Operational Strategies and Internal Logistic Costs Analysis in a Real Warehouse Based on Modeling & Simulation

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Abstract

The article focuses on the warehouse management problem within supply chain nodes. A simulation model of a real warehouse is used as decision-making tool with the aim of analyzing different operational strategies by using approaches based on multiple performance measures and user-defined set of input parameters. An application example is presented that considers the effect of resources allocation on internal logistic costs.

Keywords: *Warehouse Management, Modeling & Simulation, Logistic Costs.*

1. Introduction

The internal logistic management within each supply chain node (i.e. warehouse management in a distribution center) may strongly affect supply chain performances. The correct organization of all the logistic processes and activities that take place within a supply chain node (i.e., capability of using material-handling systems efficiently, time windows planning for suppliers/retailers unloading/loading operations, etc.) could have a remarkable impact on both processes upstream and downstream the supply chain and on supply chain node internal costs as well.

As in many other cases, Modeling & Simulation can be profitably used for supporting supply chain node design and management (Bruzzone et al., 2007; Bruzzone and Longo, 2010; Longo, 2010). It is worth saying that the internal logistics management of each supply chain node (above all when considering warehouse management problems) also provides researchers and practitioners with challenging problems. Warehouses are usually large plain buildings used by exporters, importers, wholesalers, manufacturers for goods storage. Warehouses are equipped with loading docks, cranes, forklifts and material handling systems for moving goods. The main processes that take place within a warehouse are: items reception, items storage, items retrieval, items picking and items shipping. Warehousing costs can be distinguished in general overhead costs, delivery costs and labor costs. General surveys on the warehouse management problem can be found in Van den Berg (1999), Rowenhorst et al. (2000), Cormier (2005).

According to Gu et al. (2007), the warehouse management problem can be re-conducted to five major decisions:

- defining the overall warehouse structure in terms of functional departments and their relationships by analyzing warehouse materials flow; further information can be found in Park and Webster (1989), Gray et al. (1992), Yoon and Sharp (1996), Meller and Gau (1996).
- Warehouse sizing and dimensioning that aim at defining warehouse size and dimensions and its departments; further information can be found in White and Francis (1971), Levy (1974), Rosenblatt and Roll (1988), Cormier and Gunn (1996), Goh et al. (2001), Lowe et al. (1979), Hung and Fisk (1984) and Rao and Rao (1998).
- Defining the detailed layout within each department, i.e. aisle design in the retrieval area, pallet block-stacking pattern in the reserve storage area, configuration of an Automated Storage/Retrieval System, etc.; references that deal with the watrehouse layout problem can be found in Moder and Thornton (1965), Berry (1968), Marsh (1979), Marsh (1983), Goetschalckx and Ratliff (1991), Larson et al. (1997), Bruzzone et al. (1999), Roodbergen and Vis (2006).
- material handling systems design and selection (determination of an appropriate automation level for the warehouse and identification of equipment types for storage, transportation, order picking, and sorting); further information can be found in Cox (1986), Sharp et al. (1994),
- selection of the operational strategies (i.e. the choice between randomized storage or dedicated storage, whether or not use zone picking, the choice between sort-while-pick or sort-after-pick, etc.); additional references are Hausman et al. (1976), Graves et al. (1977), Schwarz et al. (1978), Goetschalckx and Ratliff (1990), Thonemann and Brandeau (1998), Lin

and Lu (1999), Bartholdi et al. (2000) and Petersen (2000), Gu *et al.* (2007).

2. Warehouse Management based on Modeling & Simulation

An accurate analysis of the references listed into the introduction reveals that, very often, models proposed are not able to recreate the whole complexity of a r eal warehouse system (including stochastic variables, huge number of items, multiple deliveries, etc). Therefore the main contribution of this article to the state of the art is an application example that shows how Modeling & Simulation can be profitably used to tackle the warehouse management problem. In particular the application example investigates the effects of warehouse resources management and allocation on the warehouse efficiency highlighting as the interactions among operational strategies and available resources strongly affect the internal logistic costs. The simulation model of a real warehouse is presented. The warehouse simulator has been developed under request of one of the major Italian company operating in the large scale retail sector.

