INVENTORY MANAGEMENT COSTS ANALYSIS UNDER DIFFERENT CONTROL POLICIES

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ABSTRACT
The objective of the paper is to use a simulator, implemented in Anylogic™ by *XJ Technologies*, for testing the effect of demand variability, demand intensity and lead time on the inventory management costs within a warehouse.

Keywords: inventory management, costs analysis, Anylogic™

1. INTRODUCTION

Nowadays Inventory Control (*IC*) has a critical role in systems' management: a correct IC allows the manufacturing plant to satisfy customers' demand reducing operation costs; from the other side, IC failures may generate serious consequences, as reported in Lee and Wu (2006).

More in detail, the importance of IC becomes more relevant when applied to the whole Supply Chain (*SC*). For instance, the Bullwhip effect, very frequent along the SC, generates large inventories because of the information distortion amplification as the SC moves to the upstream.

According to Stenger (1996), the effective planning and control of inventories is very difficult in the modern manufacturing systems because the theoretical models adopted, based on several restrictive assumptions, need a great amount of data and lack flexibility.

There is a long history of literature about Inventory Systems (*ISs*).

Lee and Billington (1993) provide a detailed overview on multi-echelon inventories; Cohen and Lee (1988) discuss about the lead time definition for replenishment in a network characterized by a single plant with multiple inputs. Fleischmann et al. (1997) propose a general overview on quantitative approaches for production planning and inventory control systems.

Van der Laan et al. (1996) introduce several approaches based on continuous-review models in which inventory policies parameters are optimized by using queuing theory results. From the other side, Whisler (1967) develop a periodic-review model adopting a dynamic programming approach.

Lee and Wu (2006) make studies on replenishment policies in order to reduce the number of backorder and inventory costs.

Heizer and Render (2001) classify four types of inventory for distinguishing relative costs:

- raw material inventory to reduce suppliers' variability in terms of quality, quantity and delivery time;
- work-in-process inventory for providing production changes;
- maintenance and operating inventory to guarantee the correct running of plants;
- finished products inventory represented by items waiting for shipping.

In addition, several research studies have been made on a specific SC node, as for instance, the warehouse systems. Mason et al. (2003) implement an integrated application for warehouse inventory and transportation management. Chen and Samroengraja (2000) carry out a research study on a warehouse, multi-retailer systems for testing the effectiveness of the two allocation policies adopted and to define their optimal parameters' values. Ahire and Schmidt (1996) analyze the performance of a warehouse, n-retailer system with a continuous review inventory policy.

As before mentioned, the focus of this paper is to present a simulation model for analyzing the performance of a warehouse system in terms of inventory costs under the effect of different demand trends and lead times. In the sequel a brief description of each section of the paper is reported. Section 2 reports the description of the simulation model; Section 3 deals with the inventory policy implemented while an application example is reported in Section 4. Finally, conclusions summarize critical issues and results of the paper.

2. THE SIMULATION MODEL

The simulation model recreates all the most important processes and operations which characterize a warehouse system and it becomes a useful tool for testing and monitoring inventory management costs in function of different inventory policies.

The model is implemented using the commercial package Anylogic™ by *XJ Technologies*.

In particular, for reproducing each process and for increasing model flexibility, different classes have been implemented by using software library objects; in addition, ad-hoc programmed routines implement the logics and rules governing the system.

2.1. The conceptual model

Figure 1 proposes the conceptual model of the warehouse system under analysis.

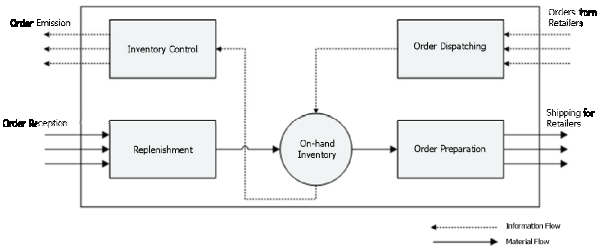

Figure 1: The Warehouse Conceptual Model

As shown in Figure 1, there are two types of data flows:

- the first one related to information flow from retailers;
- the second one concerns items' deliveries from the warehouse to retailers.

In fact, when retailers send orders to the warehouse system, data related to each order are stored in specific databases. After the inventory control, order are processed and items are prepared for deliveries.

