A simulation based approach for Warehouse Management

Francesco Costantino[(a)], Duilio Curcio[(b)], Giulio Di Gravio[(c)], Giovanni Mirabelli[(d)]

[(a)] [(c)] Operations Management Group
Department of Mechanical and Aeronautical Engineering
University of Rome "La Sapienza"
Via Eudossiana, 18
Rome, 00184, ITALY
{francesco.costantino, giulio.digravio}@uniroma1.it

[(b)] [(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
{dcurcio, g.mirabelli}@unical.it

Keywords: Warehouse Management, DOE, ANOVA, Anylogic™

Abstract

This paper focuses on a flexible simulation model of a real warehouse. In particular, the objective of this research work consists in evaluating analytical relations between system input parameters (the number of suppliers' and retailers' trucks per day, the number of forklift and lift trucks, the number of shelves levels) and the output performance measures (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 and management. In order to test all the possible combinations of the input parameters, the Design Of Experiments methodology is adopted while simulation results are then studied by means of the Analysis Of Variance.

1. INTRODUCTION

During the last years, several research works have been carried out on warehouse management Modeling & Simulation. These researches are particularly favored by the continuous development of computer technology and new materials handling equipment.

[Ashayeri and Gelders 1985] suggest a solution for the warehouse layout problem minimizing building costs or material handling costs; [Eben-Chaime and Pliskin 1997] investigate the effect of operations management tactics on performance measures of automatic warehousing systems with multiple machines. From the other side, [Daniels et al. 1998] provide an overview on order picking systems while [Macro and Salmi 2002] present a ProModel-based simulation tool of a warehouse for analyzing the warehouse storage capacity and rack efficiency. Finally, [Amato et al. 2005] develop control algorithms for the management of an automated warehouse system by using the colored Petri nets framework and [Hsieh and Tsai 2006] implement a simulation model for finding the optimum design parameters of a real warehouse system.

The research work proposed investigates the effect of some warehouse critical parameters on the waiting time of suppliers' and retailers' trucks before starting the unloading or loading operation. To this end, a simulation model, supported by a graphic user interface and capable of recreating the high complexity of a real warehouse, is developed.

The paper is structured as follows: Section 2 reports the description of the warehouse considered while the implementation of the simulation model is proposed in Section 3; Section 4 is dedicated to the Design of Experiments and to simulation results analysis; finally, the last Section introduces conclusions summarizing critical issues and results of the paper.

2. THE WAREHOUSE

The objective of this research work is to analyze the performance of a real warehouse system by monitoring some key performance measures (i.e. trucks waiting time which deliver goods from/to suppliers to/from retailers).

The authors take into consideration a real warehouse which supports the retail sector and it is characterized by the following technical features:

- a surface of 13000 m^2;
- a shelves' surface of 5000 m^2;
- a surface for packing and shipping processes of 3000 m^2;
- a surface for unloading operations of 1800 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 [de Koster et al. 2007], warehouses represent an important part of a firm's logistics system because of their function to store or buffer products (raw materials, goods-in-process, finished products).

To this end, for analyzing all the processes and interactions of the warehouse, a powerful tool is needed. For this reason, the simulation based approach is adopted for exploring and experimenting possibilities in order to evaluate system behavior under internal/external changes, [Eben-Chaime et al. 2004].

In particular, the warehouse simulation model implemented in this research work has the objective to investigate the relationship between input parameters (related to warehouse management) and output parameters (related to warehouse performance measures).

For this reason, the simulator is characterized by a high flexibility level in terms of parameters variation and scenarios definition.

3.1. Warehouse Processes Modeling

The main modeling effort was carried out to recreate with satisfactory accuracy the most important operations of the real warehouse (i.e. trucks arrival and departure for items deliveries, forklift and lift trucks for material handling operations, performance measures control and monitoring).

The simulation tool adopted for the model implementation is the commercial package Anylogic™ by XJ Technologies.

In order to implement all the logics and rules of the real warehouse, ad-hoc Java routines are developed, as reported in [Bocca et al. 2008].

These routines are used for allowing the flow of information, stored in tables, through model sub-sections (oppositely to the classical modeling approach, based on library objects for reproducing static and dynamic entities).

Figure 1 shows the simulation model Flow Chart.