2.1 The real warehouse and the warehouse simulation model

As before mentioned, the warehouse belongs to one of the most important company operating in the large scale retail sector (in Italy) and it is characterized by:

- total surface: 13000 m^2;
- shelves surface: 5000 m^2;
- surface for packing and shipping operations: 3000 m^2;
- surface for unloading and control operations: 1800 m^2;
- three levels of shelves;
- eight types of products;
- capacity in terms of pallets: 28400 pallets;
- capacity in terms of pallets for each product: 3550 pallets;
- capacity in terms of packages: about one million packages.

The main modelling effort was carried out to recreate with satisfactory accuracy the most important warehouse operations, including

- trucks arrival and departure for items delivered from suppliers to the warehouse and from the warehouse to retailers;
- warehouse materials handling operations (performed by using forklifts and lift trucks) including, trucks unloading operations, inbound quality and quantity controls, preparation for storage, storage operations, retrieval operations, picking operations, preparation for shipping, packaging operations, trucks loading operations and shipping;
- performance measures control and monitoring (a detailed description of performance measures will be provided later on).

The warehouse simulation model is a Java-based simulator that implements all the operations mentioned above jointly with the logics and rules of the real warehouse. Figure 1 shows the mainframe of the warehouse simulation model

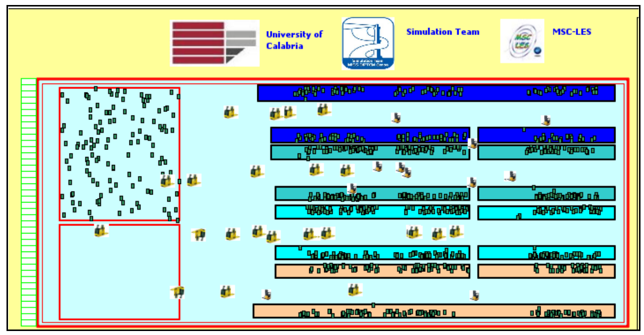

Fig. 1 The warehouse simulation model mainframe

The warehouse simulator is also equipped with a dedicated Graphic User Interface (GUI) with a twofold functionality: (i) to increase the simulation model flexibility changing its input parameters both at the beginning of the simulation run and at run-time observing the effect on the warehouse behaviour (Input Section); (ii) to provide the user with all simulation outputs for evaluating and monitoring the warehouse performances (Output Section).
The Input Section (see figure 2) is in four different parts:

- The Suppliers' Trucks section which includes slider objects for changing the following parameters: suppliers' trucks arrival time, number of suppliers' trucks per day, time window in which suppliers' trucks deliver products;
- the Retailers' Trucks section includes slider objects for changing the following parameters: retailers' trucks arrival time, number of retailers' trucks per day, time window for retailers' trucks arrival, time for starting items preparation;
- the Warehouse Management parameters section which includes slider objects for changing the following parameters: shelves levels, number of forklifts, number of lift trucks, number of docks available for loading and unloading operations, forklifts and lift trucks efficiency, stock-out costs parameters;
- the Logistics Internal Costs section which includes slider objects for changing the following parameters: sanction fee for retailers/suppliers, time after which

the warehouse has to pay a sanction fee to retailers for operations performed out of the scheduled period, time after which suppliers have to pay a sanction fee to the warehouse for operations performed out of the scheduled period.

