WAREHOUSE MANAGEMENT: INVENTORY CONTROL POLICIES COMPARISON

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ABSTRACT
This paper aims at investigating the effect of some parameters (i.e. the demand intensity, the demand variability and the lead time) on three different inventory control policies. To this end a parametric simulator is implemented in order to perform what-if analyses and scenarios investigation. The performance parameter chosen for the inventory management policies comparison is the unit inventory management cost. Finally, the analytical relationship between the unit inventory management cost and the input parameters is determined.

Keywords: Warehouse Management, Inventory Policies, Simulation, DOE, ANOVA

1. INTRODUCTION

According to literature warehouse management and internal logistics planning and control received, during the last years a great deal of attention. Van den Berg (1999) presents a literature survey on methods and techniques for planning and control of warehouse systems. Planning and control deal from one side with long-term goals, supply chain organization and warehouse design, from the other with inventory management and control policies with the aim of storing the correct quantity of products as well as determining the optimal time for placing purchase orders (considering production and transportation lead times).

Ashayeri and Gelders (1985) propose a review of different warehouse design models. Other research studies deal with the inventory management problem within warehouses: Hariga and Jackson (1996) present a review of inventory models for warehouse management while Van Oudheusden, Tzen, and Ko (1988), Frazelle, Hackman, Passy and Platzman (1994), Brynzér and Johansson (1995) investigate the advantages (in terms of productivity enhancement) due to a correct warehouse planning and control.

In addition, recent research studies regard data/information management in warehouse systems: Eben-Chaime and Pliskin (1997) investigate the effect of operations management tactics on performance measures of automatic warehousing systems with multiple machines.

The main goal of this paper is to compare three different inventory control policies in a warehouse located within an industrial plant devoted to produce different types hazelnuts based products. The inventory control policies are compared under different demand and lead time constraints using as performance measure the inventory management cost. As support tool the authors implemented as simulator that recreates stochastic scenarios based on different demand intensity, demand variability and lead time values.

The overall structure of the paper is as follows. Section 2 describes the hazelnut production process and the main warehouse technical characteristics. Section 3 describes the simulation model implementation. The inventory policies adopted are discussed in Section 4. Section 5 reports simulation results analysis and scenarios comparison. Finally, concluding remarks are given in Section 6.

2. THE WAREHOUSE SYSTEM

This research work aims at investigating and comparing three classical inventory control policies within a warehouse used to store hazelnuts in order to select the more efficient policy in terms of unit inventory management costs (*UICs*).

The warehouse has a rectangular shape with a surface of about 300 m^2 (the industrial plant surface is about 2000 m^2). Figure 1 shows the industrial plant layout (red arrows shows the material flow through the different work station).

The plant layout is subdivided in 8 different areas/department each one including different workstations carrying out the following main operations:

- ✓ pre-cleaning;
- ✓ drying;
- ✓ calibration;
- ✓ shelling;
- ✓ selection;
- ✓ roasting;
- ✓ graining;
- ✓ pasting;
- ✓ packaging.

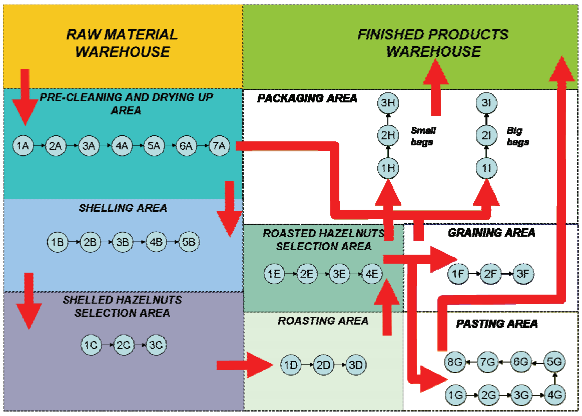

Figure 1: The Layout of the Manufacturing System

Figure 2 shows the flow chart of the production process including all the main operations.

