be extended accounting for cancellations given for a large waiting time of unsatisfied customers. Table2 show the average cancellations that each distributor faced during four cases of our simulations. In the first column of the table, we can see that there are not cancellations and that the problems described in the previous paragraphs are due to the existences of shortages. Columns 2 to 4 show an increasing number of cancellations. This is, the higher the probability of an order to be duplicated, the higher the future orders' cancellations and the higher the underperformance of the general supply chain.

Table2. Cancellations to each distributor

		C1	**C2**	**C3**	**C4**
Distributor1	**Mean**	0.00	2.64	7.09	83.61
	SD	0.00	4.64	9.81	42.26
Distributor2	**Mean**	0.00	0.39	2.36	4.31
	SD	0.00	1.33	4.83	7.19

4. DISCUSSION AND FUTURE RESEARCH

In this paper we extend Armony and Plambeck's (2005) analysis by developing a system dynamic model which considers a supply chain with a single manufacturer who sells to two distributors facing demand from final customers. Our analyses focus on the changes in the probability to duplicate orders and in the time to build capacity with the corresponding effects in distributors' inventory management and manufacturer's capacity investment.

Our results allow us to better understand the endogenous dynamics leading to distributors' order amplification decisions, which directly affect manufacturer's capacity. For instance, we find that the increase of the amount of orders being duplicated affect the extent to which the manufacturer's capacity will be amplified. This result is supported by the conclusion of Armony and Plambeck

(2005), who state that any manufacturer that overlooks duplicate orders will make mistakes in planning her capacity, even if the demand is stable. Nevertheless, we also found that the time to build capacity could help regulate the duplications' effect.

A limitation of this study is the consideration of a fixed probability to duplicate orders. According to Armony and Plambeck (2005), after a customer has experienced several times a shortage from his distributor, he will be more likely to duplicate his orders in the future.

This paper is just a starting point to better understand all the dynamics related with duplicated orders and their effect in general supply chains. For this reason, future research should focus in better understanding all the dynamics described here and relaxing some assumptions made. For example, the system dynamics model should directly account for the fact that the distributors are competing for the manufacturer scarce supply. Also, it would be interesting to include another cancellation type, which is due to the fact customers do not want to wait too much time to be attended; hence, they prefer to leave the system without any purchase. Finally, we would like to test the model developed in this paper in a controlled environment (experimentally). This will give us a better understanding of people behavior, the dynamics and heuristics involved in a competitive setting.

REFERENCES

Anupindi, R., Bassok, Y. 1999. Centralization of Stocks: Retailers vs. Manufacturer. Management Science, 45(2), 178-191.

Armony M, Plambeck E. 2005. The Impact of Duplicate Orders on Demand Estimation and Capacity Investment. Management Science 51 (10): 1505-1518.

Byrne, J. A., Elgin, B. 2002. "Cisco: Behind the Hype." Business Week, January 21.

Foremski T. 1999. Intel struggles to meet strong demand for chips. Financial Times (London), November 18, 42.

Gaither C. 2001. Intel Beats Forecast; Warns of Revenue Shortfall. The New York Times, January 17, C1.

Gonçalves P. 2003. Phantom Orders and Demand Bubbles in Supply Chains. Ph.D. Dissertation, Sloan School of Management, MIT, Cambridge: MA.

Lee H, Padmanabhan V, Seungjin W. 1997a. Information Distortion in a Supply Chain: The Bullwhip Effect. Management Science 43(4): 546-558.

Lee H, Padmanabhan V, Seungjin W. 1997b. The Bullwhip Effect in Supply Chains. Sloan Management review 38(3): 93-102.

Li, L. 1992. The Role of Inventory in Delivery-Time Competition. Management Science, 38(2), 182-197.

Mitchell TW. 1924. Competitive Illusion as a Cause of Business Cycles. Quarterly Journal of Economics 38(4): 631-652.

Sterman JD. 1989a. Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment. Management Science 35(3): 321-339.

Sterman JD. 1989b. Misperceptions of Feedback in Dynamic Decision making. Organizational Behavior and Human Decision Sciences 43(3): 301-335.

Sterman JD. 2000. Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hill/Irwin: Boston, MA.

