SIMULATION AND OPTIMIZATION OF PRODUCTION SYSTEM BASED ON FUZZY LOGIC AND QUICK RESPONSE MANUFACTURING

Centobelli P. [(a)], Murino T. [(b)], D'Addona D. [(c)], Naviglio G. [(d)]

[(a), (b), (c), (d)] *Department of Materials and Production Engineering*
University of Naples Federico II, Naples, Italy
P.le Tecchio 80, 80125, Naples, Italy

[(a)] piera.centobelli@unina.it, [(b)] murino@unina.it, [(c)] daddona@unina.it, [(d)] giuseppe.naviglio@unina.it

ABSTRACT
Since 1979, european and american clients had benchmarked the performance of theirs factories with those of Japanese competitors. The differences included substantially higher productivity, better quality, significantly less inventory, less space, more flexibility and much faster throughput times. Everyone knows that time is money and mangers understand the importance of quick response to customers. Lean Manufacturing techniques can be powerful in several situations, but for companies making a large variety of products with variable demand or companies making highly engineered products, Lean Manufacturing has several drawbacks. Quick Response Manufacturing (QRM) can be more effective competitive strategy for companies targeting such markets, which focuses on lead time reduction. The importance of define the lead time required in an engineer-to-order company is critical in particular during the New Product Development (NPD) process. This paper presents how to apply Quick Response Manufacturing to a manufacturing industry through the previous calculation of product components Run Time using a Fuzzy Logic approach, in order to predict whether a decision will improve lead times.

Keywords: Fuzzy Logic, quick response manufacturing, processing time, new product development

1. INTRODUCTION

In the past few years the world attend a rapid growth in the number of options provided by manufacturers to their customers. Even beyond providing pre-specified options though, is the fact that the modern technology has given companies the ability to custom-engineer and then manufacture products for individual clients without incurring the high additional costs that such customization would have required two decades ago.

Along with this has come the power of internet, which allows customers to easily evaluate many different options and select from them. All of these development mean that there will be increasing demand for customized products in the 21st century (D'Addona and Teti, 2008). Today customers expect products to be delivered with a much shorter lead time than was acceptable in the past (Converso, Santillo and De Vito, 2013), (Chiocca, Guizzi, Murino, Revetria and Romano, 2012), (Converso, Aveta, Santillo and Gallo, 2012).

The improvement of flexibility has become increasingly important as a method to achieve competitive advantage in manufacturing (Beckman, 1990), (DeMeyer et al., 1989§), (Holusha, 1989), (Goldhar and Jelinek, 1983), (Zelenovic, 1982).

Flexibility may be seen as both a set of capabilities (internal) and a source of competitive advantage in a particular environment (external). It is important to distinguish the (internal) capability of being flexible from the (external) competitive need it is intended to match or the advantage derived from it (Shaouta and Al-Shammari, 1998). A possibility is to build capabilities which allow the manufacturing system to switch effortlessly and quickly between products, avoiding the carrying cost of the inventory and facilitating "just-in-time" production. This internal form of flexibility has been termed mobility, see (Upton, 1994),(Murino, Romano and Santillo, 2011),(Guizzi, Chiocca and Romano 2012).

Recently, many manufacturing companies affected by the economic slump due to challenge of competition by low-wage countries in the globalized market have looked inward, struggling to find ways to reduce response time, improve quality and costs (Suri, 2003).

The ability to change the product being manufactured quickly, on an on-going basis is the capability which most frequently supports the ability to provide quick response (Danny J. Johnson, 2003). And this is where Quick Response Manufacturing (QRM) comes in. These strategy enables companies to dramatically shorten their lead times to deliver products faster and, at the same time, improving their quality.

Factories lead times, work-in-process and actual capacities are all the result of complex dynamics and interactions on the manufacturing shop floor. A powerful methodology, called Rapid Modeling Technology (RMT), describes factory floor dynamics particularly well. An easy-to-use software tool (based on RMT) to assist companies in achieving and sustaining quick response in their manufacturing is the

MPX®. MPX® can assist engineers and managers analyze their operations to find opportunities for improvements related capacity, work-in-process, labour allocation, new product introduction and many other manufacturing issues. The key issue here is that lead time depends on both processing time and queue time that is the time parts spend waiting to get their turn at machines when the machines are busy.

