LOGISTICS AND TRANSPORTATION WITHIN THE RETAIL SECTOR: SENSITIVITY ANALYSIS ON THE DISTRIBUTION SYSTEMS

Antonio Cimino[(a)], Duilio Curcio[(b)], Francesco Longo[(c)], Giovanni Mirabelli[(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, f.longo, g.mirabelli}@unical.it

ABSTRACT

In the following paper the effect of some critical parameters on the efficiency of a logistics & transportation system operating within the supply chain supporting the large scale retail sector is presented. In particular a three stages supply chain made up by 5 suppliers, 3 distribution centres and 120 stores, is considered. A Modelling & Simulation based approach is used for investigating the relationship between the mean service level provided to customers and the organization of the unloading and loading operations at the distribution centres. To this end two critical parameters (the trucks arrival time and the trucks waiting time at the distribution centres) are considered.

Keywords: Logistics & Transportation, Dustribution systems, Modelling, Simulation,

1. INTRODUCTION

Efficient logistics and transportation processes should have as priority objective the complete fulfilment of customers' need, guarantying the right products at the right time, complying with delivery schedules, respecting required conditions and minimizing logistics and transportation costs.

An efficient logistics & transportation system within the retail sector is characterized by a number of critical points: huge number of supply chain actors located in different regions (suppliers, distribution centres and stores), thousands of items type, different alternatives for transportations; furthermore in the case of the fresh food (i.e. fish or meat) additional critical aspects regards stocking rules, items deterioration and food quality preservation.

Note that the interactions among the logistic flows that take place inside the distribution centres can strongly affect the service level provided to final stores. In effect within each distribution centre suppliers' deliveries need to be divided, mixed (for creating the assortment required by each store), loaded on trucks and finally shipped to each store. The capability to optimize the trucks loading scheduling plays an important role and impacts the system efficiency. Each truck loading operation should be scheduled trying to fill the stores orders in terms of ordered quantity.

There are many examples in which inadequate supplies and communications caused the decrease of business market shares associated to revenues reduction and lower quality of services to customers. Among the various tools at present available for planning, analysing and managing logistics and distribution systems, simulation plays a critical role. Logistics simulation models are used for planning and analysing the supplies and communications chains and to test different possible scenarios such as changes in transportation modes (by rail, ship etc. or multi-pick and multi-drop strategies), supply management policies as well as products demand fluctuations.

The present work focuses on the distribution system within a supply chain devoted to support the large scale retail sector. In particular the main goal of the research work is to investigate the effects of trucks arrival time and trucks waiting time at the distribution centres on the mean service level provided to final stores.

Before getting into the details of the paper let us give a brief summary of the paper. Section 2 describes processes and activities that take place within the supply chain. Section 3 presents the experiments carried out by using the simulation model and section 4 the results analysis. Finally the conclusions that summarize the main results achieved by the research work and the research activities still on going.

2. THE SUPPLY CHAIN AND THE DISTRIBUTION PROCESS

The figure 1 shows the flows of products and information within the supply chain. We focalize on logistics and transportation of fresh products (the supply chain considered operates in the south part of Italy, Calabria). Final stores emit purchase orders in the morning before 9.00 am. The deliveries related to such orders reach the stores the morning after. Purchase orders are sent to the distribution centres that according to items availability, sent new orders to suppliers (suppliers selection is made according to pre-defined percentages or according to suppliers prices).

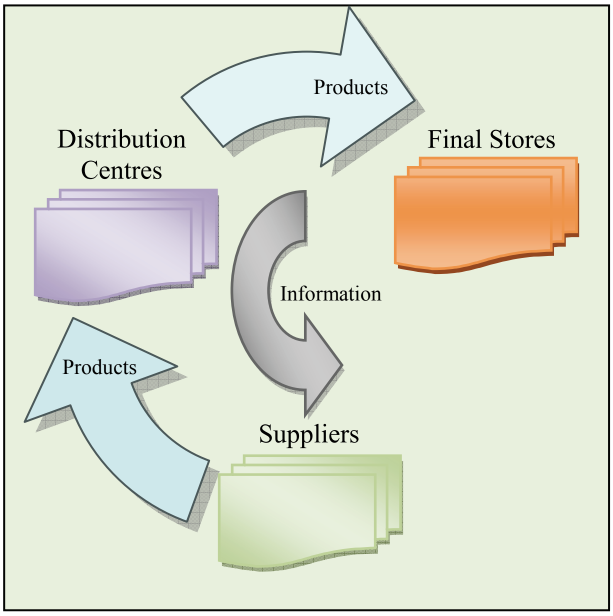

Figure 1 – Supply Chain actors, flow of products and flow of information

As before mentioned the purchase orders regard fresh products, so each supplier informs the distribution centres about its products delivery schedule, based on the number of orders received. Such information is sent before the 12.00. According to the suppliers' products delivery schedule, the distribution centres organize and schedule the delivery missions to stores.