Villa S., Gonçalves P., Arango S. 2013. “Exploring Retailer’s Ordering Decisions under Delays”, 31st International Conference of the System Dynamics Society, Cambridge-USA, 2013.

Appendix 1. General Model formulation in Vensim

```
Planned Capacity= Max(Capacity Gap,0)
Capacity Gap=
      Desired Capacity-Capacity under Construction-Manufacturer Capacity
Manufacturer Capacity= INTEG (
      Increase in Capacity-Reduction in Capacity, 100)
Reduction in Capacity = max(-Capacity Gap/Time to build Capacity,0)
Capacity under Construction= INTEG (+Planned Capacity-Increase in
Capacity,0)
C1 Orders to D2= IF THEN ELSE(C1 Orders delayed to D2<=0, 0, IF THEN
ELSE(RANDOM UNIFORM(0,1,0.3)<Duplication\ ,C1 Orders delayed to D2,0) )
Increase in Capacity = Capacity under Construction/Time to build Capacity
M Expected New Orders = SMOOTH3(D1 Orders+D2 Orders,M Time to Average
Orders)
C1 Orders to D1= 50+STEP(20, 3)
C2 Orders to D2 = 50
D1 Adjust for Inventoty =     (D1 Desired Inventory-(D1 Inventory-D1
Backlog))/D1 Time to adjust inventory
D1 Adjustment for Supply Line=      D1 Supply Line Accounted for*((D1
Desired Supply Line*D1 Expected New Orders)-D1 Supply Line\)
D1 Backlog = D1 Backlog C1+D1 Backlog C2
D1 Backlog C1= INTEG (D1 Change in Backlog C1-D1 Cancellation C1, 0)
D1 Backlog C2= INTEG (D1 Change in Backlog C2-D1 Cancellation C2, 0)
D1 Cancellation C1= min(D2 Shipping C1,D1 Backlog C1)
D1 Cancellation C2=IF THEN ELSE(D2 Change in Backlog C2<0, IF THEN
ELSE(D1 Backlog C2>0, (D1 Backlog C2\ /D2 Backlog C2)* min(-D2 Change in
Backlog C2,D1 Backlog C2),0) , 0 )
D1 Change in Backlog C1= C1 Orders to D1-D1 Shipping C1
D1 Change in Backlog C2 = C2 Orders to D1-D1 Shipping C2
D1 Desired Coverage=1
D1 Desired Inventory=   D1 Desired Coverage*D1 Expected New Orders
D1 Desired Supply Line=1
D1 Effective Inventory= D1 Inventory-D1 Backlog
D1 Expected New Orders = SMOOTH3(C1 Orders to D1+C2 Orders to D1, D1 Time
to Average Orders)
D1 Incoming Orders= M Shipping 1
D1 Inventory= INTEG (D1 Incoming Orders-D1 Shipping C1-D1 Shipping C2,
50)
D1 Max Shipping= C1 Orders to D1+C2 Orders to D1+D1 Backlog C1+D1 Backlog
C2
D1 Orders=D1 Adjust for Inventoty+D1 Adjustment for Supply Line+D1
Expected New Orders
D1 Orders placed=D1 Orders
D1 Orders Received=M Shipping 1
D1 Shipping C1= IF THEN ELSE(D1 Max Shipping>D1 Inventory, ((C1 Orders to
D1+D1 Backlog C1)/D1 Max Shipping\)*(D1 Inventory), C1 Orders to D1+D1
Backlog C1)
D1 Shipping C2= IF THEN ELSE(D1 Max Shipping>D1 Inventory, ((C2 Orders to
D1+D1 Backlog C2)/D1 Max Shipping\)*(D1 Inventory), C2 Orders to D1+D1
Backlog C2)
D1 Supply Line= INTEG (D1 Orders placed-D1 Orders Received,50)
D1 Supply Line Accounted for= 0.3
D1 Time to adjust inventory = 3
D1 Time to Average Orders=3
Desired Capacity=max(0,M Adjust for Inventoty+M Expected New Orders)
Duplication=0
M Adjust for Inventoty= (M Desired Inventory-(M Inventory-M Backlog))/M
Time to adjust inventory
M Time to adjust inventory= 3
M Time to Average Orders= 3
Production = Manufacturer Capacity
Time to build Capacity= 4
```