

A New System Dynamics Distribution Network Simulation Model with Uncertain Demands for Analyzing Lead Times Effect

Sahraeian R.¹, Moslemi A²., Jafarinasab A³.

Abstract - In this paper, lead times effects on the supply chain networks while there is uncertainty in demand defined by probabilistic distribution are investigated. Real distribution networks consists of some segments that behavior of each segment can affect whole network. Regularly, the behaviors are not linear and expectable and one parameter can have very bad effect on results of the problem. Therefore, system dynamics simulation can be useful to study the behavior and relationships within a supply chain. Demand is one of the most important parameter involving in whole distribution network, so fluctuation in this parameter can affect all the consequent deductions. In an uncertain demand situation, lead times and their coordination between them are going to be more important and especially in this paper, they are considered precisely. One case is described to define the simulation modeling better. The results show that lead times have significant effect on behavior of whole network.

Keywords - Uncertainty demand; Distribution network; System dynamics; lead time.

1 INTRODUCTION

A supply chain is a complex system which involves multiple components and the main idea discussed in this term is about activities such as moving goods and

¹Rashed Sahraeian (✉)

Department of Industrial Engineering, Shahed University, Tehran, Iran
e-mail: Sahraeian@shahed.ac.ir

² Amir Moslemi

Department of Industrial Engineering, Shahed University, Tehran, Iran

³ Arash Jafari Nasab

Department of Industrial Engineering, Shahed University, Tehran, Iran

adding value from the raw material stage to the final delivery stage. Along the chain, various types of uncertainties exist e.g., demand uncertainty, production uncertainty and delivery uncertainty. Making decisions as to how much and when to replace, often involves a feedback process causing interaction between system segments, which may result in system nonlinearity.

A delay is observed when there is a lag between when a decision is made and when its effect is felt, which often further complicates the interaction between entities. Feedback, interaction, and time delay are inherent to many processes in a supply chain, making it a dynamic system. The mentioned dynamics and complex behaviors in a supply chain can be appropriately modeled by applying the system dynamics approach.

Current research on system dynamics modeling in supply chain management focuses on inventory decision and policy development, compression different types of times, demand amplification, supply chain design and integration, capacity planning of the remanufacturing networks, vendor-managed inventory on transport operations, bullwhip effect and inventory oscillations, and international supply chain management (e.g. (Disney et al., 2003);(Ozbayrak et al., 2007); (Coppini, 2010)). In particular, (Minegishi and Thiel, 2000) used system dynamics modeling and simulation approach to study the complex logistics behavior of the poultry industry.

(Angerhofer and Angelides, 2000) reviewed using the system dynamics modeling in supply chain management. (Heikkilä, 2002) investigated the customer's situation and need considering the right offering contribute to good cooperation. (Hwang and Xie, 2008) investigate how this class of variability, chaos, may occur in a multi-level supply chain and offer insights into how to manage relevant supply chain factors to eliminate or reduce system complexity.

(Kumar and Nigmatullin, 2010)examined the non-perishable product food supply chain performance under a monopolistic environment. A system dynamics approach was used to study the behavior and relationships within a supply chain for a non-perishable product, and to determine the impact of demand variability on supply chain performance.

In this paper, it is considered that the distribution network consists of three main segments. First the orders are received by retailers and if the amount of the orders are larger than the inventory of the retailer's warehouse, it will be sent to the distributor else the order is satisfied by retailers. Like previous stage, if the order is larger than the amount of distributor's inventory, the orders pass to the factory. In this paper, the main idea is evaluating the effect of lead times such as the lead time to deliver the goods to each segment or time to receive the order to each segment by simulation modeling. The simulation based on dynamics systems is applied in this paper to survey the effect of lead times on the main parameters of the model such as size of warehouses and the amount of orders in each stage. In this problem, the demands are not deterministic and it is assumed that it follows probabilistic distribution such as uniform distribution.

This paper is organized as follows: section 2 is dedicated to the modeling the distribution network based on system dynamics approach, in section 3, simulation based on dynamic systems modeling and applying Vensim software is given. The results of simulations are given in section 4. Finally the conclusion is the last section.