Note that a truck should leave the distribution centre for delivering mission only when all the items required by the stores are available. Let us use the following notation:

- I_{ij} : quantity of the item *i-th* required by customer *j-th*
- I_{ia} : quantity of the item *i-th* delivered by the supplier *a*
- I_{ib} : quantity of the item *i-th* delivered by the supplier *b*
- Q_{ic} : quantity of the item *i-th* delivered by the supplier *c*
- t_a : Supplier *a* delivery schedule
- t_b : Supplier *b* delivery schedule
- t_c : Supplier *c* delivery schedule

Consider the logic used by the distribution centres for missions planning. Let us consider the case of a single item (the item *i-th*). The total quantity of the item *i-th* increases as the time goes by (in correspondence of each supplier's delivery). The quantity I_{ij} of the item *i-th* required by store *j-th* is available at the distribution centre by the time t_c.

By generalising to *n* items, trucks arrivals at the distribution centre should be scheduled by the time t_k in order to provide the store with the required quantity of items (or to minimize the lost quantity). Note that the grater is the time t_k for truck arrival at the distribution centre, the higher could be the probability to completely fill the store order. To this end the trucks arrival at the distribution centre is usually scheduled by adding to the time t_k an additional time called t_{ad}.

The historical data analysis shows that the fill rate provided by suppliers to distribution centres is lower than one; in other words, it can happen that the quantity produced and shipped by suppliers is lower than the quantity ordered by the distribution centres. For each suppliers and distribution centre, we were able to identify the probability to have quantity produced and shipped equals to quantity ordered and the probability that the quantity produced and ordered takes a value between zero and the quantity ordered (i.e. this happens in the case of transportation or production problems).

Due to the problems above mentioned, the distribution centres can receive items quantity lower than the required quantity and they have to perform items distribution to stores according to stores importance (usually defined by a priority number) and to trucks waiting time at the distribution centres.

Trucks organisation in the distribution centre is scheduled as follows: the truck reaches the distribution centre at a given time as estimated in the evaluation phase. If the quantity of items ordered by the overriding store is already available, the truck is loaded and it leaves the distribution centre to supply the products.

In case the amount of products in the warehouse is not enough to fill the order of the overriding store, the operators check whether further deliveries from suppliers are scheduled. In case other deliveries are expected, the truck is put on hold for a certain time interval; otherwise, available products are loaded and the truck leaves the distribution centre to deliver such products to the store. In case no products are available, the truck leaves the distribution centre if and only if returns must be collected at the store.

Note that the time interval during which trucks wait at the distribution centres for suppliers' deliveries (let us indicate this time with t_w) has an impact on the fill rate provided to customers. Moreover, in case after the t_w time interval, no additional supplies are delivered, the truck is loaded with available items and leaves the distribution centre to deliver them and/or to collect returns. In addition another parameter affecting the fill rate provided to stores is the time t_{ad} added to the estimated trucks arrival time at the distribution centre.

The objective of the analysis being proposed in the paper is to understand the effect of the t_w and t_{ad} on the fill rate provided to stores. Let $Ir_{i,j}$ be the quantity of the item *i-th* received by the store *j-th*, let $I_{i,j}$ be the total quantity if the item *i-th* required by the store *j-th*, the fill rate F_r is defined as follows.

$$F_r = \frac{\sum_{i=1}^{n} Ir_{i,j}}{\sum_{i=1}^{n} I_{i,j}} \qquad (1)$$

Different measures of the fill rate can be evaluated by using equation 1 in correspondence of different instant of time: i.e. the fill rate can be evaluated early in the morning (before trucks departure from the distribution centres) and at 10:00 am for those trucks/stores waiting for additional deliveries from suppliers.

In order to carry out the analysis before mentioned, we implemented a discrete event simulation model of the supply chain. The main modelling steps are include the supplier, distribution centre and store classes implementation, the integration of the supply chain actors within a cooperating network (flow of items and information). Within each class specific activities were implemented: orders out, pallets unloading, control of incoming items, returns loading trucks (stores); customers' order acceptance, suppliers' selection, suppliers trucks unloading, items mixing, pallets and trucks loading for stores deliveries (stores); orders acceptance, production, items loading on pallets and on trucks (suppliers).