3.2. The Graphic User Interface for input/output parameters

For reproducing different warehouse operative scenarios, input parameters values need to be changed.

To this end the authors developed a dedicated Graphic User Interface (*GUI*) with a twofold functionality:

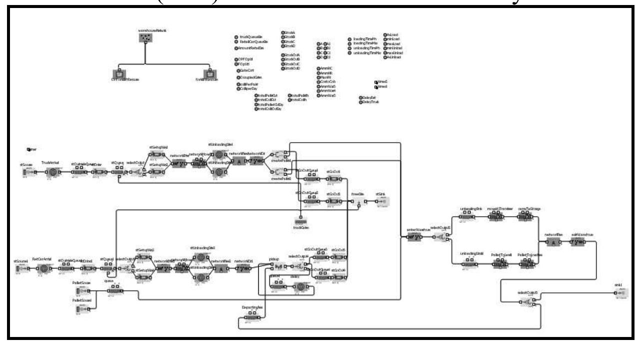

Figure 1. The simulation model Flow Chart

- 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 behavior (Input Section);
- to provide all the output parameters for evaluating and monitoring the warehouse performances (Output Section).

The Input Section can be subdivided in four different sub-sections:

- the *Suppliers' Trucks* section which contains parameters related to the suppliers' trucks arrival time, the number of suppliers' trucks per day, the time window in which suppliers' trucks deliver products;
- the *Retailers' Trucks* section which groups parameters like the retailers' trucks arrival time, the number of retailers' trucks per day, the time window in which retailers' trucks deliver products, the time for starting items preparation;
- the *Warehouse Management parameters* section in which the user finds parameters of the real warehouse such as shelves levels, number of forklift, number of lift trucks, number of aisles available for loading and unloading operations, forklifts and lift trucks efficiency, stock-out costs parameters;
- the *Logistics Internal Costs* section which contains parameters like the fine cost for retailers/suppliers, the time after which the warehouse has to pay fines to retailers, the time after which suppliers have to pay fines to the warehouse.

The Output Section provides all the parameters necessary to evaluate and monitor the warehouse performances. These parameters are:

- the forklifts utilization level;

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

The upper part of Figure 2 shows the GUI Input Section while the lower part shows the Output Section.

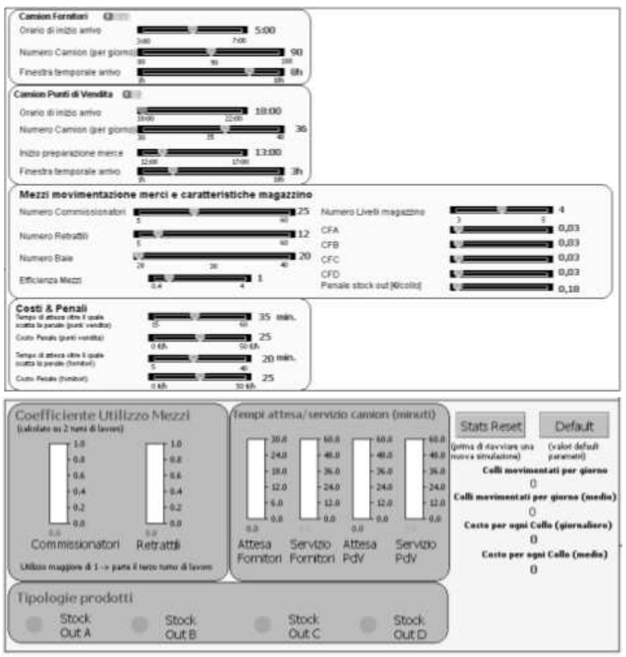

Figure 2. The Simulation Model GUI including the Input and Output Sections

4. WAREHOUSE OPERATIVE SCENARIOS AND EXPERIMENTS PLANNING

As before mentioned, the objective of this research work consists in evaluating the analytical relationships between the system input parameters and the performance measures chosen in order to build a valid tool for a correct warehouse design and management.

In this paper, the authors adopt the Design of Experiments (*DOE*) as a systematic approach to change the input parameters and define a number of different warehouse operative scenarios.

The input parameters (*factors* or *design variables*) considered for the DOE are:

- the number of suppliers' trucks per day (*DST*);
- the number of retailers' trucks per day (*DRT*);
- the number of forklift (*F*);
- the number of lift trucks (*L*);
- the number of shelves levels (*SL*).