While processing time may be known based on the machining parameters, queue time depends on many "dynamic" factors such as, which other parts are already in queue to use the machine, whether the machine has broken down, whether an operator is available, and so on. In order to predict whether a decision will improve lead times, it is thus necessary to be able to predict these queue times, which means any lead time reduction tool must model these dynamics and interactions. The RMT technology in MPX© models these complex dynamics of the manufacturing facility in terms of mathematical equations. Until a few years ago, these equations couldn't be solved. However, with the progress that has been made in queuing theory in recent years, very good estimates can now be obtained for system performance with amazingly little computer time, often just seconds on a personal computer (MPX user manual).

In this paper the MPX© has been used to simulate 'what if' scenarios which impact a variety of manufacturing parameters, including parts routing, labour, equipment, equipment failure/repair, set-up, run time and lot size.

The software has help the experts to evaluate the effects of alternative management decisions during the new product development. It helps in obtaining an insight into the factors that influence the lead time performance of cells and establish what would be the ideal cell configuration. The components processing time has calculated using a fuzzy approach.

The process followed is shown in Figure 1.

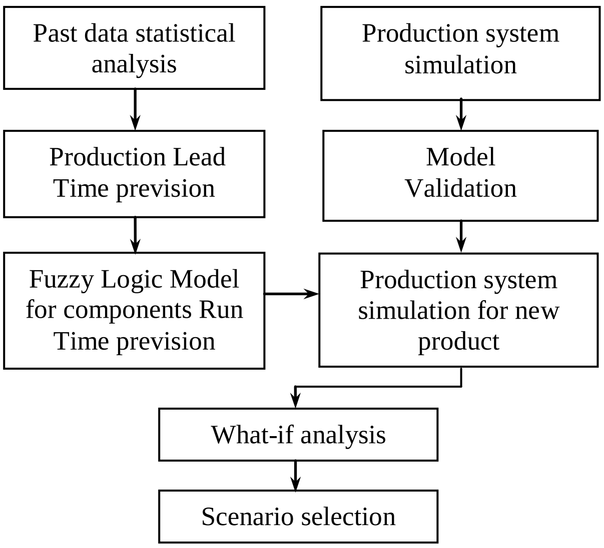

Figure 1: Application Architecture

2. STATISTICAL ANALYSIS

The product at issue is a gas turbine coating for thermal and sound insulation. The gas turbine can be divided in six different macroareas similar for geometric structure. However every component runs the same operations routing shown in Figure 2.

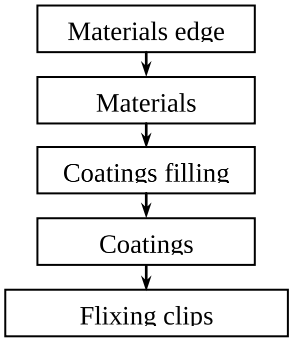

Figure 2: Components operations routing

First were analyzed labours daily work schedules related to time spent by each for every commission and for each operations. Time has been plotted choosing a significant feature as allocation base for each operation routing as shown in Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7 dividing two-dimensional (2D) and three-dimensional (3D) case for 2D and 3D components.