2.2. The model setup

Data necessary to model setup are stored in dedicated databases built in Microsoft Excel concerning:

- the trucks arrival time from Suppliers;
- the daily number of trucks from suppliers and for retailers;
- the time interval in which trucks deliver products to the warehouse from Suppliers.
- the shelves levels;
- the number of material handling equipment (i.e. forklifts)
- the shelves capacity
- inventory unitary costs (including manpower)

Such parameters are evaluated before starting the simulation as shown in figure 2.

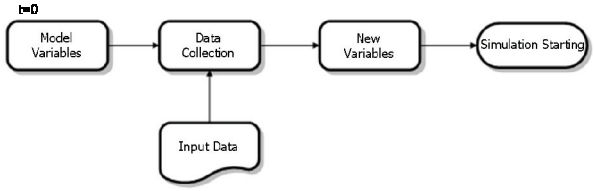

Figure 2: The Model Start-up

The figure 3 shows the orders' processing block diagram.

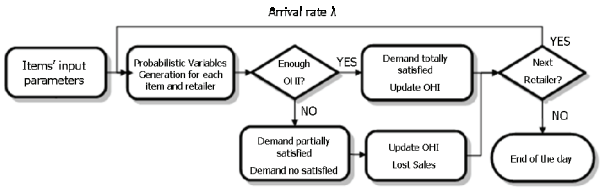

Figure 3: The Orders' Processing Block Diagram

The inter-arrival time Retailers demand is defined by an exponential negative distribution with a λ arrival rate. Each quantity requested is determined by uniform distributions, as reported in Table 1.

Table 1: Probability Distribution for each Retailer

Probability	***Distribution***
P_1	Unif (a_1,b_1)
P_2	Unif (a_2,b_2)
P_n	Unif (a_n,b_n)

P_n is the probability related to retailer demand obtained from the n-th uniform distribution characterized by the two parameters, a_n and b_n. More in detail, each distribution is related to a particular scenario characterized by particular levels of demand intensity and variability and lead times. Next step consists in verifying if the current on-hand inventory (*OHI*) is necessary to satisfy retailers' requests.

Orders can be:

- fully satisfied;
- partially satisfied.

Items number of incoming orders is compared with the OHI. If there is enough OHI, retailers' demand is totally satisfied and an update of the OHI level is made; if demand is partially satisfied or unsatisfied, the OHI is too updated and lost sales are recorded.

Next Section describes the inventory policies implemented in the simulation model for answering to the following questions:

- the time for purchasing order emission;
- the quantity to be ordered.

3. THE INVENTORY POLICIES IMPLEMENTED

The objective of this paper is to compare, by using a Modeling & Simulation based approach, the

performance of a warehouse in terms of inventory costs evaluated in function of three classical different inventory policies:

- the periodic-review, order-up-to-level policy *(R, S)*;
- the periodic-review, order-point, order-up-to-level policy *(R, s, S)*;
- the order-point, order-quantity policy *(s, Q)*.

The notation adopted by authors is the following:

- R_i, review period of the item *i*;
- $S_i(t)$, order-up-to-level at time *t* of the item *i*;
- $s_i(t)$, order-point at time *t* of the item *i*;
- $I_i(t)$, on-hand inventory at time *t* of the item *i*;
- $QO_i(t)$, quantity already on order at time *t* of the item *i*;
- $QS_i(t)$, quantity to be shipped at time *t* of the item *i*;
- $Q_i(t)$, quantity to be ordered at time *t* of the item *i*;
- $D_i(t)$, demand at time *t* of the item *i*;
- LT_i, lead time of the item *i*.

3.1. The periodic-review, order-up-to-level policy *(R,S)*

As reported in Silver et al. (1998), this policy is the classical replenishment cycle policy, particularly adopted by companies not using computer control techniques.

This policy works better when all the items are ordered from the same supplier.

At each review period a control on the Inventory Position ($IP_i(t)$) is made and, if necessary, a quantity is ordered to increase it up to the re-order level $S_i(t)$.