2 Modeling the distribution networks

The main aim of distribution network model is investigating the behavior of the supply chain network in which the customers purchase their needs from the retailers, while the retailers are connected to the distributors and order their needs to replenishment their warehouses when the inventory levels in their warehouses are going to decrease. At the final stage, the distributors are connected to the factory and their demands are satisfied in specific periods of time. So the supply chain network defined in this paper consists of three main stages. First stage is retailer, second stage is a group of distributor and the last one is factory. The parameters which are important and effective in this model are such as demand and lead times like time for receiving orders of retailers to distributors, time for receiving orders of distributors to factory, time for delivering products from distributors to retailers and time for delivering products from factory to distributors. The consequent deductions about the network behavior are affected by the distribution of customer's demand and also these lead times. The variables should be investigated in this model are such as the amount of products in warehouses and amount of orders of each segment delivered to next segment in the networks.

The problem which we want to investigate in this model can be defined as follows: In all chain networks, fluctuation in customers demand may have bad effect on whole system. The outcomes can be defined as unlimited increasing in the warehouses' inventory results in increasing cost of inventory holding and also since the warehouses have specific capacity, it should not exceed upper bound level of inventory. Therefore, considering the demands fluctuation, the lead times involving in this model have an important role in whole behavior of network. The coordination of these lead times helps the network to perform well. Since this system is complex and with usual programming we cannot detect the interaction between different segments, suitable tool to simulate this problem is system dynamics simulation.

3. Simulation modeling of distribution networks

The parameters and variables are defined as follows in this section:

Customer orders (CO), Orders received by retailers (ORR), Delivering goods to customers (DGC), Changing in retailers' warehouse (CRW), Retailer's warehouse (RW), Delivering 1, Retailers' orders (RO), Orders received by distributors (ORD), Delivering goods to retailers (DGR), Time for receiving orders to retailers (TROR), Time for delivering goods to retailers (TDGR), Changing in distributor's warehouse (CDW), Distributor's warehouse (DW), Delivering 2, Distributor's orders (DO), Orders received by factory (ORF), Delivering goods to distributors (DGD), Time for receiving orders to distributors (TROD), Time for delivering goods to the distributors (TDGD), Changing in factory's warehouse (CFW), Factory's warehouse (FW), Delivering 3. The simulation model is given in Figure 1 as follows:

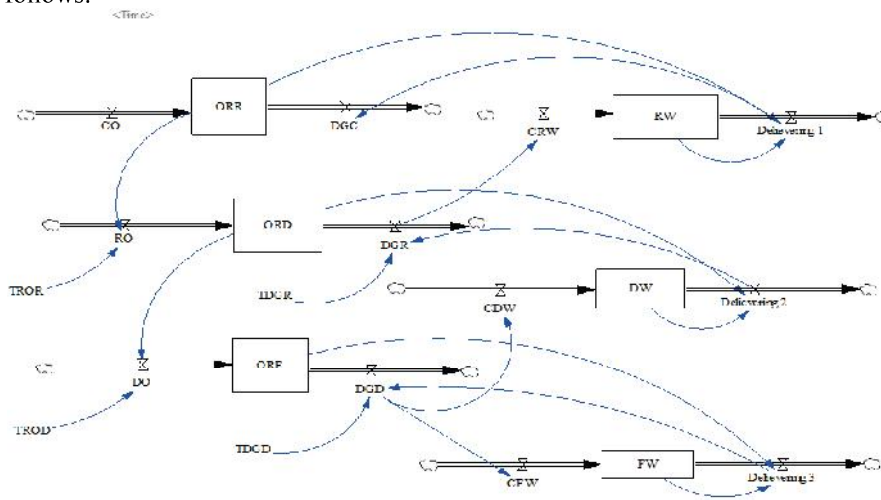


Fig. 1.1 The stock and flow simulation diagram of distribution networks

The variables defined in this model are described as follows:

CO=RANDOM UNIFORM (100, 200, 150),

ORR=CO-DGC,

RW=CRW-Delivering 1,

Delivering 1= IF THEN ELSE (ORR<RW, ORR, RW),

RO=ORR/TROR,

ORD=RO-DGR,

DGR=Delivering 2/TDGR,

DW=CDW-Delivering 2,

Delivering 2= IF THEN ELSE (ORD<DW, ORD, DW),

DO=ORD/TROD,

ORF=DO-DGD,

DGD=Delivering 3/TDGD,

FW=CFW-Delivering 3,

Delivering 3=IF THEN ELSE (ORF<FW, ORF, FW),
 FINAL TIME = 50,
 TIME STEP= 0.125

First series of results after running the model are dedicated to the simulation in which the lead times are as follows:

TROR=1, TDGD=0.4, TROD=0.4, TDGD=1.