From a Modelling & Simulation point of view the system under consideration is a terminating system since simulation duration is a natural consequence of the model and of its assumptions. In this type of system the results accuracy only depends on the number of replications evaluated so as to ensure a confidence interval of 95% concerning the fill rate. By replicating 5 times each simulation runs we found out that the simulated fill rate confidence interval is similar to the real system fill rate confidence interval.

The simulation model was implemented to carry out the analysis of sensitivity on the trucks waiting time at the distribution centre, t_w and on the additional time, t_{ad}, in order to evaluate their impact on the fill rate provided to stores.

Let *h* be the number of final stores, the mean fill rate in output from the generic simulation run *k* is defined as follows:

$$\overline{F_{r,k}} = \frac{\sum_{k=1}^{5} F_{r\,h,k}}{5} \quad (2)$$

3. EXPERIMENTAL DESIGN AND SENSITIVITY ANALYSIS

The validity of the simulation results obviously depends on how experiments are carried out. Due to this reason, in the present work simulation runs were carried out by using the Design of Experiment (DOE).

The sensitivity analysis concerning the effect of t_w and t_{add} (factors) on the fill rate F_r provided to stores (performance measure) has been carried out by using the factorial experimental design. In a factorial experimental design, simulation runs are made for all possible level combinations of the factors taken into account. Simulation results obtained according to the factorial experimental design have been then analyzed by using the Analysis of Variance. For each factor five different levels have been considered, as reported in table 1. TAC and FS are fixed factors, in fact the aim of the analysis is not to draw conclusions on the entire population of factors levels, but to focus only on the values selected for experiments shown in Table 1.

Table 1 – Five different levels for each factor

	t_w	t_{ad}
Level 1	0	0
Level 2	30 min	30 min
Level 3	60 min	60 min
Level 4	90 min	90 min
Level 5	120 min	120 min

Table 2 shows experiments results in correspondence of each different combination of the factor level, in terms of mean fill rate provided to final stores. Note that for each scenario 5 different replications are reported.

3.1 Sensitivity analysis

The aim of the sensitivity analysis is twofold: (i) identify the effect of t_w and t_{add} on the mean fill rate provided to stores; to this end we aim at evaluating an analytical model (usually called meta-models of the simulation models) capable of expressing the performance measure (the mean fill rate) as function of the critical parameters being considered (also conducting a sensitivity analysis devoted to eliminate insignificant effects); (ii) identify the optimal trucks organization at the distribution centre both in terms of trucks waiting time and trucks arrival time at the distribution centres. The input output analytical model should be as follows.

$$\overline{F_{r\,ijk}} = \mu + t_{wi} + t_{adj} + (t_w * t_{ad})_{ij} + \varepsilon_{ijk} \quad (3)$$

$i = 1.....,5$; number of levels of factor t_w;
$j = 1.....,5$; number of levels of factor t_{ad};
$k = 1.....,5$; number of replications.

In equation (3), μ is the global average of the simulation results, t_{wi} is the main effect on F_{rijk} of the *i-th* level of t_w, t_{adj} is the main effect on F_{rijk} of the *j-th* level of t_{ad}, $(t_w*t_{ad})_{ij}$ is the effect on F_{rijk} of the interaction between the *i-th* level of t_w and the *j-th* level of the t_{ad}, while ε_{ijk} is a component of casual error normally distributed with zero mean and variance σ^2.

The sensitivity analysis allows to understand the importance of the main effects t_w and t_{ad} as well as the importance of the interaction effects $t_w * t_{ad}$. To this end an effect can be neglected when by changing the level of the factor there is no effect on the mean fill rate. On the contrary, the effect has to be considered when the levels of the factor have an impact on the average value of the fill rate. It is common knowledge that a sensitivity analysis can be carried out by using the Analysis of Variance (ANOVA). In effect the ANOVA factorises the total variability of detected data in different components and compares the different components by using a Fisher statistics.