$IP_i(t)$ is evaluated as the on-hand inventory plus the quantity already on order minus the quantity to be shipped:

$$IP_i(t) = I_i(t) + QO_i(t) - QS_i(t) \tag{1}$$

In particular, the re-order level $S_i(t)$ is evaluated in this way:

$$S_i(t) = LTD_i(t) + SS_i \tag{2}$$

where:

- $LTD_i(t)$ is the demand forecast over the lead time;
- SS_i is the safety stock calculated as a standard deviation of the lead time demand.

The quantity to be ordered $Q_i(t)$ is given from the following equation:

$$Q_i(t) = S_i(t) - IP_i(t) = LTD_i(t) + SS_i - IP_i(t) \tag{3}$$

This policy is particularly adopted for production systems characterized by a demand pattern changing with time.

3.2. The periodic-review policy *(R,s,S)*

This policy can be considered as a combination of the order-point, order-up-to-level policy *(s,S)* and of the periodic-review, order-up-to-level policy *(R,S)*.

$IP_i(t)$ is checked every review period so two cases can occur:

- $IP_i(t)$ is at or below the re-order point $s_i(t)$;
- $IP_i(t)$ is above $s_i(t)$.

In the first case the quantity to be ordered is enough to raise the $IP_i(t)$ to $S_i(t)$ while in the second nothing is ordered until the next review.

According to Silver et al. (1998), it is demonstrated that, in function of specific assumptions on demand pattern and cost factors involved, the *(R,s,S)* policy generates total costs lower those of other inventory policies.

More in detail, in this policy the re-order point is evaluated according to equation 4:

$$s_i(t) = LT * \frac{\sum_{t}^{t+R-1} D_i(t)}{R_i} + SS_i \tag{4}$$

while:

$$S_i(t) = \frac{\sum_{t}^{t+R-1} D_i(t)}{R_i} + s_i(t) \tag{5}$$

The quantity to be ordered is:

$$Q_i(t) = S_i(t) - IP_i(t) \tag{6}$$

3.3. The order-point, order-quantity policy *(s,Q)*

This policy is a continuous review policy. The fixed quantity $Q_i(t)$ is ordered when the $IP_i(t)$ equals or it is less than the re-order point $s_i(t)$.

In particular, the quantity to be ordered is defined according to the economic order quantity (*EOQ*).

As it is possible to understand this policy is simple to apply and in particular errors that can occur are very low.

4. THE DESIGN OF EXPERIMENTS

As mentioned into the introduction, the goal of this paper is to use the simulator, implemented in Anylogic™ by *XJ Technologies*, for testing warehouse performance under different operative scenarios in order to understand how changes in some critical input parameters (demand variability and intensity and lead

time) affect inventory costs monitored in function of three different inventory policies.

The total Inventory management costs are evaluated according to equation 7:

$$TMC_i(t) = TFC_i + UCS_i * AHOI_i(t) + UPC_i * LS_i(t) \qquad (7)$$

where:

- TFC_i are the total fixed costs for the item *i*;
- UCS_i is the unitary storage cost for the item *i*;
- $AHOI_i(t)$ represents the average HOI at time *t* for the item *i*;
- UPC_i is the unitary penalty cost for the item *i*;
- $LS_i(t)$ are the lost sales at time *t* for the item *i*.

Each operative scenario is obtained by changing system input parameters between specific values and conditions. In particular, the input parameters are:

- demand intensity (*IN*) which can assume three different conditions (low, medium, high);
- demand variability (*VAR*) which can vary from low to high conditions;
- lead time (*LT*) which can be changed respectively in one day, three and five days.

Table 2 shows factors and levels adopted for the design of experiments (*DOE*).

Table 2: Factors and Levels of DOE

Factors	***Level 1***	***Level 2***	***Level 3***
IN	Low	Medium	High
VAR	Low	Medium	High
LT	1	3	5

Each factor has three levels: in particular, Level 1 indicates the lowest value for the factor, Level 2 the medium value while Level 3 represents the greatest value.

In order to test all the possible factors combinations, the total number of the simulation runs is 3^3 (3 factors x 3 levels x 3 values). Each simulation run has been replicated three times, so the total number of replications is 27 (27x3=81).

5. SIMULATION RESULTS ANALYSIS

In this Section, results analyses for the total inventory management costs evaluated in function of the different inventory policies implemented are reported.