The performance measures (*response variables*) monitored are:

- the waiting time of suppliers' trucks before starting the unloading operation (*STWT*);
- the waiting time of retailers' trucks before starting the loading operation (*RTWT*).

The table below reports factors and levels adopted for the DOE.

Table 1. Factors and levels for DOE

Factors	*Level 1*	*Level 2*
DST	80	100
DRT	30	40
F	6	24
L	12	50
SL	3	5

As reported in Table 1, for each factor two levels are considered: Level 1 which represents the lowest value for the factor and Level 2 which is its greatest value.

Adopting a Full Factorial Design for testing 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

Analyzing simulation results by means of *ANOVA,* effects and interaction graphs, it is possible to:

- identify and evaluate the weight of those factors that affect the performance indexes (*sensitivity analysis*);
- deduce an analytical tool capable of expressing the performance measures as function of the most critical factors.

Equation 1 expresses the i-th performance measure as linear function of the factors without considering fourth and fifth order effects because they are negligible.

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

where:

- Y_i is the i-th performance measure;
- x_i is the i-th factor;
- 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;
- ε_{ijhkpn} is the error term;
- *n* is the number of total observations.

Next Section proposes results analysis for the two performance parameters monitored:

- the waiting time of suppliers' trucks before starting the unloading operation (*STWT*);
- the waiting time of retailers' trucks before starting the loading operation (*RTWT*).

5.1. Suppliers' waiting time before unloading operations

The first analysis carried out aims at detecting factors that influence the waiting time of suppliers' trucks before starting the unloading operation (*STWT*) in order to introduce an analytical relation between design and response variables.

Adopting a confidence level 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 Pareto Chart in Figure 3 points out factors that influence the response parameter STWT. These factors are:

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

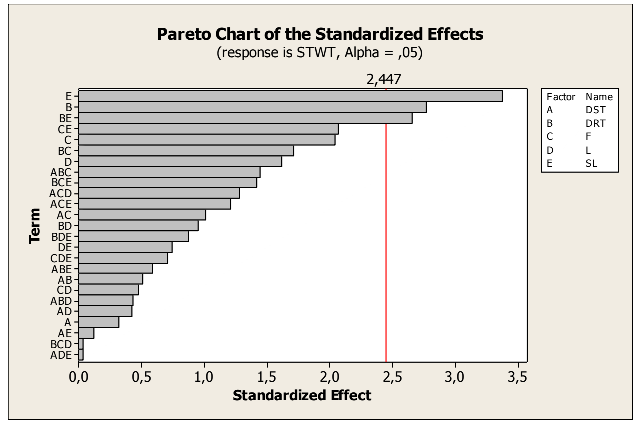

Figure 3. The Pareto Chart for the STWT

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 adopted, as reported in Table 2.

Table 2. ANOVA results for the most significant factors

Source	DF	AdjSS (10^4)	AdjMS (10^4)	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 relation between the STWT parameter and the most significant factors is reported in Equation 2:

$$STWT = 713{,}58 - 24{,}19 * DRT - 234{,}32 * SL + 8{,}17 * (DRT * SL) \quad (2)$$

This equation can be adopted for correctly explaining how the waiting time of suppliers' trucks before starting the unloading operation changes in function of the system available resources.

5.2. Retailers' waiting time before loading operations

The same analysis has been carried out taking into consideration the waiting time of retailers' trucks before starting the loading operation (*RTWT*).

Figure 4 shows the Normal Probability Plot of the Standardized Effects in which the predominant effects can be distinguished; in this case they are the first order effects and some effects of the second and third order:

- the number of retailers' trucks per day (*DRT*);
- the number of lift trucks (*L*);
- the number of shelves levels (*SL*);
- the interaction factor between DST and DRT (*DST*DRT*);
- the interaction factor between DST and F (*DST*F*);
- the interaction factor between DRT and SL (*DRT*SL*);
- the interaction factor between F and L (*F*L*);
- the interaction factor between F and SL (*F*SL*);
- the interaction factor between DRT, F and SL (*DRT*F*SL*);
- the interaction factor between F, L and SL (*F*L*SL*).