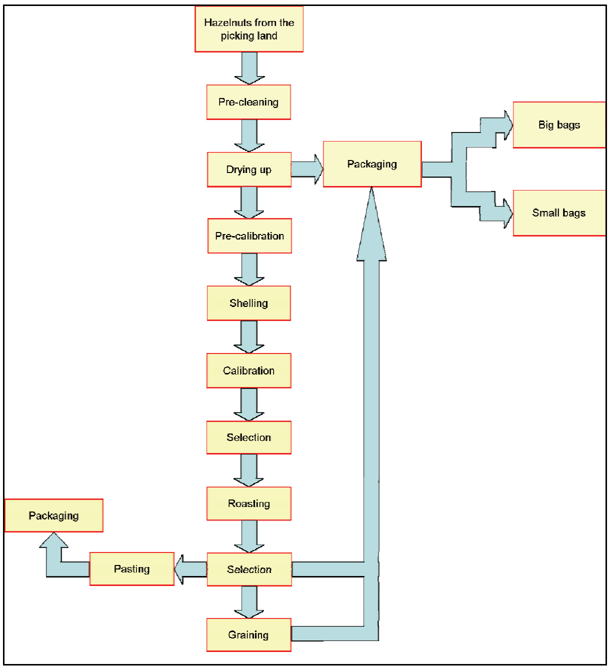

Figure 2: The production process flow chart

As before mentioned, the goal of this research work consists in monitoring the performance of three classical inventory management policies for understanding how some critical parameters (demand intensity, demand variability and lead time) affect the unit inventory management costs.

3. THE WAREHOUSE SIMULATION MODEL

Longo and Mirabelli (2008) and De Sensi et al. (2008) in their research work highlight the importance of simulation as an effective tool for inventory management problems and control policies comparison.

In fact, the use of simulation allows to explore and experiment possibilities for evaluating how the system under consideration reacts in correspondence of internal or external changes. As a consequence, one specific feature of the simulation model must be the flexibility for a complete scenarios design and analysis.

Bocca et al. (2008) implement a simulation model of a real warehouse highlighting the importance of building flexible simulation models while Cimino et al. (2008) analyze the performance of a real warehouse by monitoring its performance under different system configurations and by considering as performance measure the fill rate level.

The warehouse simulation model presented in this paper has been implemented by using Anylogic™ by *XJ Technologies* and it reproduces all the main warehouse operations. Warehouse main operations include trucks arrival and departure for items deliveries and internal materials handling operations. The simulation model implements different performance measures, including waiting times for suppliers' trucks and inventory costs.

4. THE INVENTORY CONTROL POLICIES

The objective of an inventory control policy is twofold:

- ✓ evaluation of the time for order emission;
- ✓ evaluation of the quantity to be ordered.

The focus of this paper is to test the effect of the demand intensity, the demand variability and the lead time on three different inventory control policies by using as support tool the simulation model before presented. The authors implement within the simulation model the following three inventory control policies:

- the reorder time-order quantity policy (*RTOQ*);
- the reorder point-order quantity policy (*RPOQ*);
- the (s, S) policy.

4.1. The analytical models of each inventory policy

Before introducing the analytical model of each inventory control policy, let us introduce the following notation:

- *s(t)*, the re-order level at time *t*;
- *S(t)*, the target level at time *t*;
- *SS(t)*, the safety stock level at time *t*;
- *DF(t)*, the demand forecast at time *t*;
- *OHI(t)*, the on-hand inventory at time *t*;

- *OQ(t)*, the quantity already on order at time *t*;
- *SQ(t)*, the quantity to be shipped at time *t*;
- *Q(t)*, the quantity to be ordered at time *t*;
- *L(t)*, the lead time;
- *DFL(t)*, the demand forecast over the lead time;
- *IP(t)*, the inventory position at time *t*.

The inventory position *IP(t)* is the on-hand inventory plus the quantity already on order minus the quantity to be shipped. In particular, it is defined as:

$$IP(t) = I(t) + QO(t) - QS(t) \quad (1)$$

4.1.1. The Reorder Time-Order Quantity (RTOQ) Policy

The RTOQ inventory control policy is based on a periodic check. If *T(t)* is the review period, the quantity to order is defined by *S(t)* minus *IP(t)*. The value of *T(t)* can be defined using the inverse formula usually used for evaluating the Economic Order Quantity (EOQ), refer to Silver et al. (1998).

$$Q(t) = S(t) - IP(t) = DFL(t) + SS - IP(t) \quad (2)$$

In this policy, *S(t)* represents the target level. This policy should be used when the inventory level is not automatically monitored, there are advantages related to scale economy, and orders are not regular.

4.1.2. The (s(t), S(t))Policy

This policy can be derived from the previous policy. According to literature, there are two main parameters:

- *s(t)*, the re-order level at time *t*;
- *S(t)*, the target level at time *t*.

IP(t) is checked periodically on the basis of the review period so two cases can occur:

- *IP(t)* is at or below the re-order point *s(t)*;
- *IP(t)* is above *s(t)*.