Table 3 shows all the 27 combinations of the input factors; the first three columns report settings indicating the low, medium and high levels for each factor considered while the last columns contain the total inventory costs results provided by the simulation model for the three inventory policies.

Table 3: Output Data for Total Inventory Management Costs

IN	***VAR***	***LT***	***(R,S)***	***(R,s,S)***	***(s,Q)***
Low	Low	1	141944	149464	148585
Medium	Low	1	334906	350763	342885
High	Low	1	550285	557752	534855
Low	Medium	1	166029	163635	160014
Medium	Medium	1	375278	380820	369176
High	Medium	1	601292	616563	567996
Low	High	1	177830	166757	165775
Medium	High	1	407363	411343	392193
High	High	1	754792	639089	651687
Low	Low	3	154986	159391	152598
Medium	Low	3	360885	365780	386033
High	Low	3	576094	585462	559106
Low	Medium	3	177588	173490	172565
Medium	Medium	3	411387	415806	399984
High	Medium	3	669729	658459	628045
Low	High	3	192845	203489	186893
Medium	High	3	441840	438648	436726
High	High	3	709631	732033	709365
Low	Low	5	163045	168096	157921
Medium	Low	5	370033	383555	382664
High	Low	5	607295	612608	598744
Low	Medium	5	186265	191701	184587
Medium	Medium	5	412897	462012	436579
High	Medium	5	747470	721440	700442
Low	High	5	208494	192065	205423
Medium	High	5	467202	502172	508377
High	High	5	754792	837508	723377

5.1. Simulation results analysis for the total inventory management costs – *demand variability*

These results for total inventory management costs are obtained in function of different operative scenarios. Let us consider the case in which demand variability and lead times are kept constants and the demand intensity is varied.

The total inventory management costs comparison in correspondence of low demand variability and lead time of one day shows that the (R,S) and (R,s,S) have a similar performance but the (s,Q) policy performs better because it provides the lowest inventory management costs.

For low variability demand and lead time of three days, the (s,Q) policy performs better than the others for low and high demand intensity while for medium demand intensity the (R,S) policy gives lower inventory management costs than the others policies. This is confirmed by numerical values reported in Table 3.

In correspondence of a lead time of 5 days, the (R,S) policy performs better for low and medium demand intensity, but the (s,Q) policy provides the lowest total inventory management costs for high demand intensity. The (R,s,S) policy gives the highest costs.

The same analysis is carried out changing variability setting to medium and high. In particular, the (s,Q) policy performs better than the others.

5.2. Simulation results analysis for the total inventory management costs – *demand variability*

In this section the authors describe the results related to demand variability; the total inventory management costs are compared keeping constant both demand intensity and lead times.

The demand intensity is set to its lower value and lead time to 5 days. For low and medium demand variability the (s,Q) policy provides the lowest inventory management costs, but for high variability the better policy is the (R,s,S) policy.

The total inventory management costs trend obtained keeping constant demand intensity to its medium value and lead time to 3 days is analyzed. For low demand variability, the (R,S) policy provides the lowest inventory management costs, but for medium and high variability the better policy is the (s,Q) policy.

Keeping fixed intensity to its high setting and lead time to one day, three cases occur:

- for low demand variability the better policy is the (R,S) policy;
- for medium demand variability the better policy is the (s,Q) policy;
- for high demand variability the better policy is the (R,s,S) policy.

5.3. Simulation results analysis for the total inventory management costs – *lead time*

The same analyses have been carried out taking into consideration lead times values and all the combinations of demand intensity and variability. More in detail, in this section, authors presents results related to:

- low demand intensity and variability;
- medium demand intensity and variability;
- high demand intensity and variability.

The total inventory management costs of the three different inventory policies implemented are compared. For low demand intensity and variability, these cases occur:

- for lead time of one day, the (R,S) policy provides the lowest total inventory management costs;
- for lead time of three days, the (s,Q) policy performs better;
- for lead time of five days, the (s,Q) policy guarantees the lowest total inventory management costs.

Figure 12: Total Inventory Management Costs – Low Intensity and Low Variability

For medium demand intensity and variability and for lead time values of one day and 3 days, the three policies provide approximately the same total costs, but for lead time of five days the (R,S) policy provides the lowest inventory management costs.