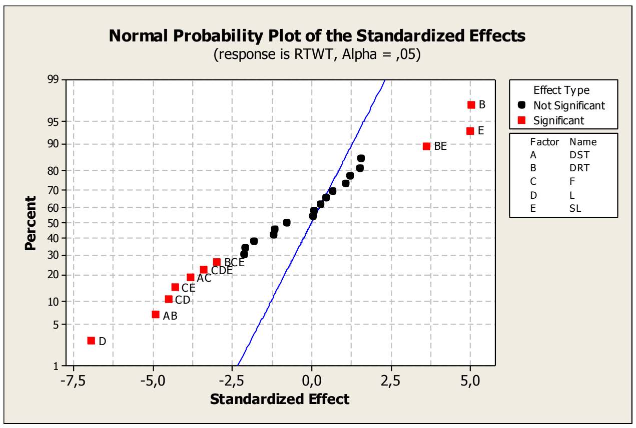

Figure 4. The Normal Probability Plot for the RTWT

Table 3 reports the *p-value* for the predominant effects while Equation 3 describes the analytical relation between the RTWT parameter and the predominant effects:

$$
\begin{aligned}
RTWT &= 2618{,}43 - 131{,}25 * DRT + 31{,}59 * L + \\
&- 1662{,}99 * SL + 0{,}81 * (DST * DRT) + \\
&- 0{,}29 * (DST * F) + 59{,}30 * (DRT * SL) + \\
&+ 1{,}22 * (F * L) + 10{,}27 * (F * SL) + \\
&- 0{,}73 * (DRT * F * SL) - 0{,}22 * (F * L * SL)
\end{aligned}
\qquad (3)
$$

Figure 5 plots Equation 3 in terms of main effects: each plot provides additional information about the effects of the most significant factors on the response variables.

Considering the DRT parameter, if the number of retailers' trucks per day increases the waiting time of retailers' trucks before starting the loading operation (*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 (*L*) from its low to high value, the RTWT drops off.

Table 3. ANOVA results for the most significant factors

Source	DF	AdjSS (10^4)	AdjMS (10^4)	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		
Total	31				

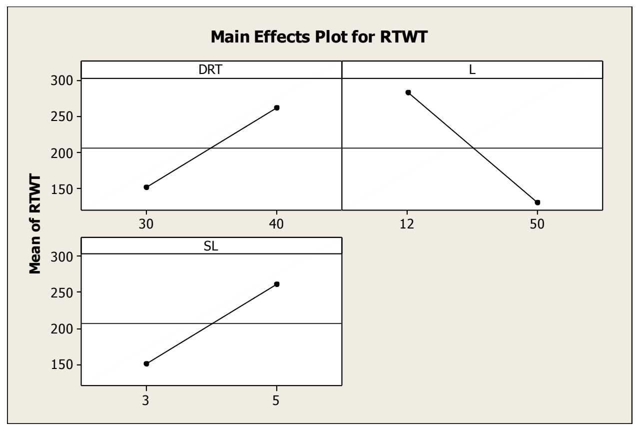

Figure 5. Main Effects Plots for RTWT

Figure 6 shows simulation results for the RTWT parameter projected on a cube considering the DRT, L and SL parameters. At each corner of the cube the RTWT values are reported: setting L at its high value while DRT and SL at their low values is the best choice to obtain the lowest RTWT value.

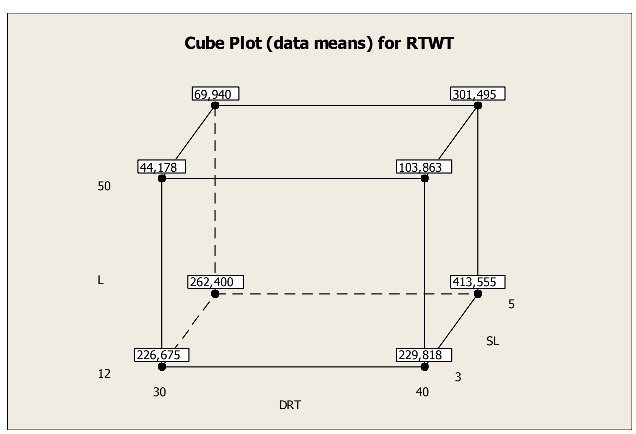

Figure 6. Cube Plot for RTWT

Moreover, Figure 7 reports the three-dimensional surfaces of the response parameter in function of different combinations of the input parameters.