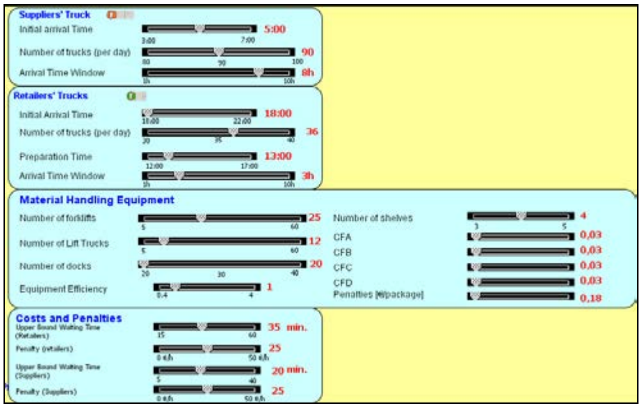

Fig. 2 The warehouse simulation model: input section

The Output Section (see figure 3) provides the user with the most important warehouse performance measures. The main performance measures include the following:

- forklifts utilization level;
- lift trucks utilization level;
- service level provided to suppliers' trucks;
- service level provided to retailers' trucks;
- waiting time of suppliers' trucks before starting the unloading operations;
- waiting time of retailers' trucks before starting the loading operations;
- number of packages handled per day (actual and average values);
- daily cost for each handled package (actual and average values).

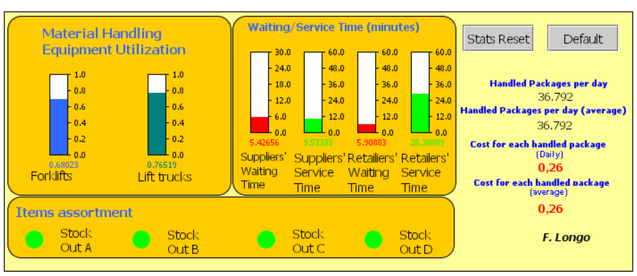

Fig. 3 The warehouse simulation model: output section

3. Experiments planning and results

The simulation model has been used to investigate the effects of warehouse resources management on warehouse efficiency highlighting as the interactions among operational strategies and available resources strongly affect the internal logistic costs. The analysis carried out by using the simulator considers the internal resources allocations versus the daily cost for each handled package. Additional analysis also consider the internal resources allocations versus number of packages handled per day and the internal resources allocations versus suppliers' waiting time and retailers' waiting time.

In each case, a sensitivity analysis is preliminary carried out and an input-output analytical model is finally determined. The simulation approach is jointly used with the Design of Experiments and Analysis of Variance.

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 forklifts (NFT);
- the number of lift trucks (NMT);
- the number of shelves levels (SL).

The variation of such parameters creates various scenarios characterized by different operative strategies and resources availability, allocation and utilization. The performance measures considered are: the average value of the daily cost for each handled package (ADCP), the average number of handled packages per day (APDD), the waiting time of suppliers' trucks before starting unloading operations (STWT), the waiting time of retailers' trucks before starting loading operations (RTWT).

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

Table 1: Factors and Level for the experiments planning

Factors	**Level 1**	**Level 2**
Number of suppliers' trucks per day, *NTS* (x_1)	**80**	**100**
Number of retailers' trucks per day, *NTR* (x_2)	**30**	**40**
Number of forklifts, *NFT*, (x_3)	**6**	**24**
Number of lift trucks, *NMT*, (x_4)	**12**	**50**
Number of shelves levels, *SL*, (x_5)	**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 25. Each simulation run is replicated three times, so the total number of replications is 96 (32x3=96). The simulation results are studied, according to the various experiments, by using the Analysis Of Variance (ANOVA) and graphic tools. Let Y_i be the *i-th* performance measure and let x_i be the factors, equation 1 expresses the *i-th* performance measure as linear function of the factors.

$$Y_i = \beta_0 + \sum_{i=1}^{5}\beta_i x_i + \sum_{i=1}^{5}\sum_{j>i}^{5}\beta_{ij}x_i x_j + \sum_{i=1}^{5}\sum_{j>i}^{5}\sum_{h>j}^{5}\beta_{ijh}x_i x_j x_h + \sum_{i=1}^{5}\sum_{j>i}^{5}\sum_{h>j}^{5}\sum_{k>h}^{5}\beta_{ijhk}x_i x_j x_h x_k + \sum_{i=1}^{5}\sum_{j>i}^{5}\sum_{h>j}^{5}\sum_{k>h}^{5}\sum_{p>k}^{5}\beta_{ijhkp}x_i x_j x_h x_k x_p + \varepsilon_{ijhkpn} \quad (1)$$

where:

- β_0 is a constant parameter common to all treatments;
- $\sum_{i=1}^{5}\beta_i x_i$ are the five factors main effects;
- $\sum_{i=1}^{5}\sum_{j>i}^{5}\beta_{ij}x_i x_j$ are the ten two-factors interactions;
- $\sum_{i=1}^{5}\sum_{j>i}^{5}\sum_{h>j}^{5}\beta_{ijh}x_i x_j x_h$ represent 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 aims at:

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

3.1 Internal resources allocations versus the daily cost

The first analysis takes into consideration the average daily cost per handled packages (*ADCP*). Table 2 reports the design matrix and the simulation results. Note that table 2 reports both the simulation results for the analysis presented in this section (table 2, column 6) and the simulation results for the analysis presented in the next section 3.2 (Table 2, column 7). The design matrix (table 2, columns 1 to 5) is the same for each analysis.

Table 2: Design Matrix and Simulation Results (ADCP and APDD)

NTS	*NTR*	*NFT*	*NMT*	*SL*	*ADCP*	*APDD*
80	30	6	12	3	1.38	30370
80	30	6	12	5	1.33	30345
80	30	6	50	3	0.48	30439
80	30	6	50	5	0.483	30457
80	30	24	12	3	3.06	30421
80	30	24	12	5	3.91	30358
80	30	24	50	3	2.27	30387
80	30	24	50	5	0.62	30488
80	40	6	12	3	1.38	40574
80	40	6	12	5	13.82	40501
80	40	6	50	3	0.45	40603
80	40	6	50	5	11.54	40580
80	40	24	12	3	4.69	40551
80	40	24	12	5	5.30	40568
80	40	24	50	3	3.69	40553
80	40	24	50	5	2.89	40541
100	30	6	12	3	3.05	38528
100	30	6	12	5	4.31	37181
100	30	6	50	3	0.53	30361
100	30	6	50	5	6.72	30399
100	30	24	12	3	5.00	30388
100	30	24	12	5	6.28	30405
100	30	24	50	3	0.64	30416
100	30	24	50	5	0.62	30388
100	40	6	12	3	3.72	35846
100	40	6	12	5	8.18	37186
100	40	6	50	3	1.06	40499
100	40	6	50	5	8.97	40532
100	40	24	12	3	2.7	40550
100	40	24	12	5	11.00	35447
100	40	24	50	3	0.48	40530
100	40	24	50	5	0.47	40564

The normal probability plot in Figure 4 allows to evaluate the predominant effects (red squares): in this case the first order effects and some effects of the second order:

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

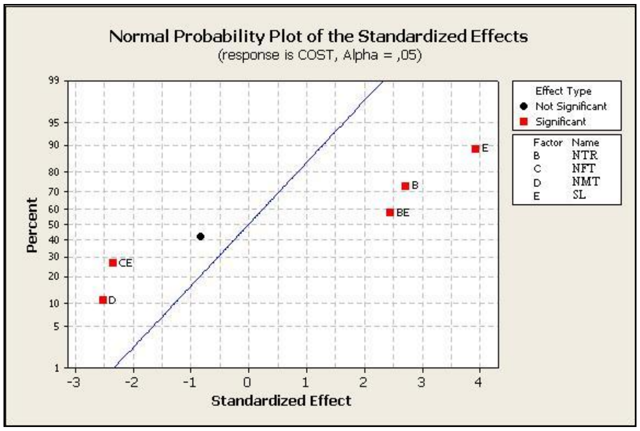

Fig. 4 The Most Significant Effects for the ADCP

Figure 5 shows the trend of ADCP in function of the main effects NTR, NMT and SL. As reported in Figure 5, when the number of lift trucks increases, the average daily cost for packages delivered decreases; the contrary happens with the shelves levels and the number of retailers' trucks variations.