The total inventory management costs trend for high demand intensity and variability is as follows: the (R,S) policy is the worst policy for lead time of one day; for lead time of three days, the three inventory policies provide approximately the same total inventory management costs while for lead time of 5 days, the best policy is the (s,Q) policy because it provides the smallest total inventory management costs.

6. CONCLUSIONS

In this paper a simulation model of a warehouse system has been developed. The software tool adopted for the model implementation is Anylogic™ by *XJ Technologies*. The goal of the research work consists in testing system behavior under different operative scenarios. The performance parameter chosen is represented by the total inventory management costs evaluated according to three different inventory policies, the *(R,S)*, the *(R,s,S)* and the *(s,Q)*.

The output data of the simulation model allows to understand how demand variability and intensity and lead time affect the total inventory management costs.

Results obtained highlight the weight of each factor in the performance parameter evaluation allowing to choose the best inventory management policy.

REFERENCES

Ahire, S. L., Schmidt, C. P., 1996. A model for a Mixed Continuous-Periodic Review One-Warehouse, N-Retailer inventory system. *Operational Research*, 92, 69 – 82.

Amato, F., Basile, F., Carbone, C., Chiacchio, P., 2005. An Approach to control automated warehouse systems. *Control Engineering Practice*, 13, 1223–1241.

Axsäter, S. 2003. Optimal Policies for Serial Inventory Systems Under Fill Rate Constraints. *Management Science*, 49(2), 247-253.

Baganha, M. P., Cohen, M.,1998. The stabilizing effect of inventory in supply chains. *Operations Research* 46 (3), S72-S73.

Balci, O., 1998. Verification, Validation and Testing, in *Handbook of Simulation*, edited by J. Banks, pp. 335-393, Wiley Interscience: New York.

Ballou R., 2003. *Business Logistics/Supply Chain Management*. Prentice Hall, Readings.

Beamon, B. M. 1999. Measuring supply chain performance.*International Journal of Operations and Production Management* 19 (3), 275-292.

Bertsimas, D., Thiele, A., 2006. A robust Optimization approach to Inventory Theory, *Oper. Res.*, 54(1), 150 – 168.

Birkin, M., Clarke, G., Clarke, M.P, 2002. *Retail Intelligence and Network Planning*. New York: J.Wiley.

Blackwell, R.D., 1997. *From Mind to Market*. New York: Harper-Collins Publisher.

Brunetta, L., Romanin-Jacur, G., 1999. Passenger and baggage flow in an airport terminal: a flexible simulation model. *Air Traffic Management*, 6, 361 – 363.

Bruzzone A.G., Simone S., Bocca E., 2004. Intelligent Management of a Logistics Platform for Fresh Goods. *Proceedings of SCI2004, Orlando, July.*

Bruzzone, A.G., Longo, F., Massei, M., Saetta, S., 2006. The vulnerability of supply chain as key factor in supply chain management. *Proceedings of Summer Computer Simulation Conference* pp. 181-186, Calgary, Canada.

Chan, F.T.S., Chan H.K., 2005. Simulation modeling for comparative evaluation of supply chain management strategies. *Journal of Advanced Manufacturing Technology* 25, 998–1006.

Chang, Y., H. Makatosoris, 2001. Supply chain modelling using simulation, *Int. J. Simulation*, 2001, 2(1), 24 – 30.

Chen, F., Samroengraja, R., 2000. A Staggered Ordering Policy for One-Warehouse, Multiretailer Systems. *Operations Research*, 48 (2), 281 – 293.

Christofides, N., Colloff, I., 1973. The Rearrangement of Items in a Warehouse. *Operations Research*, 21 (2), 577 – 589.

Cohen, M., Lee, H., 1988. Strategic Analysis of integrated production-distribution systems: models and methods. *Operational Research*, 36, 216 – 228.

Cormier, G., Gunn, E.A., 1996. Simple Models and Insights for Warehouse Sizing. *Operational Research*, 47, 690 – 696.

Curcio, D., Longo, F., Mirabelli, G., 2007. Inventory policies comparison in a manufacturing process using modeling & simulation. *Proceedings of the International Mediterranean Modelling Multiconference,* pp. 237 – 242. October 04 – 06, Bergeggi (Italy).

D'Agostino R.B., Stephens, M.A., 1986. *Goodness of fit techniques*, 1986, Marcel Dekker: New York.