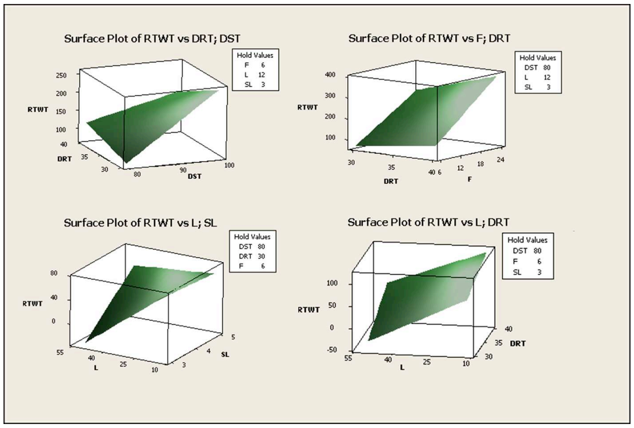

Figure 7. Response Surfaces for RTWT

6. CONCLUSIONS

This paper aims at the investigation of the effect of some critical input parameters (the number of suppliers' and retailers' trucks per day, the number of forklift and lift trucks, the number of shelves levels) on the waiting time of suppliers'/retailers' trucks before starting the unloading/loading operation.

To this end the authors developed a simulation model, implemented in Anylogic™, supported by a Graphic User Interface for monitoring the most important warehouse performance measures.

The Full Factorial Design is adopted for testing all the possible factors combinations while simulation results have been studied by means of ANOVA in order to evaluate the input-output analytical relationships which become powerful tools for warehouse design and management.

References

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

Ashayeri, J., Gelders, L.F., 1985. Warehouse design optimization. *Operational Research*, 21, 285–294.

Bocca, E., Curcio, D., Longo, F., Tremori, A., 2008. Warehouse and Internal Logistics Management based on Modeling & Simulation. *Proceedings of the I3M 2008 Multiconference*, September 17-19, Campora S.Giovanni (CS), Italy.

Callahan, R.N., Hubbard, K.M., Bacoski, N.M., 2006. The use of simulation modeling and factorial analysis as a method for process flow improvement. *Advanced Manufacturing Technology*, 29 (1-2), 202–208.

Daniels, R. L., Rummel, J.L., Schantz, R., 1998. A model for warehouse order picking. *European Journal of Operational Research,* 105 (1), 1–17.

De Koster, R., Le-Duc, T., Roodbergen, K., 2007. Design and control of warehouse order picking: a literature review. *Operational Research*, 182, 481–501.

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

Eben-Chaime, M., Pliskin, N., 1997. Operations management of multiple machine automatic warehousing system. *Production Economics*, 95, 373–385.

Galbraith, L., Standridge, C.R., 1994. Analysis in manufacturing systems simulation: a case study. *Simulation*, 63 (6), 368–375.

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

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

Hsieh, L., Tsai, L., 2006. The optimum design of a warehouse system on order picking efficiency. *International Journal of Advanced Manufacturing Technology*, 28, 626 – 637.

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.

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*, 54 (3), 570-588.

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

Macro, J.G., Salmi, R.E., 2002. A simulation tool to determine warehouse efficiencies and storage allocations. *Proceedings of the 2002 Winter Simulation Conference.*

Montgomery, D.C. and Runger, G.C., 2003. *Applied statistics and probability for engineers*. 3rd ed. London: McGraw-Hill.

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

Biographies

FRANCESCO COSTANTINO: BSc in Mechanical Engineering, Master Degree in Quality Management and Engineering and Ph.D. in Engineering of Industrial Production, he is an assistant professor of Mechanical and Industrial Plants at the Faculty of Engineering, University of Rome "La Sapienza".

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.

GIULIO DI GRAVIO: BSc in Mechanical Engineering, Master Degree in Quality Management and Engineering and Ph.D. in Engineering of Industrial Production, he is a researcher of Mechanical and Industrial Plants at the Faculty of Engineering, University of Rome "La Sapienza".

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 an assistant professor at the Mechanical Department (Industrial Engineering Section) of University of Calabria. His research interests regard work measurement and human reliability.