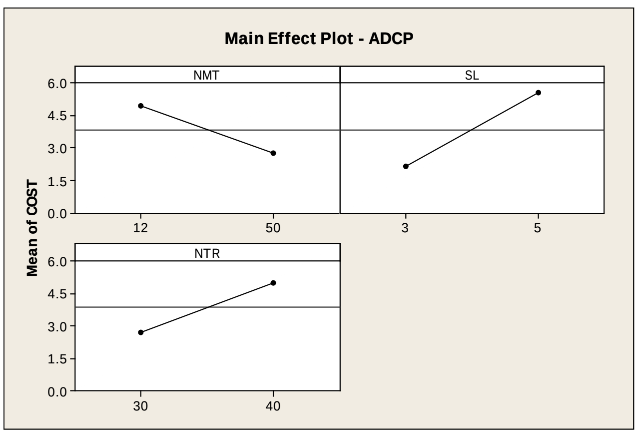

Fig. 5 ADCP versus Main Effects

Finally, figure 6 presents the plots concerning the interaction effects between some couples of parameters (i.e NTR-NFT, NFT-SL). T he results obtained by means of DOE and ANOVA allow to correctly arrange warehouse internal resources in order to maximize the average number of handled packages per day and to minimize the total logistics internal costs. In effect an accurate combination of the number of forklifts and lift trucks, help to keep under control both the number of handled packages per day and the total logistics costs.

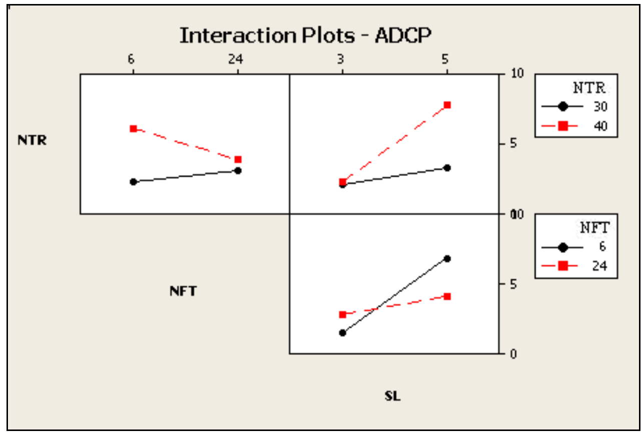

Fig. 6 Interactions Plots for the ADCP

3.2 Internal resources allocations versus number of packages handled per day (*APDD*)

Simulation results for this analysis are reported in table 2, column 7 in terms of average number of handled packages per day. Note that the APDD values are obtained as average on three simulation replications.
The Pareto Chart of the effects in Figure 7 allows to evaluate the predominant effects: in this case the first order effects and some effects of the second and third order.

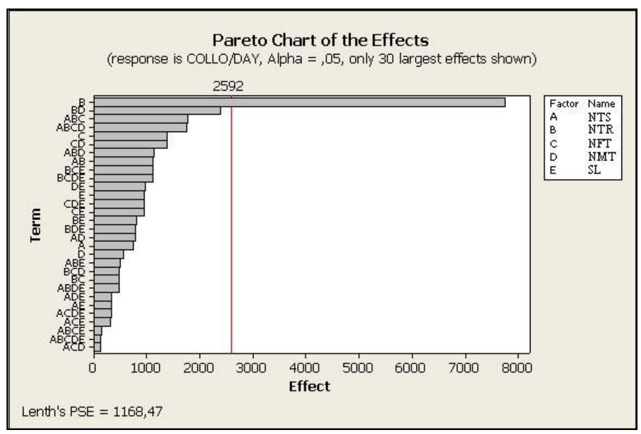

Fig. 7 The Pareto Chart for APDD

According to the ANOVA theory, the non-negligible effects are characterized by *p-value* $\leq \alpha$ where *p* is the probability to accept the negative hypothesis (the factor has no impact on the performance measure) and $\alpha = 0.05$ is the confidence level used in the analysis of variance. The most significant factors are:

- NTS (the number of suppliers' trucks per day);
- NTR (the number of retailers' trucks per day);
- NFT (the number of forklifts);
- NMT (the number of lift trucks);

- NTR*NMT (the interaction between the number of retailers' trucks per day and the number of lift trucks);
- NTS* NTR* NFT (the interaction between the number of suppliers' trucks per day, the number of retailers' trucks per day and the number of forklifts).

The ANOVA has been repeated for the most important factors and 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 Adjusted Mean Squares;
- the 5th column is the Fisher statistic;
- the 6th column is the p-value.

Table 3: ANOVA Results for APDD (most significant factors)

Source	*DOF*	*AdjSS*	*AdjMS*	*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**				

The input-output meta-model expressing APDD as function of the most important factors is the following:

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

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, the average number of packages handled per day in function of the warehouse available resources.

3.3 Internal resources allocations versus suppliers' waiting time (STWT) and retailers' waiting time (RTWT)

This Section focuses on evaluating the analytical relationship between factors defined in Table 1 and the waiting time of suppliers' trucks before starting the unloading operation and the waiting time of retailers' trucks before starting the loading operation. Such relationships should be used for a correct system design.

The first analysis carried out aims at detecting factors that influence the waiting time of suppliers' trucks before starting the unloading operations (*STWT*). Adopting also in this case a confidence level α = 0.05, the Pareto Chart in figure 8 highlights factors that influence STWT. These factors are:

- the number of retailers' trucks per day (*NTR*);
- the number of shelves levels (*SL*);
- the interaction factor between NTR and SL (*NTR*SL*).

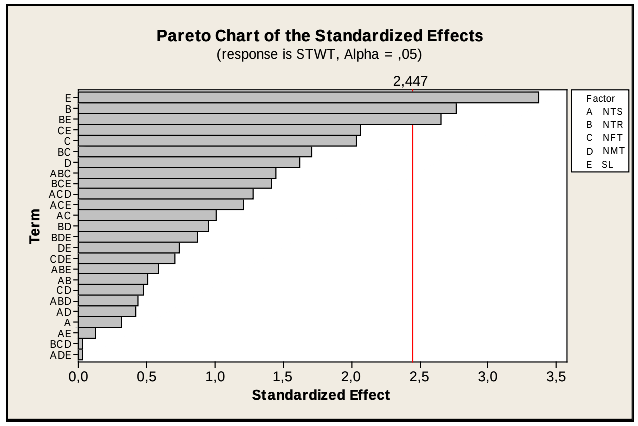

Fig. 8 The Pareto Chart for the STWT

Repeating the ANOVA for the most important factors, it is confirmed that factors are correctly chosen because their *p-value* is lower than the confidence level, as reported in Table 4.

Table 4: ANOVA Results for STWT

Source	*DF*	*AdjSS*	*AdjMS*	*F*	*P*
Main Effects	2	14,38	7,19	8,26	0,002
2-Way interactions	1	5,34	5,34	6,14	0,02
Residual Error	28	24,39	0,871		
Total	31				

The input-output meta-model which expresses the analytical relationship between the STWT and the most significant factors is reported in equation

$$\begin{aligned} STWT &= 713{,}58 - 24{,}19 * NTR - 234{,}32 * SL + \\ &+ 8{,}17 * (NTR * SL) \end{aligned} \qquad (3)$$

This equation clearly explains how the waiting time of suppliers' trucks before starting the unloading operation changes depends on warehouse available resources.