Daganzo, C. F., On the stability of the supply chains, *Op. Res.*, 2004, 52(6), 909 – 921.

De Sensi, G., Longo, F., Mirabelli, G., Papoff, E., 2006. Ants colony system for supply chain routes optimization, in the *Harbour, Maritime & Multimodal Logistics Modelling and Simulation Conference*, 763 – 768.

De Sensi, G. , Longo, F., Mirabelli, G., 2007. Inventory policies analysis under demand patterns and lead times constraints in a real supply chain. *International Journal of Production Research*, doi: 10.1080/00207540701528776

Department of Defense, Deputy under Secretary of Defence, DoD modelling and simulation (M&S) management, *DoD Directive 5000.59*, 1994

Dunn R.H., 1987. The quest for software reliability, in *Handbook of software quality assurance*, edited by G.G. Schulmeyer and J.I. McManus, pp. 342 – 384, Van Nostrand Reynold: New york.

Eben-Chaime, M., Pliskin, N., Sosna, D., 1997. Operations management of multiple machine automatic warehousing systems. *Production Economics*, 51, 83–98.

Eben-Chaime, M., Pliskin, N., Sosna, D., 2004. An integrated architecture for simulation. *Computer and Industrial Engineering*, 46, 159–170.

Fleisch, E., Tellkamp, C., 2005. Inventory inaccuracy and supply chain performance: a simulation study of a retail supply chain. *International Journal of Production Economics* 95, 373–385.

Fleischmann, M., Bloemhof-Ruwaard, J.M., Dekker, R., Van der Laan, E., Van Nunen, J.A.E.E., Va Wassenhove, L.N., 1997. Quantitative models for reverse logistics: a Review. *Operational Research*, 103, 1 – 17.

Ganeshan, R., Boone, T., Stenger, A. J., 2001. The impact of inventory and how planning parameters on supply chain performance: An exploratory study. *International Journal of Production Economics* 71, 111–118.

Giannoccaro, I., Pontrandolfo, P., 2002. Inventory management in supply chains: a reinforcement learning approach, *Int. J. Prod. Econ.*, 2002, 78, 153 – 161.

Graves, S.C., Willems, S. P., 2005. Optimizing the Supply Chain Configuration for New Product. *Management Science*, 51(8), 1165–1180.

Heizer, J. and B. Render. 2001. *Operations Management*.6th ed. N.J.: Upper Saddle River.

Hill, R.M., 1989. Allocating Warehouse Stock in a Retail Chain. *Operational Research*, 40 (11), 983 – 992.

Ingalls, R. G., 1998. The value of simulation in modeling supply chain. *Proceedings of the 1998 Winter Simulation Conference,* pp. 1371-1375 Washington D.C.

Johonson N.L., Kotz, S., Balakrishnan, N., 1994. *Continuous Univariate Distributions*, Vol. 1, 2nd ed., Houghton Mifflin: Boston.

Johonson N.L., Kotz, S., Balakrishnan, N., 1995. *Continuous Univariate Distributions*, Vol. 2, 2nd ed., Houghton Mifflin: Boston.

Johonson N.L., Kotz, S., Kemp, A.W., 1992. *Univariate Discrete Distributions*, 2nd ed., Houghton Mifflin: Boston.

Kelle, P., Milne, A. The effect of (s, S) ordering policy on the supply chain, *Int. J. Prod. Econ.*, 59, 113 – 122.

Kreipl, S., Pinedo, M., 2004. Planning and scheduling in supply chains: an overview of Issues in Practise, *Prod. Op. Manag.*, 2004, 13(1), 77 – 92.

Hoare, N. P., Beasley, J. E., 2001. Placing Boxes on Shelves: A Case Study. *Operational Research*, 52 (6), 605 – 614.

Lee, C., Çetinkaya, S., Jaruphongsa, W., 2003. A Dynamic Model for Inventory Lot Sizing and Outbound Shipment Scheduling at a Third-Party

Warehouse. *Operations Research*, 51 (5), 735 – 747.

Lee, H.T., Wu, J.C., 2006. A study on inventory replenishment policies in a two-echelon supply chain system. *Computers & Industrial Engineering*, 51, 257 – 263.