Table 2 – Simulation results

t_w	t_{ad}	F_{rijk}				
0	**0**	0.87	0.90	0.87	0.88	0.85
0	**30**	0.83	0.84	0.91	0.85	0.89
0	**60**	0.88	0.89	0.84	0.89	0.80
0	**90**	0.83	0.87	0.83	0.87	0.89
0	**120**	0.85	0.88	0.80	0.86	0.88
30	**0**	0.87	0.90	0.85	0.88	0.85
30	**30**	0.84	0.85	0.90	0.85	0.89
30	**60**	0.90	0.85	0.80	0.87	0.77
30	**90**	0.84	0.88	0.82	0.89	0.90
30	**120**	0.84	0.90	0.79	0.86	0.90
60	**0**	0.85	0.84	0.84	0.84	0.83
60	**30**	0.80	0.83	0.89	0.80	0.87
60	**60**	0.89	0.85	0.79	0.85	0.76
60	**90**	0.80	0.82	0.81	0.87	0.87
60	**120**	0.83	0.88	0.78	0.84	0.88
90	**0**	0.85	0.84	0.84	0.84	0.83
90	**30**	0.80	0.81	0.89	0.80	0.87
90	**60**	0.89	0.85	0.79	0.85	0.76
90	**90**	0.80	0.82	0.81	0.87	0.87
90	**120**	0.83	0.88	0.78	0.84	0.88
120	**0**	0.85	0.84	0.84	0.84	0.83
120	**30**	0.80	0.81	0.89	0.80	0.87
120	**60**	0.89	0.85	0.79	0.85	0.76
120	**90**	0.80	0.82	0.81	0.87	0.87
120	**120**	0.83	0.88	0.78	0.84	0.88

Let MS and DOF and α respectively be the mean squares of the factors being considered, the degree of freedom and the confidence level and let *f* be the Fisher Statistics; the comparison between the different components of the total variability is expressed by equation 4 for the components of the variability related to the truck waiting time t_w.

$$F_0 = \frac{MS(t_w)}{MS_E} > f_{\alpha,\,DOF(tw)DOF(\varepsilon)} \qquad (4)$$

The effect cannot be neglected (it has an impact on the fill rate) when – at a confidence level α (in this specific case α=0.05) – the ratio F_0 is higher than the value *f* of the Fisher statistics that depends on α and on the degrees of freedom. The effect importance can also be estimated by comparing the probability that the value *f* is higher than F_0 with a level of confidence α. In this case the effect has an impact on the fill rate when this probability is equal to, or lower than the selected confidence level.

Table 5 reports the results of the analysis of variance, the last column indicated the probability value (*P*) that *f* is higher than F_0.

The results of the analysis of variance show that both the main effects of t_w and t_{ad} have an impact on the mean fill rate. On the contrary the interaction effect can be neglected.

Figure 4 shows, respectively, the trend of the mean fill rate when factors t_w and t_{ad} change. Note that by increasing the trucks waiting time at the distribution centre, the mean fill rate provided to stores decreases from 0.87 to 0.84. A different behaviour can be found in the mean fill rate versus t_{ad} graph: the higher is the additional time the lower is the mean fill rate provided to store (if 0 min < t_{ad} < 60 min); for t_{ad} > 60 min the mean fill rate increases again.

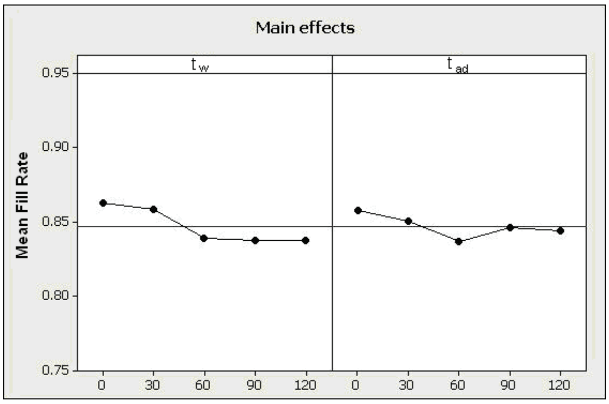

Figure 2. Main effects of t_w and t_{ad} on the mean fill rate provided to stores

The figure 5 shows the mean fill rate by contemporarily changing t_w and t_{ad}. Such graph can be used for understanding the best combination of the factors levels (the combination guarantying the highest mean fill rate). The highest mean fill rate is obtained when t_w = 30 min and t_{ad} = 0 min.

Note that the starting hypotheses of the analysis of variance assume that the observations are normally and independently distributed, with the same variance for any combination of levels of factors. These assumptions are usually verified by using the residuals analysis. A residual is the difference between an observation in terms of fill rate and the corresponding average value calculated on the 5 simulation replication.