The same analysis has been carried out taking into consideration the waiting time of retailers' trucks before starting loading operations (*RTWT*). Figure 9 (Normal Probability Plot of the Standardized Effects) helps in understanding those factors that have a significant impact on RTWT; in this case the first order effects and some effects of the second and third order:

- the number of retailers' trucks per day (*NTR*);

- the number of lift trucks (*NMT*);
- the number of shelves levels (*SL*);
- the interaction factor between NTS and NTR (*NTS*NTR*);
- the interaction factor between NTS and NFT (*NTS*NFT*);
- the interaction factor between NTR and SL (*NTR*SL*);
- the interaction factor between NFT and NMT (*NFT*NMT*);
- the interaction factor between NFT and SL (*NFT*SL*);
- the interaction factor between NTR, NFT and SL (*NTR*NFT*SL*);
- the interaction factor between NFT, NMT and SL (*NFT*NMT*SL*).

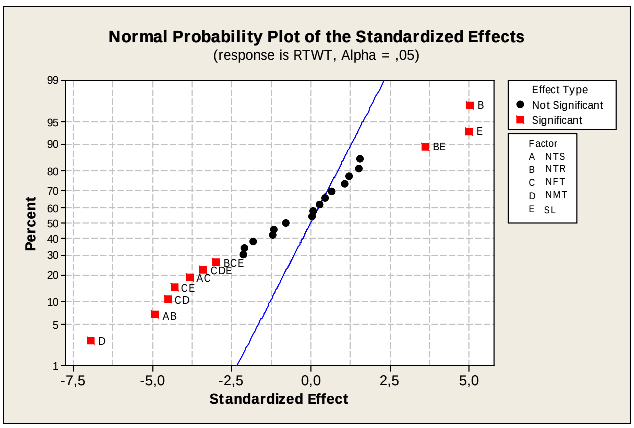

Fig. 9 The Normal Probability Plot for the RTWT

Table 5 reports analysis of variance results while equation 4 is the input-output analytical model that expresses RTWT as function of the predominant effects.

Table 5: ANOVA Results for RTWT

Source	*DF*	*AdjSS*	*AdjMS*	*F*	*P*
Main Effects	5	39,65	7,93	20,32	0,001
2-Way interactions	10	39,46	3,94	10,11	0,005
3-Way interactions	10	11,96	1,19	3,07	0,045
Residual Error	6	23,41	0,39		

$$\begin{aligned} RTWT = {} & 261{,}843 - 13{,}125 * NTR + 3{,}159 * NMT + \\ & -166{,}299 * SL + 0{,}081 * (NTS * NTR) + \\ & -0{,}029 * (NTS * NFT) + 5{,}930 * (NTR * SL) + \\ & +0{,}122 * (NFT * NMT) + 1{,}027 * (NFT * SL) + \\ & -0{,}073 * (NTR * NFT * SL) - 0{,}022 * (NFT * NMT * SL) \end{aligned} \quad (4)$$

Figure 10 plots equation 4 in terms of main effects: each plot provides additional information about the effects of the most significant factors on the waiting time of retailers' trucks before starting loading operations.

Consider the NTR parameter, if the number of retailers' trucks per day increases the waiting time of retailers' trucks before starting the loading operations (*RTWT*) increases too because of trucks' traffic density. The same happens if the number of shelves levels (*SL*) changes from 3 to 5; on the other hand, when increasing the number of lift trucks (*NMT*) from its low to high value, the RTWT significantly decreases.

