WAREHOUSE AND INTERNAL LOGISTICS MANAGEMENT BASED ON MODELING & SIMULATION

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ABSTRACT
The paper focuses on warehouse and internal logistics management. The objective of the paper is to investigate the effect of some critical parameters (i.e. the number of incoming trucks from suppliers, the number of outgoing trucks to retailers, the number of forklifts and lift trucks, etc.) on the warehouse internal logistic costs. To this end the authors develop a parametric simulator equipped with a graphic user interface (for changing the most important warehouse parameters) that the user can use for performing what-if analysis and scenarios investigation. An application example is finally proposed: after a sensitivity analysis, the analytical relationship between the internal logistic costs and the warehouse critical parameters is evaluated.

Keywords: Warehouse Management, Internal Logistics, Simulation, DOE, ANOVA

1. INTRODUCTION

During the last years number of research works has been developed in the sector of warehouse management and internal logistics planning and control. In particular, researches in this field are favored by the continuous development of computer technology and new materials handling equipment. Planning activities within a warehouse concern with goods assignment in each storage location and warehouse system design. Control problems are related to storage sequencing and scheduling optimization, retrieval requests in the dispatching control. Recent research studies also regard data/information management in warehouse systems.

Mason et al. (2003) investigate the integration between the warehouse management system (*WMS*) and the transportation management system (*TMS*) of an industrial company. In particular, the WMS contains information on supplier/customer warehouse inventory level and about customers' orders while the TMS stores all the information about retailers' locations, items to deliver and vehicles to adopt.

Eben-Chaime and Pliskin (1997) investigate the effect of operations management tactics on performance measures of automatic warehousing systems with multiple machines.

Moreover, several researches focalize on warehouse system design (i.e. Hsieh and Tsai, 2006 implement a simulation model for finding the optimum design parameters of a real warehouse system).

The paper investigates how some warehouse critical parameters affect the logistic internal costs. To this end, the authors use as support tool a simulation model capable of recreating the high complexity of a real warehouse.

Before getting into details of the study, a brief overview of the paper is proposed. Section 2 reports the description of the warehouse. Section 3 describes the implementation of the simulation model. Section 4 investigates the relationship between the internal logistic costs and the warehouse management parameters. The last section reports the conclusions that summarize critical issues and results of the paper.

2. WAREHOUSE DESCRIPTION

This research work proposes a study on the relationship between the warehouse management parameters and the effect of such parameters on the internal logistics costs.

The warehouse being considered in this paper is a real warehouse (supporting the retail sector) with the following characteristics:

- a surface of 13000 m^2;
- a shelves' surface of 5000 m^2;
- 3 levels of shelves;
- a capacity in terms of pallets of 28400 pallets;
- a capacity in terms of pallets for each product of 7100 pallets;

- a capacity in terms of packages of about one million packages.

3. THE WAREHOUSE SIMULATION MODEL

According to Eben-Chaime et al. (2004), simulation is the most effective tools for designing and analyzing manufacturing systems and, more in detail, for making warehousing context analysis. In fact, one of the most important advantages of Simulation is to explore and experiment possibilities for evaluating system behavior under internal/external changes.

In particular, the warehouse simulation model implemented by the authors has the objective to investigate the relationship between input (warehouse management parameters) and output (warehouse performance measures) parameters. To this end the simulator is characterized by high flexibility in terms of parameters variation and scenarios definition.

3.1. The simulation model architecture

The simulation model presented in this research work reproduces all the most important processes and operations of the real warehouse related to:

- trucks arrival and departure for items deliveries (from suppliers to the warehouse and from the warehouse to retailers);
- forklift and lift trucks for materials handling operations
- performance measures control and monitoring (number if items handled, waiting times for trucks, suppliers' and retailers' service levels).

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 software libraries. Figure 1 displays the structure diagram of the simulation model.

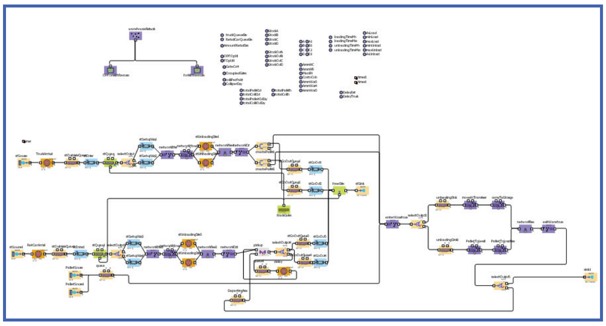

Figure 1: The Structure Diagram of the Simulation Model

3.2. The input parameters

In order to increase the flexibility of the model for scenarios investigation, a number of warehouse management parameters have been implemented within a graphic user interface by using sliding bars as shown in figure 2. Such parameters can be varied both at the beginning of the simulation run and at run-time observing the effect on the warehouse behavior.

