WAREHOUSE INVENTORY MANAGEMENT BASED ON FILL RATE ANALYSIS

Antonio Cimino[(a)], Duilio Curcio[(b)], Giovanni Mirabelli[(c)], Enrico Papoff[(d)]

[(a) (b) (c) (d)]Modeling & Simulation Center - Laboratory of Enterprise Solutions (MSC – LES)
M&S Net Center at Department of Mechanical Engineering
University of Calabria
Via Pietro Bucci, Rende, 87036, ITALY

[(a) (b) (c) (d)]{acimino, dcurcio, g.mirabelli, e.papoff}@unical.it

ABSTRACT
The focus of this paper is the warehouse inventory management considering three inventory control policies under the effect of different demand patterns and lead times. The behavior of the inventory control policies in terms of fill rate is tested and the relationship between the policies and the demand patterns and lead time is evaluated.

Keywords: warehouse inventory management, inventory control policies, fill rate, Modeling & Simulation

1. INTRODUCTION

Different research studies on warehouse systems' design, planning and control have been carried out during the last years. Ratliff and Rosenthal (1983) address the problem of order-picking in a rectangular warehouse with crossovers only at the end of the aisles. Cormier and Gunn (1996) examine simple analytical models to find the unique warehouse size that satisfies some service requirements or minimizes costs. Chen and Samroengraja (2000) carry out a research study on a warehouse, multi-retailer systems for testing the effectiveness of two allocation policies and to define their optimal parameters values. Roodbergen and De Koster (2001) introduce a routing algorithm for finding the shortest order picking tour within a warehouse. Amato et al. (2005) asses the difference between planning and control activities; planning activities include items assignment to shelves levels and warehouse design problems, control activities are related to activities scheduling and deliveries monitoring. Hsieh and Tsai (2006) implement a simulation model for finding the optimum design parameters of a real warehouse system.

Concerning the inventory management and optimal items allocation on the shelves, Christofides and Colloff (1973) implement an algorithm for achieving the desired rearrangement of items minimizing items movements and costs; Ahire and Schmidt (1996) analyze the performance of a warehouse, n-retailer system with a continuous review inventory policy. Hoare and Beasley (2001) carry out a research study on a system development for the effective design of stockroom layouts.

The main goal of this paper is to analyze three different inventory control policies within a warehouse under the effect of different demand patterns and lead times. The performance measure being considered for monitoring policies behavior is the fill rate. The authors develop a simulation model of the warehouse, implement the inventory control policies and perform a number of simulation experiments (supported by statistical techniques) for achieving the objective above mentioned. Before getting into the details of the study, a brief summary of the paper is presented. Section 2 reports a description of the analytical models of the inventory control policies; section 3 describes the warehouse simulation model; section 4 presents the analysis of the inventory control policies under the effect of demand patterns and lead times; finally, conclusions summarize critical issues and results of the paper.

2. THE INVENTORY CONTROL POLICIES

The inventory control policies being considered are the following:

- 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)*.

In the sequel a brief description of each inventory control policy is reported. The following notation is used:

- 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.

2.1. 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 inventory control policy is particularly used when the demand pattern changing with time.

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

This policy has to be regarded 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, under specific assumptions on demand pattern and cost factors, the *(R,s,S)* policy generates total costs lower than other inventory control 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:

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

2.3. 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 lower than the re-order point $s_i(t)$. In particular, the quantity to be ordered is defined according to the economic order quantity (*EOQ*).

3. THE SIMULATION MODEL

A general warehouse simulation model describes the system under study in details, but it can lacks in some aspects like flexibility: a warehouse simulation model implemented to satisfy specific requests could not be applied to solve problems of a warehouse system different from that considered. From the other side, a generalized flexible simulation model could be applied to analyze general problems of warehouse systems under different operative scenarios.

The simulation model implemented by the authors aims at achieving a certain level of flexibility in order to be adopted easily for studying similar warehouse systems and to provide the user with a tool for investigating the warehouse behavior under different operative conditions. In effect, the simulation model proposed by authors reproduces all the most important processes and operations that take place inside a warehouse. One of the performance measure monitored by the simulation model is the fill rate (the performance measure for monitoring inventory control policies behavior).