In the first case the quantity to be ordered (see equation 3) should be enough to raise the $IP_i(t)$ to $S_i(t)$ while in the second case no orders are placed.

$$Q(t) = S(t) - IP(t) \quad (3)$$

According to Silver et al. (1998), it is demonstrated that, under specific assumptions on demand pattern and cost factors, the *(s(t), S(t))* policy generates total costs lower than other inventory control policies.

4.1.3. The Reorder Point-Order Quantity (RPOQ) Policy

In this control policy, the inventory level is continuously checked according to production/demand requirements.

If *IP(t)* falls below the *s(t)*, a purchase order must be placed. The quantity to be ordered is defined using the Economic Order Quantity (*EOQ)* approach as reported in Silver et al. (1998).

$$s(t) = DFL(t) + SS(t) \quad (4)$$

$$Q(t) = EOQ(t) \quad (5)$$

Such policy should be adopted when inventory level is automatically monitored. There are no scale economies advantages and purchase orders can be regularly placed.

5. SCENARIOS DEFINITION AND DESIGN OF SIMULATION EXPERIMENTS

As before mentioned, the objective of this research work consists in evaluating how some input parameters affect the performance of the three inventory control policies before presented, in terms of unit inventory management costs (*UICs*). For each scenario the input parameters vary between specific values and conditions. In particular, the input parameters are:

- demand intensity (*DI*) which can assume three different conditions (low, medium, high);
- demand variability (*DV*) which can assume three different conditions (low, medium, high);
- lead time (*LT*) which can assume the following values be changed respectively in one day, three and five days.

The experiments planning is supported by the Design of Experiments (*DOE*) methodology; in particular, the Full Factorial Experimental Design is adopted.

Factors and levels for the design of experiments (*DOE*) are showed in Table 1.

Table 1: Factors and Levels of DOE

Factors	*Level 1*	*Level 2*	*Level 3*
DI	Low	Medium	High
DV	Low	Medium	High
LT	1	3	5

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

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

6. SIMULATION RESULTS ANALYSIS

This section presents the simulation experiments results. The behaviour of the inventory control policies has been studied by using the Analysis of Variance (*ANOVA*) supported by some statistical charts. A similar approach is also proposed in Curcio and Longo (2009).

The ANOVA is used for understanding the analytical relationship between the input factors and the unitary inventory management costs by introducing an analytical relationship (the *meta-model* of the simulation model) between the performance measure and the factors being considered.

Let x_i ($x_1 = DI$, $x_2 = DV$, $x_3 = LT$) be the factors, equation 6 expresses the UIC as linear function of the x_i.

$$UIC = \beta_0 + \sum_{i=1}^{3}\beta_i x_i + \sum_{i=1}^{3}\sum_{j>i}^{3}\beta_{ij}x_i x_j + \\ + \sum_{i=1}^{3}\sum_{j>i}^{3}\sum_{h>j}^{3}\beta_{ijh}x_i x_j x_h + \varepsilon_{ijhkpn} \qquad (6)$$

Equation 6 only considers the interaction terms up to order 3 plus an error term without considering the fourth and fifth order effects (usually such effects can be neglected). The main goal of the analysis of variance is twofold:

- to identify those factors which affect the UIC (sensitivity analysis);
- to evaluate the coefficients of equation 6 for defining the analytical relationship between the input and the output parameter.

Table 2 reports the results of the simulation experiments (the UIC) in correspondence all the factors levels combinations. The first three columns represents the experiments design matrix, while the last three columns reports the unit inventory management costs for each inventory control policy.

6.1. Simulation results for the RTOQ inventory control policy

In this section, simulation results for the first inventory policy (the reorder time-order quantity policy) are presented. The first step aims at detecting all those factors that influence the UIC. The confidence level adopted for estimating output data significance level is α=0.05 (according to the ANOVA theory the non-negligible effects are characterized by a *p-value* ≤ α where *p* is the probability to accept the negative hypothesis, i.e. the factor has no impact on the performance index). The results of the sensitivity analysis are reported in Table 3: the most significant effects are the first order effects because (their p-value is lower than the confidence level).

According to the ANOVA results, the second phase consists in introducing the analytical relationship between the input and the output parameters. Table 4 shows the coefficients for the input-output meta-model (equation 6).