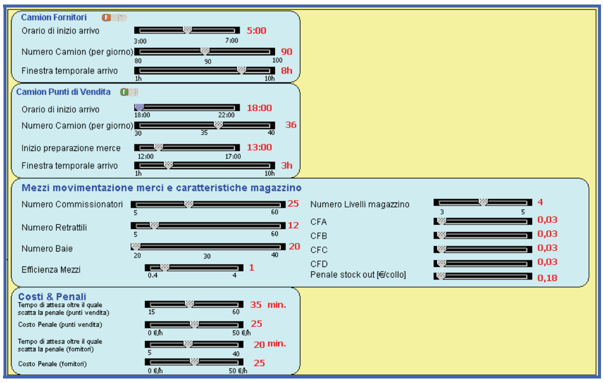

Figure 2: Simulation Model graphic user interface

The Simulation graphic user interface can be subdivided in four different sections:

- *Suppliers' Trucks section*;
- *Retailers' Trucks section*;
- *Warehouse Management parameters section*
- *Logistics Internal Costs section*

The *Suppliers' Trucks section* contains the following parameters:

- the suppliers' trucks arrival time (*TATS*);
- the number of suppliers' trucks per day (*NTS*);
- the time window in which suppliers' trucks deliver products (*TDTS*).

The *Retailers' Trucks section* contains the following parameters:

- the retailers' trucks arrival time (*TATR*);
- the number of retailers' trucks per day (*NTR*);
- the time window in which retailers' trucks deliver products (*TDTR*).
- the time for starting items preparation (*PPT*, items to be delivered to retailers).

The Warehouse Management parameters section contains the following parameters:

- shelves levels (*SL*);
- number of forklift (*NFT*);
- number of lift trucks (*NMT*);
- number of aisles available for loading and unloading operations (*NB*);
- forklifts and lift trucks efficiency (*TPP*);
- stock-out costs parameters (SC_i).

The *Logistics Internal Costs section* contains the following parameters:

- the time after which the warehouse has to pay fines to retailers (*PTR*);

- the time after which suppliers have to pay fines to the warehouse (*PTS*);
- the fine cost for retailers (*FCR*);
- the fine cost for suppliers (*FCS*).

3.3. The output parameters

The output section, see figure 3, provides all the parameters necessary to evaluate and monitor the warehouse performances. The evolution of the performance measure can be observed at run-time.

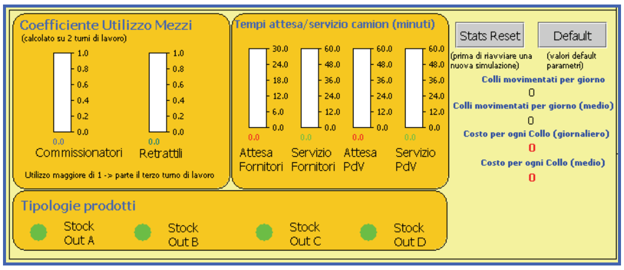

Figure 3: The simulation model Output Section

The performance measures implemented in the simulation model are described as follows:

- The forklifts utilization level (*CFT*);
- the lift trucks utilization level (*CMT*);
- the service level provided to suppliers' trucks (*LSST*);
- the service level provided to retailers' trucks (*LSRT*) ;
- the waiting time of suppliers' trucks before starting the unloading operation (*WTSU*);
- the waiting time of retailers' trucks before starting the loading operations (*WTRL*);
- the packages delivered per day, actual (*PDD*) and average value (*APDD*);
- the daily cost for each package, actual (*DCP*) and average value (*ADCP*).

4. SCENARIOS INVESTIGATION: INPUT OUTPUT RELATIONSHIP

As mentioned into the introduction, the objective of the paper is to investigate the effect of some critical parameters on the warehouse internal logistics costs.

The input parameters (factors) taken into consideration are:

- the number of suppliers' trucks per day (*NTS*);
- the number of retailers' trucks per day (*NTR*);
- the number of forklift (*NFT*);
- the number of lift trucks (*NMT*);
- the number of shelves levels (*SL*).

The variation of such parameters creates different operative scenarios characterized by different resources availability, allocation and utilization. The performance measures being taken into consideration are:

- the packages delivered per day, actual (*PDD*) and average value (*APDD*);
- the daily cost for each package, actual (*DCP*) and average value (*ADCP*).
- The forklifts utilization level (*CFT*);
- the lift trucks utilization level (*CMT*).