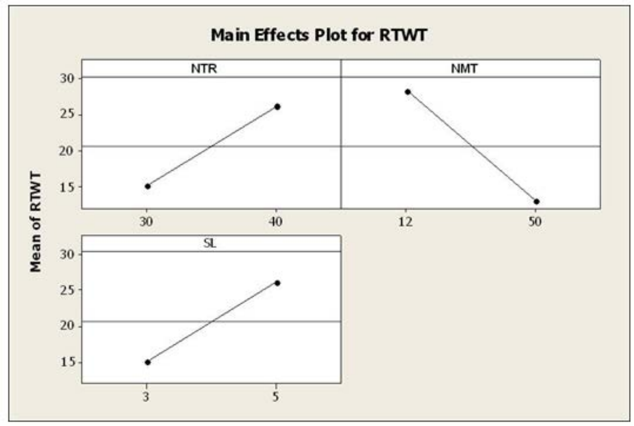

Fig. 10 Main Effects Plots for RTWT

Figure 11 shows simulation results for the RTWT parameter projected on a cube considering the NTR, NMT and SL parameters. At each corner of the cube the RTWT values are reported: NMT at its high value and NTR and SL at their low values are the best choice to obtain the lowest RTWT value.

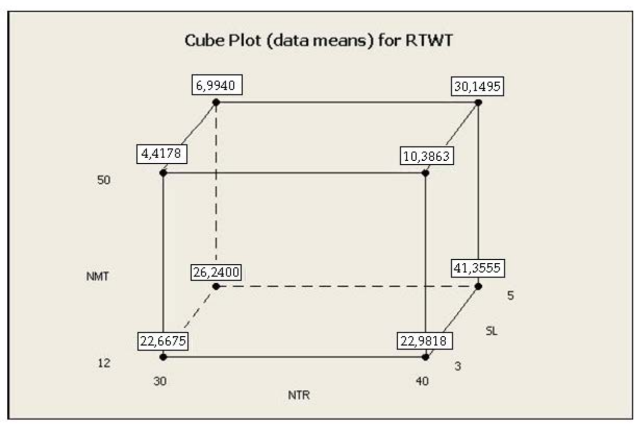

Fig. 11 Cube Plot for RTWT

Additional insights are provided by figure 12 that shows the three-dimensional surfaces of the RTWT in function of the different combinations of significant factors (NTR, SL, NMT).

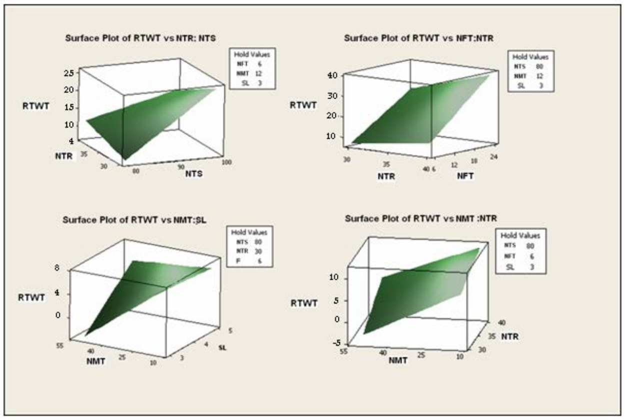

Fig. 12 Response Surfaces for RTWT

The analysis presented above show how Modeling & Simulation can be used for developing tailored solutions and tools for warehouse design and management. Input-Output analytical models and graphical tools allow to understand how changes in internal resources availability and operative strategies can affect technical and economic warehouse performances.

4. Conclusions

In this article the use of Modeling & Simulation as enabling technology is investigated, highlighting the contribution of this approach in warehouse management. The literature in these two specific fields is surveyed and discussed highlighting approaches and solutions proposed during the years as well as lacks in research studies and critical issues still to be investigated. An application example (based on a real case study) is then proposed. The application example deals the warehouse management problem within a single supply chain node. In the application example, the simulation model is a decision-making tool capable of analyzing different scenarios by using approaches based on multiple performance measures and user-defined set of input parameters.
Lesson learned includes a modus operandi for facing the warehouse management problem by using simulation for developing tailored solutions, joint use of simulation and advanced statistics techniques (DOE and ANOVA). It is not the intent of this article to investigate all the problems related to the warehouse management as well as to present all possible solutions. Indeed the literature review and the application example should help the reader in understanding how Modeling & Simulation can be profitably used for recreating supply chains complexity and tackle specific problems with ad-hoc solutions.

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