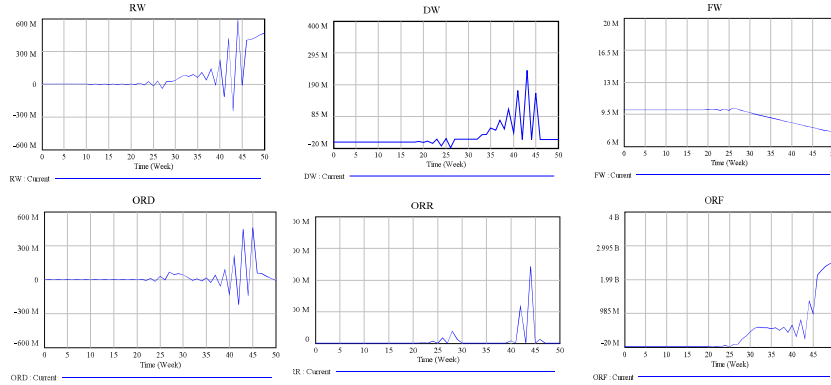
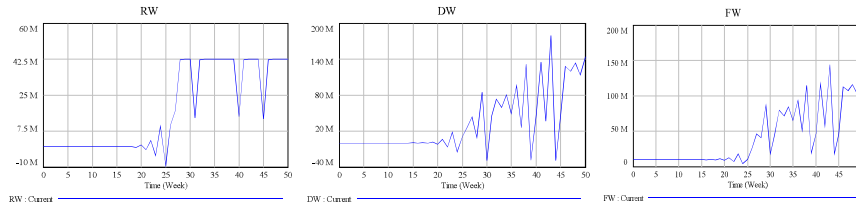


Fig. 1.2 First simulation results with TROR=1, TDGD=0.4, TROD=0.4, TDGD=1

The results show after some large fluctuations and with the mild trend the levels of each variable converge in specific stages. Because the lead time to deliver the products to retailers is smaller than distributors, the stock level in retailer's warehouses and consequently factory's warehouse increase suddenly. These Figures show the behavior of the variables during the time as well as previous ones. The results show increase in retailer's warehouses and distributor's warehouses as well as decrease in factory's warehouse. Also this network is not reliable like previous one although the orders do not fluctuate significantly. The final series of results are dedicated to the simulation in which the lead times are as follows:

TROR=1, TDGD=1, TROD=1, TDGD=1.



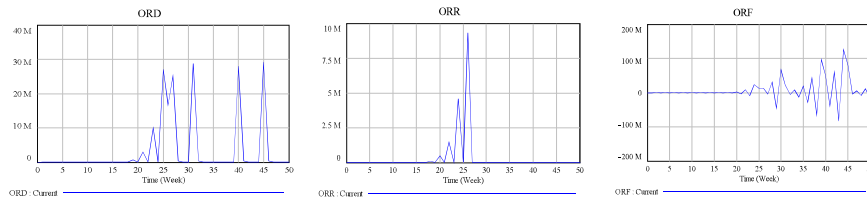


Fig. 1.2 Second simulation results with TROR=0.4, TDGD=1, TROD=1, TDGD=0.4.

Results show after some large fluctuations and with the mild trend the levels of each variable converge in specific stages. Because the lead time to deliver the products to retailers is smaller than distributors, the stock level in retailer’s warehouses and consequently factory’s warehouse increase suddenly. These Figures show the behavior of the variables during the time as well as previous ones. The results show increase in retailer’s warehouses and distributor’s warehouses as well as decrease in factory’s warehouse. Also this network is not reliable like previous one although the orders do not fluctuate significantly. The final series of results are dedicated to the simulation in which the lead times are as follows:

TROR=1, TDGD=1, TROD=1, TDGD=1.