Table 3. Analysis of Variance for LS

Source of variation	Sum of squares	DOF	Mean Square	F_0	P
t_w treatments	0.030044	4	0.007511	5.63	0.000
t_a treatments	0.011800	4	0.002950	2.21	0.069
t_w*t_{ad} interaction	0.002016	16	0.000126	0.09	1.000
Error	0.299980	225	0.001333		
Total	0.343840	249			

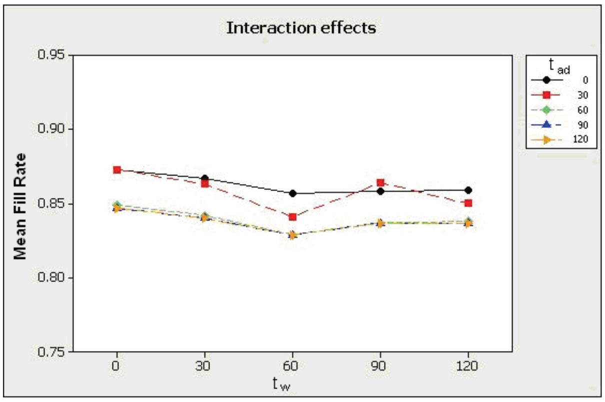

Figure 3. Interaction effects of t_w and t_{ad} on the mean fill rate provided to stores

3.2 The residuals analysis

As before mentioned the validity of the analysis of variance results can be tested by using the residuals analysis.

The assumption of normality can be tested by building a normal probability plot of residuals. If residuals approximately fall on a straight line passing form the centre of the graph, the assumption of normality can be accepted. In Figure 4 we can observe that, in the case being analyzed, the deviation from normality is not severe.

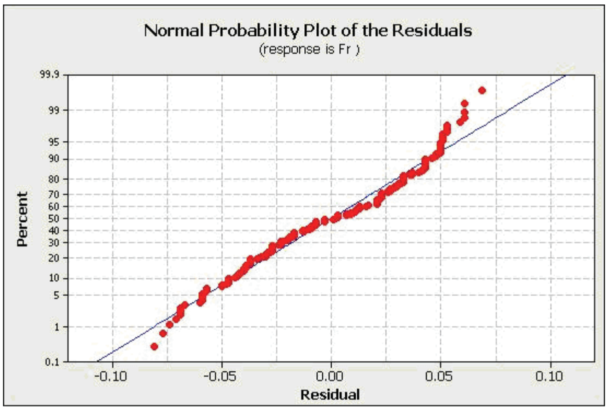

Figure 4. Normal Probability plot of residuals for testing the assumption of normality.

The assumption of equal variance can be tested by plotting residuals against the levels of factors or against the level of the average fill rate: residuals variability must anyhow not depend on the level of factors or on the mean fill rate. Figure 5 and 6, respectively, show residuals versus t_w and versus the mean fill rate and do not show any particular trend; therefore, the equal variance hypothesis can be accepted.

Finally, the assumption of independence can be tested by plotting residuals against the implementation order of the simulation runs. A sequence of positive or negative residuals could indicate that observations are not independent among themselves. Figure 79 shows that the hypothesis of independence of observations can be accepted.