Table 2: Simulation Results for the UIC

IN	*VAR*	*LT*	*RTOQ*	*(s,S)*	*RPOQ*
Low	Low	1	5,092	5,03	5,52
Medium	Low	1	5,06	5,008	5,181
High	Low	1	5,281	4,856	5,283
Low	Medium	1	6,06	5,62	6,08
Medium	Medium	1	5,633	5,673	5,727
High	Medium	1	5,965	5,655	5,923
Low	High	1	6,69	6,16	6,61
Medium	High	1	6,343	5,992	6,307
High	High	1	7,582	6,229	6,649
Low	Low	3	5,66	5,727	5,973
Medium	Low	3	5,4	5,287	5,66
High	Low	3	5,613	5,244	5,548
Low	Medium	3	6,59	6,551	6,701
Medium	Medium	3	6,74	5,997	6,405
High	Medium	3	6,692	6,267	6,398
Low	High	3	7,35	7,3	6,8
Medium	High	3	7,118	6,71	7,019
High	High	3	7,252	7,111	6,989
Low	Low	5	6,28	6,2	6,09
Medium	Low	5	5,79	5,653	5,954
High	Low	5	6,041	5,665	5,907
Low	Medium	5	7,14	6,92	7,02
Medium	Medium	5	6,493	6,61	7,007
High	Medium	5	7,182	6,959	6,594
Low	High	5	7,87	6,95	7,63
Medium	High	5	7,399	7,544	8,259
High	High	5	7,582	7,869	7,478

Table 3: Sensitivity Analysis Results – *RTOQ* policy

Source	*DF*	*Adj SS*	*Adj MS (10^{-4})*	*F*	*P*
DI	2	0,67	0,33	5,70	0,029
DV	2	12,49	6,24	106,1	0,000
LT	2	3,65	1,82	31,01	0,000
DI*DV	4	0,06	0,01	0,30	0,873
DI*LT	4	0,34	0,08	1,45	0,302
DV*LT	4	0,17	0,04	0,75	0,585
Error	8	0,47	0,05		
Total	26				

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 – *RTOQ* policy

Term	*Coefficient*	
	(-1)	*(0)*
Constant	6,44067	
DI	0,08511	-0,22111
DV	-0,86100	0,05878
LT	-0,47333	0,04989

Equation 7 reports the input-output meta-model for the performance parameter (the unit inventory management cost) when input parameters change between the medium and high levels:

$$Y_{ijkn} = 6{,}44067 - 0{,}22111 * DI + + 0{,}05878 * DV + 0{,}04989 * LT \quad (7)$$

Figure 3 shows how the unitary inventory management cost changes in function of the three main effects: the unitary inventory management cost decreases when demand intensity goes from its low to medium values; from the other side it increases with the increase when the demand intensity changes from its medium to high levels.

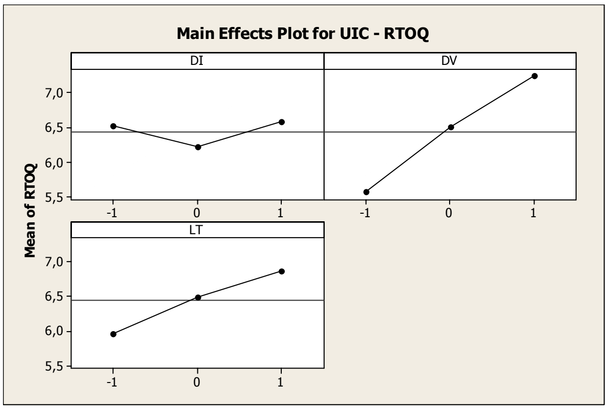

Figure 3: Unitary Inventory Management Costs versus Main Effects – *RTOQ* policy

6.2. Simulation results analysis for the (s,S) inventory control policy

The same analyses have been carried out for the (s,S) inventory control policy. From the sensitivity analysis the most significant effects are the first order effects (demand variability and lead time). The ANOVA coefficients for the (s,S) policy are reported in Table 5.

Table 5: ANOVA Coefficients – *(s,S)* policy

Term	***Coefficient***	
	(-1)	***(0)***
Constant	6,17730	
DV	-0,76952	0,07293
LT	-0,59696	0,06648

The input-output meta-model is reported in equation 8 (note that in this case low and medium levels parameters are reported).

$$Y_{ijkn} = 6{,}17730 - 0{,}76952 * DV + - 0{,}59696 * LT \quad (8)$$

Figure 4 shows the Main Effects Plot for the (s,S) policy. In this case the unit inventory management costs increases when demand variability and lead time change from their low to their high levels.