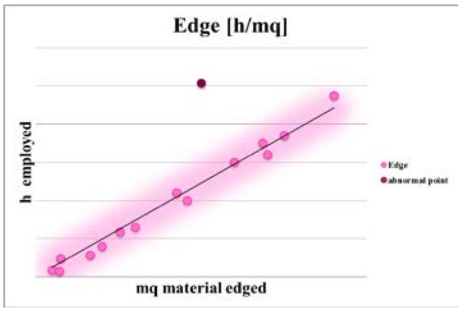

Figure 3: Materials edge

Figure 4: Materials sewing

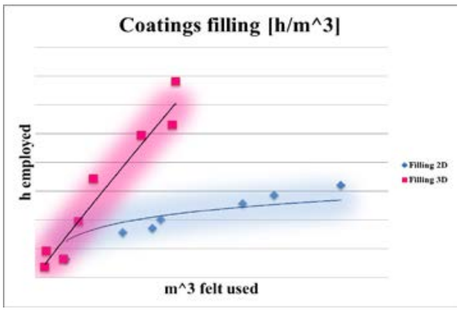

Figure 5: Coatings filling

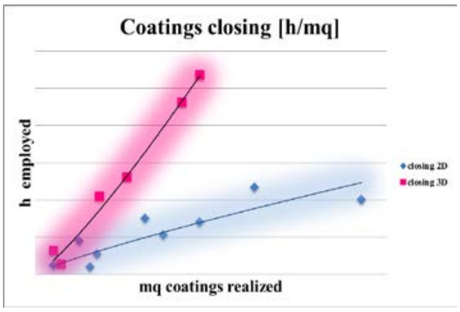

Figure 6: Coatings closing

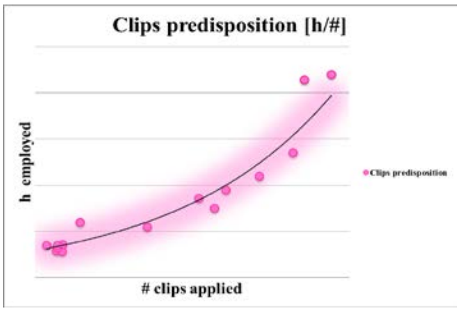

Figure 7: Number of clips applied

Near each trend line a cloud has been represented with amplitude ±10%, because mathematical methods are purely quantitative and they don't consider marketing strategies, structural problems and details, particular clients demands and other qualitative aspects.
This trend line model has been validate monitoring other processed commissions and the result is that the error of prevision never exceeds the 10%.

3. FUZZY LOGIC

The Fuzzy Set Theory allows us to represent the ambiguity contained in linguistic information (Zadeh, 1965). The first original paper on fuzzy logic encountered skepticism and hostility. Fourty years later many international journals have been published papers which include the word "fuzzy" in their title and thousands of patents have been applied.

By 1973, Zadeh had stated the principle of incompatibility on which the fuzzy approach is based: "As the complexity of a system increases, our ability almost mutually exclusive characteristics. It is in this sense that precise quantitative analyses of the behavior of humanistic systems are not likely to have much relevance to the real world societal, political, economic, and other types of problems which involve humans either as individuals or in groups" (Zadeh, 1973).

Given a universe of the discourse U, a fuzzy set A in U is defined by a membership function that assigns to each element in U a value between 0 and 1 (Figure 8). When a value 0 is assigned to an element 'u', 'u' doesn't belong to A; if instead it assumes the value 1 then it completely belongs to set A. But differently to what happens in the traditional set theory, in the fuzzy set theory a generic value can be assume an intermediate value between 0 and 1 then the element will partially belong to A with a specific membership degree (Iandoli and Zollo, 2007).

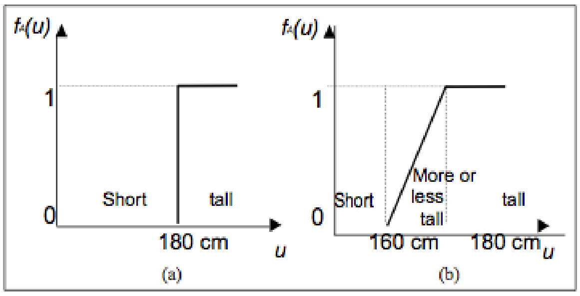

Figure 8: Example of membership function for: (a)traditional set and (b) fuzzy set

3.1. Dual Truth Model

The 'dual truth model' is a model proposed to represent verbal judgments through fuzzy logic. One of the factors which makes natural language such a flexible and efficient tool is its inherent vagueness. It is surprising, in fact, how even a fairly limited vocabulary is enough to enable a person to carry out even very complex tasks.