3.1. The model architecture

As before mentioned, the simulation model presented in this research work reproduces all the most important processes and operations of a warehouse:

- orders processing and picking;
- trucks arrival and departure;
- data collection and monitoring (number of handled packages, trucks waiting times and service levels, fill rate, etc.).

The software tool adopted for the simulation model implementation is 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 the software library. In addition, ad-hoc programmed routines have been written for implementing all the logics and rules governing the system.

4. DEMAND PATTERNS AND LEAD TIME CONSTRAINTS

The behavior of the three inventory control policies has been investigated under the effect of different demand patterns and lead time constraints. The following factors and notation have been considered:

- 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.

The combinations of such parameters' values provide different operative scenarios and affect the fill rate values of the warehouse system. For evaluating the effect of each possible factors level combination on the performance measure (the fill rate), the Full Factorial Experimental Design is adopted. Table 1 shows factors and levels adopted for the design of experiments.

Table 1: Factors and Levels of DOE

Factors	*Level 1*	*Level 2*	*Level 3*
IN	Low (-1)	Medium (0)	High (+1)
VAR	Low (-1)	Medium (0)	High (+1)
LT	1 (-1)	3 (0)	5 (+1)

As shown in Table 1, each factor has three levels: in particular, Level 1 (-1) indicates the lowest value for the factor, Level 2 (0) the medium value while Level 3 (+1) 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 twice, so the total number of replications is 27 (27x2=54).

The analysis of the simulation results is proposed in the following section.

5. SIMULATION RESULTS ANALYSIS

The results of the simulation model have been analyzed by means of ANOVA and of several graphical methods. The ANOVA partitions the total variability of the performance index in different components due to the influence of the factors considered. According to Montgomery and Runger (2003), the total variability in the data, measured by the total corrected sum of squares SQ_T, can be partitioned into a sum of squares of differences between treatment (factor level) means and the grand mean denoted $SQ_{Treatments}$ and a sum of squares of differences of observations within a treatment from the treatment mean denoted SQ_E, as reported in equation 7.

$$SQ_T = SQ_{Treatments} + SQ_E \quad (7)$$

More in detail, the difference between observed treatment means and the grand mean defines differences between treatments, while observations' differences within a treatment from the treatment mean can be due only to random errors. As a consequence, examiners can understand how each factor impacts on the performance index introducing an analytical relation (called *meta-model* of the simulation model) between the performance index and factors. In particular, the relation for a three-factor-factorial experiment is:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i x_i + \sum_{i=1}^{3} \sum_{j>i}^{3} \beta_{ij} x_i x_j + \sum_{i=1}^{3} \sum_{j>i}^{3} \sum_{k>j}^{3} \beta_{ijk} x_i x_j x_k + \varepsilon_{ijkn} \quad (8)$$

where:

- Y is the performance index;
- β_0 is a constant parameter common to all treatments;
- $\sum_{i=1}^{3} \beta_i x_i$ are the three main effects of factors;
- $\sum_{i=1}^{3} \sum_{j>i}^{3} \beta_{ij} x_i x_j$ are the three two-factor interactions;
- $\sum_{i=1}^{3} \sum_{j>i}^{3} \sum_{k>j}^{3} \beta_{ijk} x_i x_j x_k$ represents the three-factor interaction;
- ε_{ijkn} is the error term;
- n is the number of total observations.

In this research study, ANOVA is adopted for a twofold reason:

- during the first step, it is used as a screening tool in order to determine which factors are most significant on the fill rate (*sensitivity analysis*);
- subsequently, ANOVA is used for investigating the effect of the most significant factors in order to evaluate the coefficients of the input-output meta-model reported in equation 8.