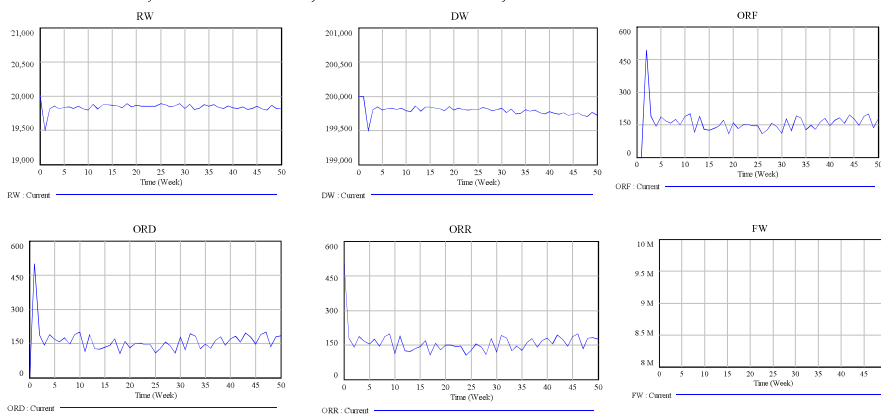


Fig. 1.3 Final simulation results with TROR=1, TDGD=1, TROD=1, TDGD=1.

Finally, we decide to set the lead times on same value and the simulation results show roughly the reliable behavior of the distribution networks. This point is very important that the reliable system is the one in which the variability in the main variables results are not in high level and the whole behavior of the system show smooth levels. The sensitivity analysis based on proposed simulation model is done for different lead times in the proposed simulation model and the results are given in Table1. It is clear that, like previous example, good results and behaviors of the model can be obtained by setting proper combination of the different lead times parameters

Table 1.1 Sensitivity analyses for different lead times

T R O R	T D G R	T R O D	T D G D		ORR (*10 ³)	RW (*10 ⁶)	ORD (*10 ⁶)	DW (*10 ⁶)	ORF (*10 ⁶)	FW (*10 ⁶)
1	1	1	0.4	Min	0.112	-3.691	0	-4.145	-9.893	3.068
				Max	13369	20.375	16.71	87.63	19.135	78.733
1	1	0.4	0.4	Min	0	-6.160	0	-1.679	-57.45	0
				Max	5838	14.130	14.13	136.945	78.4	101
1	0.4	0.4	0.4	Min	0.112	-3.6*10 ¹³	-8.9	-1.6*10 ⁵	-11.3	-3.68*10 ¹³
				Max	2*10 ⁹	0.020	7.7*10 ¹³	0.2	1.9*10 ¹⁴	15.9
0.4	0.4	0.4	1	Min	105	-235	-187	-77.56	-14.54	10
				Max	235000	482	754	214.51	1.61*10 ⁴	10
0.4	0.4	1	1	Min	0.105	-7.28	-6.48	-32.56	-41.54	10
				Max	50441	306	241	64.784	1.47*10 ³	10
0.4	1	1	1	Min	0.124	0.0195	0	0.19955	0	10
				Max	0.193	0.03168	0.00013	0.2	0.0013	10
0.4	1	0.4	0.4	Min	0.107	-7.253	0	-17.165	-97.784	0
				Max	7253	24.267	18.133	188.504	147.587	174
0.4	0.4	0.4	1	Min	0	-278.415	-247.541	-60.74	-60.35	10
				Max	231451	574.845	749.546	23.95	1.61*10 ⁴	10

For each group of input variables, the model runs and the maximum and minimum value of the model are reported. It is clear that while the lead time values have good coordination, the results will have less fluctuation, so the system is more trustworthy to success the customer's needs. Therefore, best answer can be obtained which is given in third example defined in Figure 4.

5 CONCLUSIONS

In an uncertain situation of supply chain networks, lead times and their coordination are very important. Since the behaviors of the networks and interactions between different segments are not easily predictable the system dynamics simulation software like Vensim is applied to model and analyze the networks. Results show that when demand follows uniform distribution, defined lead times should be equal to have balanced network. The sensitivity analysis illustrated that the imbalance in each lead time has bad effects on the network. As a future research, the model can be extended such as adding inventory constraint on warehouses according to types of products and also investigating effect of other types of distribution function for demand.

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