The experiments planning is supported by the Design of Experiments (Full Factorial Experimental Design is adopted). Table 1 consists of factors and levels used for the design of experiments.

Table 1: Factors and Levels of DOE

Factors	***Level 1***	***Level 2***
NTS	80	100
NTR	30	40
NFT	6	24
NMT	12	50
SL	3	5

As shown in Table 1, each factor has two levels: in particular, Level 1 indicates the lowest value for the factor while Level 2 its greatest value.

In order to test all the possible factors combinations, the total number of the simulation runs is 2^5. Each simulation run has been replicated three times, so the total number of replications is 96 (32x3=96).

The simulation results have been studied, according to the various experiments, by means of the Analysis Of Variance (*ANOVA*) and of graphic tools.

5. SIMULATION RESULTS ANALYSIS

As before mentioned, the simulation results have been analyzed by means of *ANOVA* and graphic tools. The ANOVA partitions the total variability of the performance indexes in different components due to the influence of the factors reported in Table 1. In this way, it is possible to understand which factors affect the performance indexes, or, in other words, to introduce an analytical relationship (called *meta-model* of the simulation model) between each performance index and the factors being considered.

Let Y_i be the i-th performance measure and let x_i be the factors. The equation 1 expresses the i-th performance measure as linear function of the factors.

$$
\begin{aligned}
Y_i = {} & \beta_0 + \sum_{i=1}^{5} \beta_i x_i + \sum_{i=1}^{5} \sum_{j>i}^{5} \beta_{ij} x_i x_j + \\
& + \sum_{i=1}^{5} \sum_{j>i}^{5} \sum_{h>j}^{5} \beta_{ijh} x_i x_j x_h + \\
& + \sum_{i=1}^{5} \sum_{j>i}^{5} \sum_{h>j}^{5} \sum_{k>h}^{5} \beta_{ijhk} x_i x_j x_h x_k + \\
& + \sum_{i=1}^{5} \sum_{j>i}^{5} \sum_{h>j}^{5} \sum_{k>h}^{5} \sum_{p>k}^{5} \beta_{ijhkp} x_i x_j x_h x_k x_p + \varepsilon_{ijhkpn}
\end{aligned}
\tag{1}
$$

where:

- β_0 is a constant parameter common to all treatments;
- $\sum_{i=1}^{5} \beta_i x_i$ are the five main effects of factors;
- $\sum_{i=1}^{5} \sum_{j>i}^{5} \beta_{ij} x_i x_j$ are the ten two-factors interactions;
- $\sum_{i=1}^{5} \sum_{j>i}^{5} \sum_{h>j}^{5} \beta_{ijh} x_i x_j x_h$ represents the three-factors interactions;
- $\sum_{i=1}^{5} \sum_{j>i}^{5} \sum_{h>j}^{5} \sum_{k>h}^{5} \beta_{ijhk} x_i x_j x_h x_k$ are the three four-factors interactions;
- $\sum_{i=1}^{5} \sum_{j>i}^{5} \sum_{h>j}^{5} \sum_{k>h}^{5} \sum_{p>k}^{5} \beta_{ijhkp} x_i x_j x_h x_k x_p$ is the sole five-factors interaction;
- ε_{ijhkpn} is the error term;
- n is the number of total observations.

In particular the analysis carried out by authors aims at:

- identifying those factors that have a significant impact on the performance indexes (sensitivity analysis)
- evaluating the coefficients of equation 1 in order to have an analytical tool capable of expressing the performance measures as function of the most critical factors

In the next section, the authors propose results analysis for the first two performance measure (APDD and ADCP).

5.1. Simulation results analysis for the packages delivered per day (*APDD*)

Table 2 reports the design matrix and the simulation results in terms of number of packages delivered per day. The first four table columns show all the possible combinations of the factors levels while the last column reports the results provided by the simulation model for the first performance parameter (note the last column of table 2 reports the simulation results of one replications; in effect the authors replicated three times each scenario).

The Pareto Chart (see figure 4) of the effects allows to evaluate the predominant effects: in this case they are the first order effects and some effects of the second and third order.