Lee, H., Billington, C., 1993. Material Management in decentralized supply chains. *Operational Research*, 41, 835 – 847.

Li, J., Shaw, M., Sikora, R., Tan, G. W., Yang, R., 2001. *The effects of Information sharing strategies on supply chain performance*, Working paper, University of Illinois Urbana-Champaign.

Liebeskind, A., 2005. *How to Optimize Your Warehouse Operations*. 1st ed. USA: Industrial Data & Information Inc.

Longo, F., Mirabelli, G., Papoff, E., 2005. Modeling Analysis and Simulation of a supply chain devoted to support pharmaceutical business retail, *Proceedings of the 18th International Conference on Production Research, July 31 – August 4 , Salerno, Italy.*

Longo, F., Mirabelli, G., Papoff, E., 2006. Material Flow Analysis and Plant Lay-Out Optimization of a Manufacturing System. *International Journal of Computing*, 5(1), 107-116.

Longo, F., Mirabelli, G., 2008. An Advanced Supply Chain Management Tool Based on Modeling & Simulation, *Computer and Industrial Engineering*, Vol 54(3), 570-588.

Moinzadeh, K., 2002. A Multi-Echelon Inventory System with Information Exchange. *Management Science*, 48(3), 414-426.

Monks, J.G., 1996. *Operations Management*, New york: McGraw Hill.

Montgomery, C.D. and Runger, G.C., 2003. *Applied Statistics and Probability for Engineers*. 3rd ed. USA: John Wiley & Sons.

Mulcahy, D.E., 1993. *Warehouse Distribution and Operations Handbook*. 1st ed. USA: McGraw-Hill.

Nahmias, S., 1982. Perishable Inventory Theory: A Review. *Operations Research*, 30 (4), 680 – 708.

Napolitano, M., Gross, J., 2003. *The Time, Space & Cost Guide to Better Warehouse Design*. 2nd ed. USA: Distribution Group.

O'Leary, D.E., 2000. *Enterprise Resource Planning Systems: Systems, Life Cycle, Electronic Commerce, and Risk*. Cambridge University Press.

Parker, R.P., Kapuscinski, R., 2004. Optimal Policies for a Capacitated Two-Echelon Inventory system, *Op. Res.*, 2004, 52(5), 739 – 755.

Persson, F. , Olhager, J., 2002. Performance simulation of supply chain designs, *International Journal of Production Economics*, 77, 231-245.

Ratliff, H.D., Rosenthal, A.S., 1983. Orderpicking in a rectangular warehouse: a solvable case of traveling salesman problem. *Operations Research*, 31, 507 – 521.

Roberson, J.F, 1994. *Logistics Handbook*. Free Press.

Roundy, R. O., Muckstadt, J. A., 2000. Heuristic computation of periodic-review base stock inventory policies, *Manag. Sc.,* 46(1), 104 – 109.

Sanjay, J., 2004. Supply chain management tradeoffs analysis, *Proceedings of the Winter Simulation Conference*, pp. 1358-1364. Washington (USA).

Seifert, D., Marzian, R., McLaughlin, J., 2003. *Collaborative Planning, Forecasting, and Replenishment: How to Create a Supply Chain Advantage*. Amacom

Silver, E.A., Pyke, D.F., Peterson, R., 1998. *Inventory Management and Production Planning and Scheduling.* 3rd ed. USA: John Wiley & Sons.

Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E. *Designig and Managing the Supply Chain.* McGraw-Hill.

Stadtler, H., Kilger, C., 2000. *Supply chain management and advanced planning*, Springer: Berlin.

Stenger, A.J., 1996. Reducing inventories in a multi-echelon manufacturing firm: a case study. *Production Economics*, 45, 239 – 249.

Suwanruji P., Enns, S.T., 2006. Evaluating the effects of capacity constraints and demand patterns on supply chain replenishment strategies, *Int. J. of Prod. Res.*, 44(21), pp. 4607 – 4629.

Van der Laan, E., Salomon, M., Dekker, R., 1996. Product remanufacturing and disposal: A numerical comparison of alternative strategies. *Production Economics*, 45, 489 – 498.

Whisler, W.D., 1967. A stochastic inventory model for rented equipment. *Management Science*, 13, 640 – 647.

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