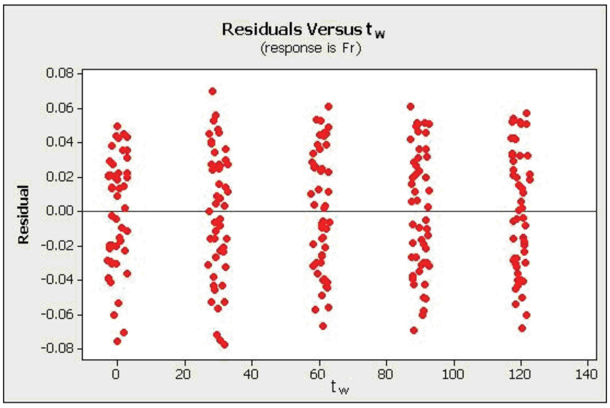

Figure 5. Residuals versus the trucks waiting time, t_w

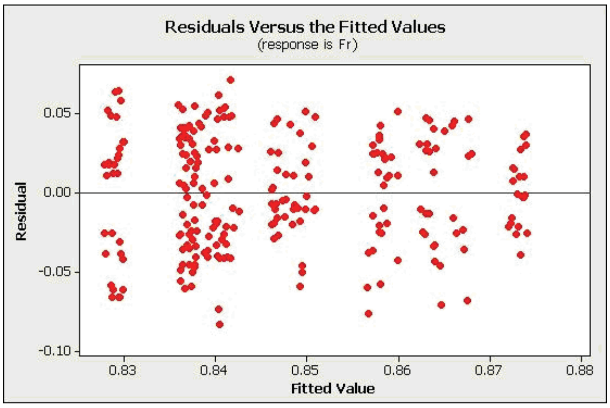

Figure 6. Residuals versus the fill rate values

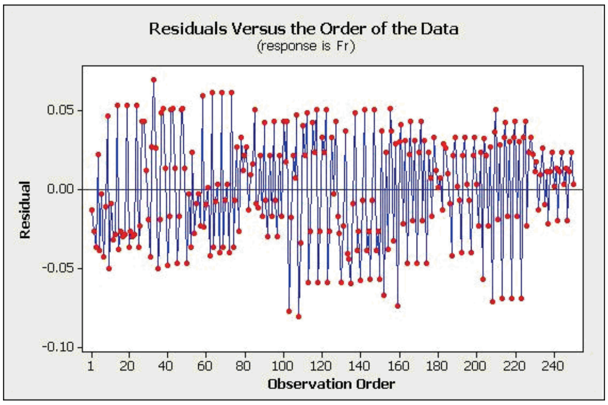

Figure 7. Residuals versus order of the data

4. CONCLUSIONS

The paper investigates the effect of some critical parameters on the efficiency of a logistics & transportation system operating within the supply chain supporting the large scale retail sector. In particular the attention is focused on trucks loading and unloading operations at the distribution centres. The results analysis shows that the trucks estimated waiting time and the distribution centre and the additional time on the estimated trucks arrival time can strongly affect the service level provided to final stores.

REFERENCES

Ballou R., 2003. *Business Logistics/Supply Chain Management*. Prentice Hall, Readings.

Banks, J., 1998. *Handbook of Simulation*. New York: Wiley Interscience.

Birkin, M., Clarke, G., Clarke, M.P, 2002. *Retail Intelligence and Network Planning*. New York: J.Wiley.

Blackwell, R.D., 1997. *From Mind to Market*. New York: Harper-Collins Publisher.

Bruzzone A.G., Simone S., Bocca E., 2004. Intelligent Management of a Logistics Platform for Fresh Goods. *Proceedings of SCI2004, Orlando, July.*

Bruzzone A.G., Mosca R., Briano C., Brandolini M. 2000. Models for Supporting Customer Satisfaction in Retail Chains. *Proceedings of HMS, Portofino, October 5-7.*

Curcio, D., Longo, F., Mirabelli, G., 2007. Inventory policies comparison in a manufacturing process using modeling & simulation. *Proceedings of the International Mediterranean Modelling Multiconference,* pp. 237 – 242. October 04 – 06, Bergeggi (Italy).

De Sensi, G. , Longo, F., Mirabelli, G., 2007. Inventory policies analysis under demand patterns and lead times constraints in a real supply chain. *International Journal of Production Research*, doi: 10.1080/00207540701528776

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*, Vol 54(3), 570-588.

Longo, F., Mirabelli, G., Papoff, E., Modeling Analysis and Simulation of a supply chain devoted to support pharmaceutical business retail, *Proceedings of the 18th International Conference on Production Research, July 31 – August 4 , Salerno, Italy.*

Monks, J.G., 1996. *Operations Management*, New york: McGraw Hill.

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

O'Leary, D.E., 2000. *Enterprise Resource Planning Systems: Systems, Life Cycle, Electronic Commerce, and Risk*. Cambridge University Press.

Roberson, J.F, 1994. *Logistics Handbook*. Free Press.

Seifert, D., Marzian, R., McLaughlin, J., 2003. *Collaborative Planning, Forecasting, and Replenishment: How to Create a Supply Chain Advantage*. Amacom

Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E. *Designig and Managing the Supply Chain.* McGraw-Hill.

AUTHORS BIOGRAPHY

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, artificial intelligence and Modeling & Simulation tools for the effective workplace design.

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.

FRANCESCO LONGO took the degree in Mechanical Engineering from University of Calabria (2002) and the PhD in Industrial Engineering (2005). He is currently researcher at the Mechanical Department (Industrial Engineering Section) of University of Calabria. His research interests regard modeling & simulation of manufacturing systems and supply chain management, vulnerability and resilience, DOE, ANOVA. He is Responsible of the Modeling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES).

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.