As known from the ANOVA theory the non-negligible effects are characterized by *p-value* ≤α where *p* is the probability to accept the negative hypothesis (the factor has no impact on the performance index) and

Table 2: Design Matrix and simulation results (APDD)

NTS	*NTR*	*NFT*	*NMT*	*SL*	*APDD*
80	30	6	12	3	30370
80	30	6	12	5	30345
80	30	6	50	3	30439
80	30	6	50	5	30457
80	30	24	12	3	30421
80	30	24	12	5	30358
80	30	24	50	3	30387
80	30	24	50	5	30488
80	40	6	12	3	40574
80	40	6	12	5	40501
80	40	6	50	3	40603
80	40	6	50	5	40580
80	40	24	12	3	40551
80	40	24	12	5	40568
80	40	24	50	3	40553
80	40	24	50	5	40541
100	30	6	12	3	38528
100	30	6	12	5	37181
100	30	6	50	3	30361
100	30	6	50	5	30399
100	30	24	12	3	30388
100	30	24	12	5	30405
100	30	24	50	3	30416
100	30	24	50	5	30387,6
100	40	6	12	3	35846,1
100	40	6	12	5	37186,2
100	40	6	50	3	40498,8
100	40	6	50	5	40532,1
100	40	24	12	3	40550
100	40	24	12	5	35447,4
100	40	24	50	3	40530
100	40	24	50	5	40563,6

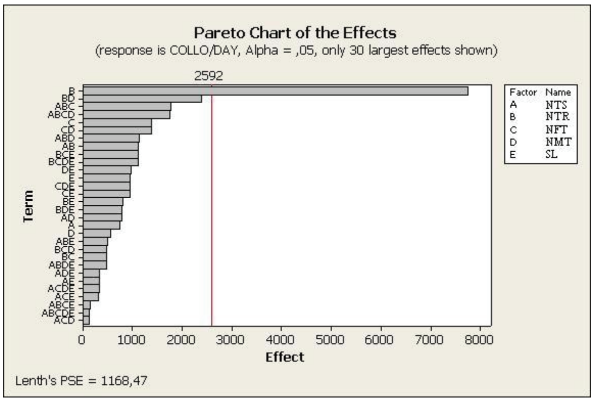

Figure 4: The Pareto Chart for the APDD

α=0.05 is the confidence level used in the analysis of variance. The most significant factors are:

- NTS;
- NTR;
- NFT;
- NMT;
- NTR*NMT;

- NTS* NTR* NFT.

The ANOVA has been repeated for the most important factors, the results are reported in table 3.

- 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: ANOVA Results for the most significant factors

Source	*DF*	*AdjSS (10^{-7})*	*AdjMS (10^{-7})*	*F*	*P*
Main Effects	4	50,30	125,75	23,22	0
2-Way interactions	1	45,24	4,52	8,35	0
3-Way interactions	1	24,84	2,48	4,59	0,04
Residual Error	25	13,53	0,54		
Total	31				

Results confirm that factors are correctly chosen because their p-value is lower than the confidence level adopted. The input-output meta-model for the APDD is as follows:

$$\begin{aligned} APDD &= 21777{,}2 + 21{,}46 * NTS + 348{,}74 * NTR + \\ &- 167{,}083 * NFT - 423{,}71 * NMT + \\ &12{,}51 * (NTR * NMT) + \\ &+ 0{,}028 * (NTS * NTR * NFT) \end{aligned} \quad (2)$$

Equation 2 is the most important result of the analysis: it is a powerful tool that can be used for correctly defining, in this case, warehouse average number of packages daily delivered in function of the system available resources.

5.2. Simulation results analysis for the average daily cost per package (*ADCP*)

The same analysis has been carried out taking into consideration the average daily cost per packages (*ADCP*). Table 4 reports the design matrix and the simulation results. The normal probability plot allows to evaluate the predominant effects: in this case they are the first order effects and some effects of the second order.

Table 4: Design Matrix and simulation results (ADCP)

NTS	*NTR*	*NFT*	*NMT*	*SL*	*ADCP*
80	30	6	12	3	1,38
80	30	6	12	5	1,33
80	30	6	50	3	0,48
80	30	6	50	5	0,483
80	30	24	12	3	3,06
80	30	24	12	5	3,91
80	30	24	50	3	2,27
80	30	24	50	5	0,623
80	40	6	12	3	1,38
80	40	6	12	5	13,82
80	40	6	50	3	0,45
80	40	6	50	5	11,54
80	40	24	12	3	4,69
80	40	24	12	5	5,3
80	40	24	50	3	3,69
80	40	24	50	5	2,89
100	30	6	12	3	3,05
100	30	6	12	5	4,31
100	30	6	50	3	0,53
100	30	6	50	5	6,72
100	30	24	12	3	5
100	30	24	12	5	6,28
100	30	24	50	3	0,64
100	30	24	50	5	0,62
100	40	6	12	3	3,72
100	40	6	12	5	8,18
100	40	6	50	3	1,06
100	40	6	50	5	8,97
100	40	24	12	3	2,7
100	40	24	12	5	11
100	40	24	50	3	0,48
100	40	24	50	5	0,47