5.1. Simulation results analysis for the fill rate – *(R,S)* inventory policy

Table 2 shows all the 27 combinations of the input factors; the first three columns report the experimental design matrix while the last column reports the simulation results in terms of fill rate (one replication) for the *(R, S)* policy

Table 2: Experimental design matrix and simulation results for the Fill Rate – *(R,S)* policy

IN	*VAR*	*LT*	*(R,S)*
-1	-1	-1	0,931
-1	-1	0	0,896
-1	-1	1	0,881
-1	0	-1	0,901
-1	0	0	0,896
-1	0	1	0,892
-1	1	-1	0,895
-1	1	0	0,883
-1	1	1	0,868
0	-1	-1	0,899
0	-1	0	0,895
0	-1	1	0,878
0	0	-1	0,899
0	0	0	0,899
0	0	1	0,886
0	1	-1	0,889
0	1	0	0,87
0	1	1	0,878
1	-1	-1	0,87
1	-1	0	0,877
1	-1	1	0,876
1	0	-1	0,87
1	0	0	0,87
1	0	1	0,863
1	1	-1	0,859
1	1	0	0,869
1	1	1	0,859

Table 3 reports the sensitivity analysis results provided: the non-negligible effects are characterized by a *p-value* $\leq\alpha$ where p is the probability to accept the hypothesis that the factor has no impact on the performance index and α=0.05 is the confidence level adopted in the analysis of variance. In this table:

- the first column reports the sources of variations;
- the second column is the degree of freedom (*DOF*);
- the third column is the Sum of Squares;
- the 4th column is the Mean Squares;
- the 5th column is the Fisher statistic;
- the 6th column is the p-value.

Table 3: Sensitivity Analysis Results – *(R,S)* policy

Source	***DF***	***Adj SS (10^{-4})***	***Adj MS (10^{-4})***	***F***	***P***
IN	2	32,51	16,25	21,5	0,001
VAR	2	10,98	5,49	7,26	0,016
LT	2	9,72	4,86	6,43	0,022
IN*VAR	4	1,88	0,47	0,62	0,658
IN*LT	4	6,83	1,70	2,26	0,152
VAR*LT	4	1,33	0,33	0,44	0,777
Error	8	6,05	0,75		
Total	26				

In this case the most significant effects are the first order effects because their p-value is lower than the confidence level. Table 4 shows the coefficients for the input-output meta-model (equation 8). In particular, for each factor the first coefficient value represents the slope of the straight line between its low and medium levels while the value in the column (0) is the slope of the straight line for medium and high factor levels.

Table 4: ANOVA Coefficients – *(R,S)* policy

Term	***Coefficient***	
	(-1)	***(0)***
Constant	0,883296	
IN	0,010370	0,004815
VAR	0,005926	0,002926
LT	0,007037	0,000593

Equation (9) reports the input-output meta-model for the performance parameter (the warehouse fill rate) when input parameters change between low and medium levels:

$$Y_{ijkn} = 0{,}883296 + 0{,}010370 * IN + + 0{,}005926 * VAR + 0{,}007037 * LT \quad (9)$$

Figure 1 shows the fill rate trend in function of the three main effects: the fill rate decreases when demand intensity and variability and lead time increase; in particular, the performance index decreases more rapidly when demand intensity and variability changes from medium to high values.

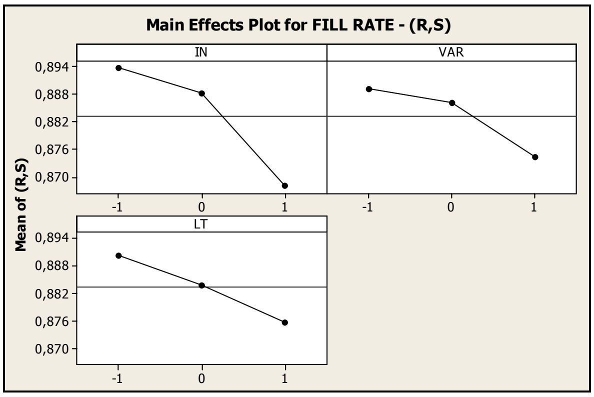

Figure 1: Fill Rate versus Main Effects – *(R,S)* policy

Figure 2 shows the plots concerning the interaction between the main effects. For example, the interaction between demand intensity and variability becomes greater when variability changes from low to medium values while for medium and low variability values the two lines (the black and the red one) are flush. From the other side, the interaction between variability and lead time is more marked when lead time changes from medium to high values.