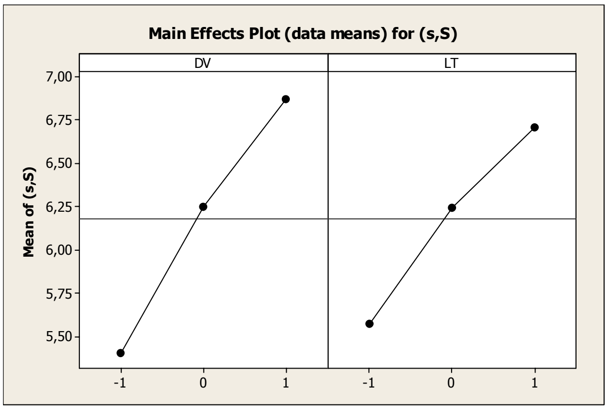

Figure 4: Unitary Inventory Management Costs versus Main Effects – *(s,S)* policy

6.3. Simulation results analysis for the RPOQ inventory policy

The third inventory control policy considered is the reorder point-order quantity policy.

Table 6 reports the sensitivity analysis results. Also in this case the most significant parameters are respectively the demand variability (*DV*) and the lead time (*LT*).

Table 6: Sensitivity Analysis Results – *RPOQ* policy

Source	***DF***	***Adj SS***	***Adj MS (10^{-4})***	***F***	***P***
DI	2	0,1526	0,076	1,37	0,277
DV	2	8,868	4,434	79,63	0,000
LT	2	4,166	2,083	37,41	0,000
Error	20	1,113	0,055		
Total	26				

The ANOVA coefficients for the RPOQ policy are reported in Table 7 while equation 9 is the input-output meta-model (consider that parameters change between the low and medium levels).

Table 7: ANOVA Coefficients – *RPOQ* policy

Term	***Coefficient***	
	(-1)	***(0)***
Constant	6,39674	
DV	-0,71719	0,03159
LT	-0,47674	-0,00863

$$Y_{ijkn} = 6{,}39674 - 0{,}71719 * DV + - 0{,}47674 * LT \quad (9)$$

Figure 5 shows the Main Effects Plot between demand variability and lead time effects.

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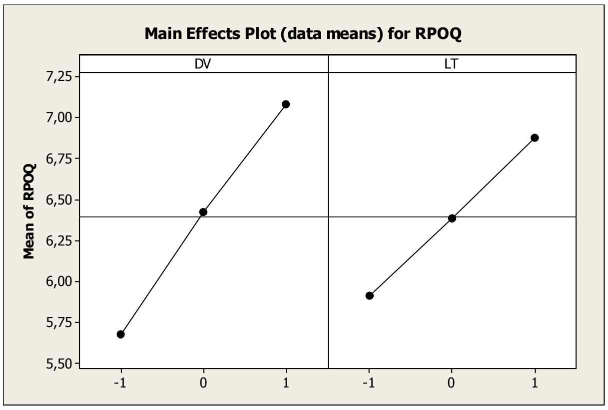

Figure 5: Unitary Inventory Management Costs versus Main Effects – *RPOQ* policy

For each scenario the validity of the analysis of variance results has been proved by using residuals analysis. To provide evidence on the results of the residuals analysis, the figure 6 shows the Normal Probability Plot of the Residuals for the RPOQ policy.

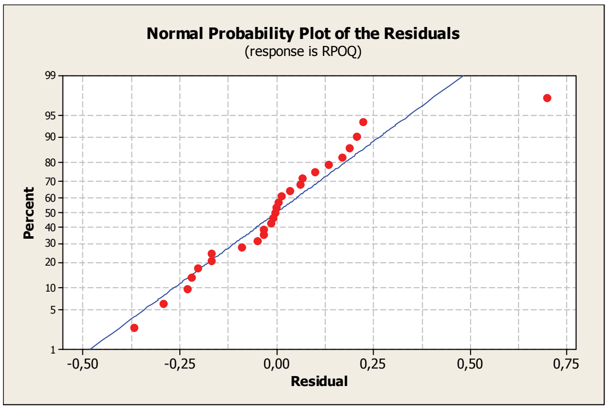

Figure 5: Normal Probability Plot of the Residuals – *RPOQ* policy

7. CONCLUSIONS

This paper aims at investigating the effect of some critical parameters (i.e. the demand intensity, the demand variability and the lead time) on three different inventory control policies within a real warehouse that support the production of hazelnuts based products. The performance measure taken into consideration is the unit inventory management cost. The simulation results have been studied by means of the Analysis of Variance both in terms of sensitivity analysis and in terms input-output analytical relationships. Such analytical relationships, one for each policy, express the unit inventory management costs as a function of the demand intensity, demand variability and lead time.

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