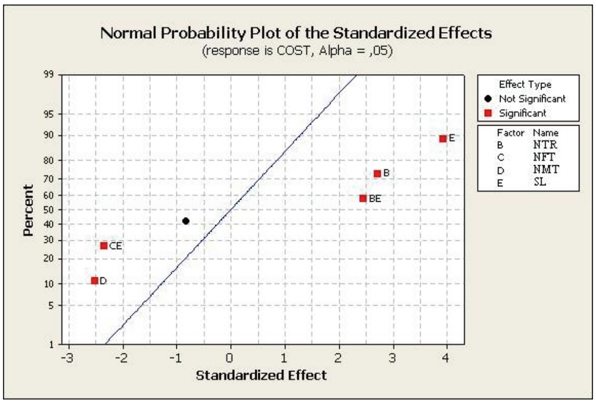

Figure 5: The Most Significant Effects for ADCP

The most significant factors (represented with a red square) are:

- NTR;
- NMT;
- SL;
- NTR*SL;
- NFT*SL.

Figure 6 shows the trend of the average daily cost for packages delivered (ADCP) in function of the main effects:

- NTR;
- NMT;
- SL.

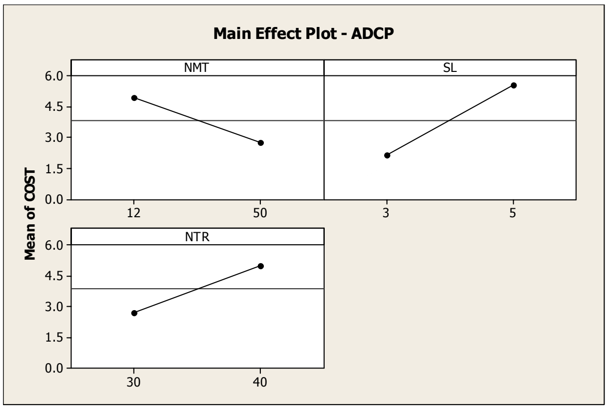

Figure 6: ADCP versus Main Effects

As shown in Figure 6, when the number of lift trucks increases, the average daily cost for packages delivered decreases; the contrary happens when the shelves levels and the number of retailers' trucks.

Figure 7 shows the plots concerning the interaction effects between some couples of parameters (i.e NTR-NFT, NFT-SL).

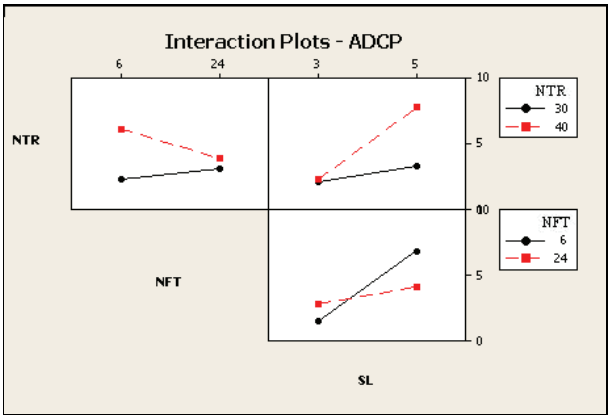

Figure 7: Interaction Plots for ADCP

Results obtained by means of DOE and ANOVA allow to correctly choose the correct resources allocation in order minimize the logistics internal costs. In effect an accurate combination of the number of forklifts and lift trucks, help to keep under control logistics internal costs. The validity of the results, obtained thanks to ANOVA, is still confirmed by residuals analysis. The starting hypothesis which ensure the validity of the ANOVA (observations normally and independently distributed, observations with the same variance for each possible combination of the factors levels) have been verified by using Normal Probability plots, residuals versus the order of the fitted data plots, and histograms of the residuals.

6. CONCLUSIONS

This research work focuses on the investigation of the effect of some critical parameters (the number of incoming trucks from suppliers, the number of outgoing trucks to retailers, the number of forklifts and lift trucks, etc.) on the number of packages delivered per days and on the warehouse internal logistics costs.

To this end the authors developed a simulation model supported by a smart graphic user interface and an output section capable of monitoring the most important warehouse performance measures.

The analyses carried out highlight how the warehouse performance measures (average number of packages delivered per day and average daily cost for each package) are affected by the warehouse resources availability and by the arrival of suppliers' and retailers' trucks. In addition, input-output analytical relations, have been evaluated by using the ANOVA. Such analytical relations become a powerful tools for warehouse design and management.

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