This model has been introduced in 1996 for the evaluation of competencies of professional workers within a large organization (Zollo, Cannavacciuolo, Capaldo, Ventre, and Volpe, 1996). In 2002 the model was used for methodological approach for the evaluation of innovation capabilities in small software firms (Capaldo, Iandoli, Raffa and Zollo, 2002).

In this paper the dual truth model has been used to define the processing time of each component of product analyzed. Dual truth model appears considerably suitable for decision making processes because, generally, decision making involves uncertainty. When the firm decides to introduce a new product there aren't historical data about time production for each operation to be processed on each component.

In this kind of problems it's very important to take in count expert's judgments on the bases of their ability and experience in a particular operation. The main task is the ability to handle these imprecise, incomplete and vague informations.

The work starts with the elaboration of a questionnaire showing component specifics and 3D figure of CAD project of new product, a new coating for gas turbine. It was necessary explain face to face to each worker of each industrial operation, every question presented in the questionnaire, asking their opinion about complexity of each component.

In agreement with dual truth model, has been used a Fuzzy Term Set (FTS) standard of five functions (Figure 9):

FTS = { ANC, PC, C, MC, EC }

Where:
ANC means "absolutely not complex" PC means not "much complex"
C means "complex"
MC means "very complex"
EC means "extremely complex"

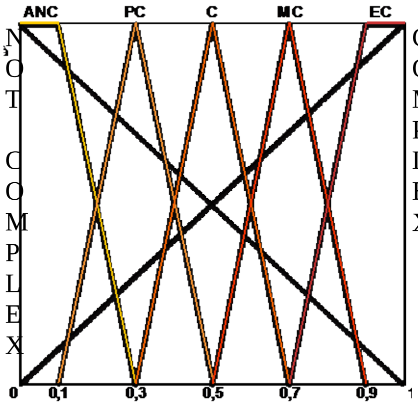

Figure 9: Term Set Fuzzy

The two diagonals of the square, represent the function COMPLEX and NOT COMPLEX. Simply they mean that the truth-value of COMPLEX increases linearly from 0 to 1, and, vice-versa, the truth value of NOT COMPLEX decreases.

Each component has a different complexity so it has been calculated a complexity rate in order to allocate the total lead time calculated with statistical and historical data.

The rate has been calculated doing the fuzzy average and then defuzzificating workers judgments. For example, when judgments are different, a new membership function, triangular or trapezoidal, must be calculated, which is obtained by the convolution of workers judgments (Figure 10).

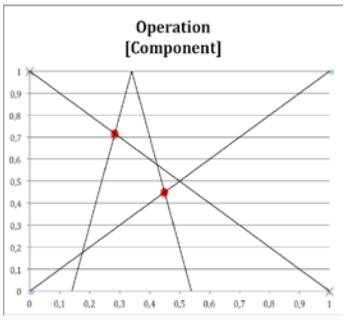

Figure 10: Judgments average represented using Dual Truth Model

Using the dual truth model a truth couple (y_{NC} , y_C) can be immediately associated to the fuzzy representation of the judgment which is obtained as shown in Figure 10 in red. The following formula can be used to get a non fuzzy reading:

$$I_{C_i} = \frac{(y_{C_i} + (1 - y_{NC_i}))}{2} \quad (1)$$

The red point on the left (y_{NC}) expresses the probability that the judgment is "not complex" so (1 - y_{NC}) is its complementary, whereas (y_C) is the possibility that the judgment is "complex". So, Ic is a kind of average of two possibilities.

This process must be repeated for each component i of product and each operation routing.