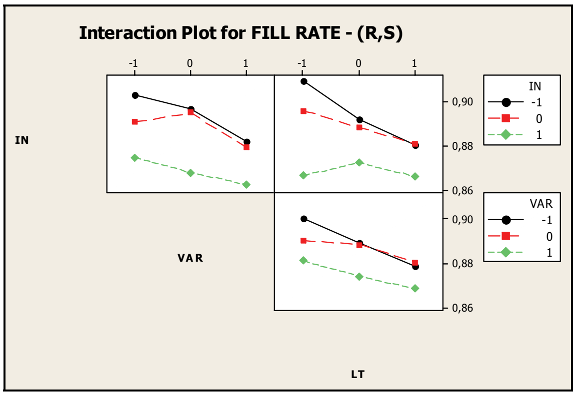

Figure 2: Interaction Plots for Fill Rate

5.2. Simulation results analysis for the fill rate – *(R, s, S)* inventory policy

Table 5 shows all the 27 combinations of the input factors; the first three columns report the experimental design matrix while the last column reports the simulation results in terms of fill rate (one replication) for the *(R,s,S)* policy. The sensitivity analysis is reported in Table 6: considering a *p-value* ≤ 0.05, the most significant effects are the first order effects. The ANOVA coefficients for the input-output meta-model are displayed in Table 7.

Table 5: Experimental design matrix and simulation results for the Fill Rate – (R,s,S) policy

IN	*VAR*	*LT*	*(R,s,S)*
-1	-1	-1	0,99
-1	-1	0	0,944
-1	-1	1	0,93
-1	0	-1	0,967
-1	0	0	0,941
-1	0	1	0,925
-1	1	-1	0,956
-1	1	0	0,942
-1	1	1	0,937
0	-1	-1	0,973
0	-1	0	0,957
0	-1	1	0,938
0	0	-1	0,952
0	0	0	0,932
0	0	1	0,923
0	1	-1	0,957
0	1	0	0,935
0	1	1	0,907
1	-1	-1	0,961
1	-1	0	0,954
1	-1	1	0,932
1	0	-1	0,936
1	0	0	0,927
1	0	1	0,908
1	1	-1	0,934
1	1	0	0,914
1	1	1	0,917

Table 6: Sensitivity Analysis Results – (R,s,S) policy

Source	*DF*	*Adj SS* (10^{-4})	*Adj MS* (10^{-4})	*F*	*P*
IN	2	12,53	6,26	7,39	0,015
VAR	2	22,50	11,25	13,2	0,003
LT	2	53,52	26,76	31,6	0,000
IN*VAR	4	2,92	0,73	0,86	0,526
IN*LT	4	3,11	0,77	0,92	0,499
VAR*LT	4	1,31	0,32	0,39	0,812
Error	8	6,78	0,84		
Total	26				

Table 7: ANOVA Coefficients – (R,s,S) policy

Term	*Coefficient*	
	(-1)	*(0)*
Constant	0,940	
IN	0,007667	0,001222
VAR	0,012889	-0,005778
LT	0,018111	-0,001889

The input-output meta-model for the *(R,s,S)* policy is:

$$Y_{ijkn} = 0{,}94 + 0{,}007667 \, * IN + \\ + 0{,}012889 \, * VAR + 0{,}018111 \, * LT \qquad (10)$$

As showed in Figure 3, the fill rate decreases when demand intensity and variability and lead time change from low to medium levels while it remains approximately constant when variability goes from medium to high levels.

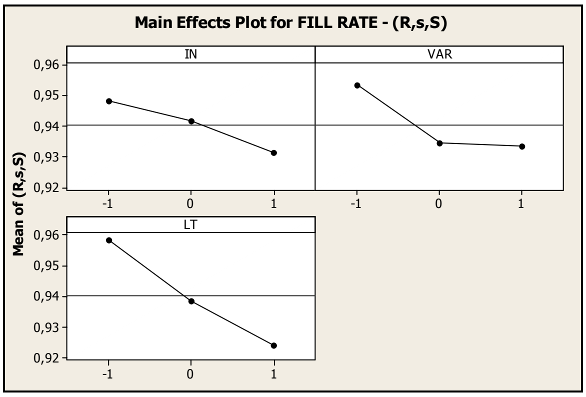

Figure 3: Fill Rate versus Main Effects

5.3. Simulation results analysis for the fill rate – *(s,Q)* inventory policy

The sensitivity analysis results for the *(s,Q)* policy are reported in Table 8.