In order to associate the real processing time to each component, starting from the total time necessary for each operation, must be calculated the I#, a rate that take in count the number of different kind components must be processed.

$$I_{\#_i} = \frac{n_i}{\sum_i n_i} \quad (2)$$

where
n_i is the number of same components
$\sum_i n_i$ is the total number of components

The total index for time allocation is:

$$I_{tot_i} = \frac{(I_{C_i} * I_{\#_i})}{\sum_i (I_{C_i} * I_{\#_i})} \quad (3)$$

4. MODELING MANUFACTURING FLOOR IN MPX®

When a production isn't automated but mainly manual it will be very difficult simulate through software the industrial plant (Di Franco, Gallo, Guizzi, and Zoppoli, 2009); in particular it will be very difficult define the processing time of each component for each operation. The main objective of the MPX® utilization is establish if the manufacturing system analysed can produce an upgrade of the product actually realized at the same time. Otherwise find solutions to optimize the performances of the manufacturing system (Grisi, Guerra and Naviglio, 2010). In the software mentioned, due to complete the simulation, is necessary insert several input data. These inputs regards:

- General Data: project name, time units, time unit conversions, maxim utilization admitted (in %)
- Labor Data: labor group name, number of workers that are present at one time, overtime (%), time unavailable (%).
- Equipment Data: equipment name and type, number of individual equipment in the group, Mean Time to Failure (MTTF), Mean Time to Repair (MTTR), overtime (%), labor group assigned to work in the group.
- Product Data and Product Operation Data: product name, end use demand for each product, average lot size; operation name and number of sequence, equipment group where this operation will be performed, % assigned. In these step it's necessary insert equipment and labor run time and setup time.

This is the real problem of manufacturing industry analyzed which has no idea of processing time of products never processed before. In this contest the fuzzy logic, and in particular the dual truth model, solved this kind of problem.

4.1. Production System Simulation

After calculated the processing time of each component it's possible insert this data in the software.

The first step is simulate the actual production system employed with the actual production, with data well-known and detectable, and with results comparable with real cases.

After simulating the production system the results related to the utilization of labors and machines (Figure 11 and Figure 12) in each work center have been compared with real cases.

Figure 11: Report Labor Utilization Chart production system "as is"

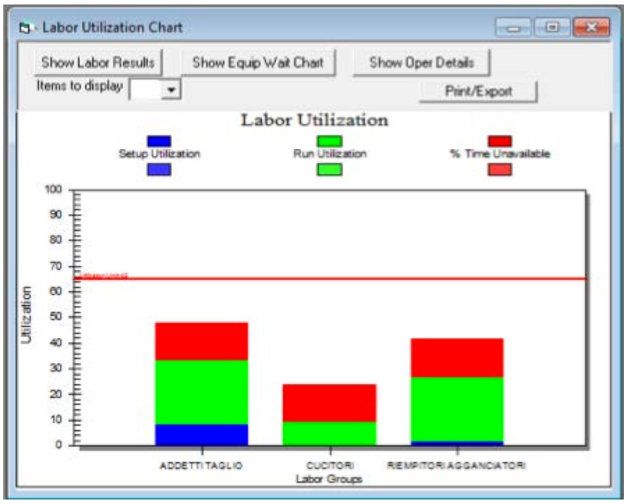

Figure 12: Report Equipment Utilization Chart production system "as is"

The sources most used are labors. Each rate time obtained (setup in Figure 13, run in Figure 14 and unavailable Figure 15) has been compared with real cases results.