The most significant effects are the first order effects and the interaction between the demand intensity and the lead time. Introducing coefficients provided by means of ANOVA, it is possible to evaluate the input-output meta-model (equation 11) for the *(s,Q)* policy (considering the slope of the straight line when each factor changes between its medium and high levels;

Table 8: Sensitivity Analysis Results – (S, Q) policy

Source	***DF***	***Adj SS (10^{-4})***	***Adj MS (10^{-4})***	***F***	***P***
IN	2	6,99	3,49	10,3	0,006
VAR	2	7,21	3,60	10,6	0,006
LT	2	4,39	2,19	6,48	0,021
IN*VAR	4	4,27	1,06	3,15	0,078
IN*LT	4	6,25	1,56	4,61	0,032
VAR*LT	4	1,65	0,41	1,22	0,373
Error	8	2,71	0,33		
Total	26				

similar coefficients have been found between low and medium levels).

$$Y_{ijkn} = 0{,}876 + 0{,}002852 * IN + \\ + 0{,}006741 * VAR - 0{,}00081 * LT + \\ - 0{,}003519 * (IN * LT) \qquad (11)$$

The validity of results obtained from the ANOVA analysis is still confirmed by the Residuals Analysis.

More in detail:

- the assumption of normality has besn tested using a Normal Probability Plot. The residuals approximately fall along a straight line, consequently the deviation from normality is not severe;
- the assumption of independence has been tested by using the Residuals versus the Order of the Data plot: no positive or negative residuals sequences have been identified;
- the hypothesis of equal variance has been tested by using the Residuals versus the Fitted Values plot: residuals variability doesn't depend on the fitted value;
- the hypothesis of residuals normally distributed has been tested by using the Histogram of the Residuals: the residuals appear as normally distributed.

6. CONCLUSIONS

The main goal of this paper is to analyze three different inventory control policies within a warehouse under the effect of different demand patterns and lead times. The performance measure being considered for monitoring policies behavior is the fill rate. The authors develop a flexible simulation model of a warehouse, implement the inventory control policies and perform a number of simulation experiments (supported by statistical techniques).

The experimental results analyzed by means of ANOVA show that the inventory control policies perform differently in relation to demand intensity and variability levels and lead time values. In addition for each scenario and for each inventory control policy analytical relationships that express the fill rate as function of the demand intensity, demand variability and lead time have been evaluated.

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AUTHORS BIOGRAPHIES

ANTONIO CIMINO was born in Catanzaro (Italy) in October the 1th, 1983. He took his degree in Management Engineering, summa cum Laude, in September 2007 from the University of Calabria. He is currently PhD student at the Mechanical Department of University of Calabria. His research activities concern the integration of ergonomic standards, work measurement techniques, artificial intelligence techniques and Modeling & Simulation tools for the effective workplace design. He collaborates with the Industrial Engineering Section of the University of Calabria to research projects for supporting innovation technology in SMEs. His e-mail address is <acimino@unical.it>.

DUILIO CURCIO was born in Vibo Valentia (Italy), on December the 15th, 1981. He took the degree in Mechanical Engineering from University of Calabria (2006). He is currently PhD student at the Mechanical Department of University of Calabria. His research activities include Modeling & Simulation and Inventory Management theory for production systems and Supply Chain design and management. He collaborates with the Industrial Engineering Section of the University of Calabria to research projects for supporting Research and Development in SMEs. His e-mail address is <dcurcio@unical.it>.

GIOVANNI MIRABELLI was born in Rende (Italy), on January the 24th, 1963. He took the degree in Industrial Technology Engineering from University of Calabria. He is currently researcher at the Mechanical Department (Industrial Engineering Section) of University of Calabria. His research interests regard work measurement and human reliability. His e-mail address is <g.mirabelli@unical.it>.

ENRICO PAPOFF was born in Naples (Italy) on February the 03rd, 1948. He took the degree in Mechanical Engineering from University of Napoli Federico II, in 1973. He is currently Associate Professor at the Mechanical Department (Industrial Engineering Section) of the University of Calabria. His research interests regard project management and business plans.