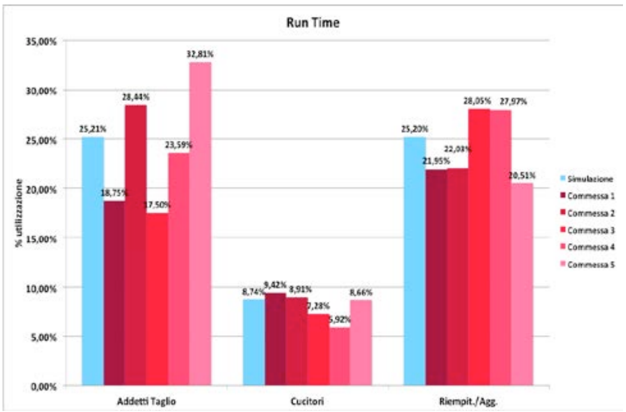

Figure 13: Labor Utilization for Run Time

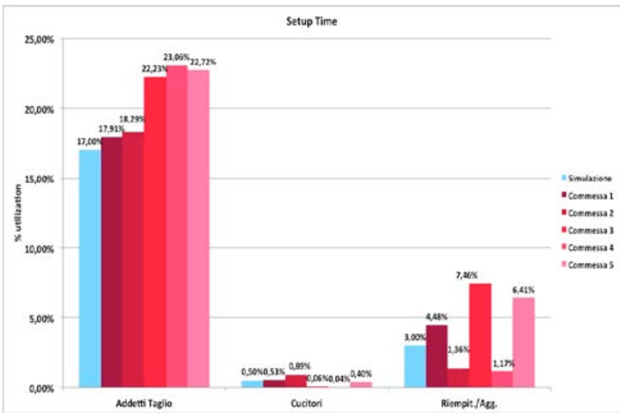

Figure 14: Labor Utilization for Setup Time

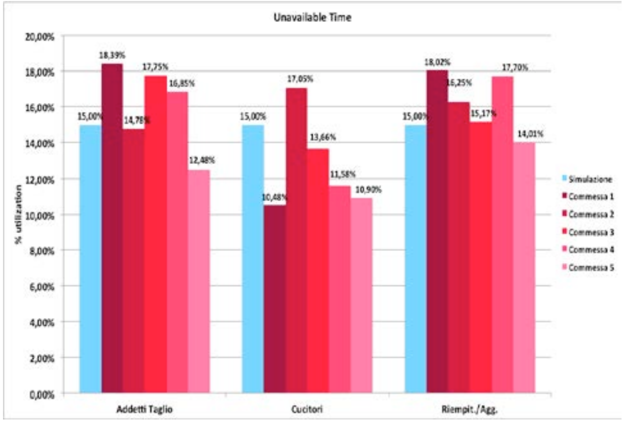

Figure 15: Labor Utilization for Unavailable Time

The difference between simulation results and real data are always under the 10% and this an acceptable value of tolerance specially for a manual manufacturing industrial system, not automated. The simulation software results a good simulator of product flow so seems consistent use it for a prevision analysis.

4.2. Simulation and optimization of industrial system employed with the new product

The new product follows the same operations routing of actual one. Obviously it is required to insert all data related to the new product, included the processing time founded with fuzzy model, and start the simulation.

In the case study analyzed software shows an error message means that production system can't realize the new product in the time established because a group of labor is overused (Figure 16). So it was necessary start a what-if analysis in order to rebalance resources.

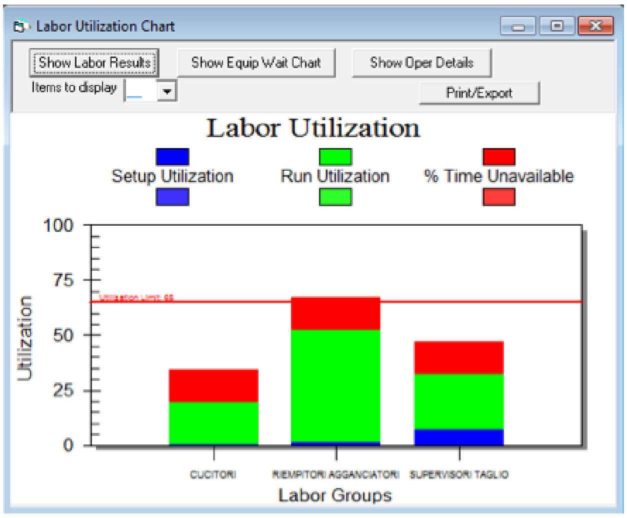

Figure 16: Labor Utilization Chart production system "to be"

4.3 What-if analysis

What-if analysis was used to compare different scenarios and their potential outcomes based on changing conditions. The what-if analysis was performed about some aspects and in particular on:

1. Increase lot-size;
2. Reduce lot-size;
3. Increase labors number in overused work center;
4. Move one (or more than one) labors from a work center to overused one;
5. Improve setup times.

Alternative 1. conduces to a growing of flow times spent waiting for lot while alternative 2. conduces to a growing setup times. Alternative 5. appears not feasible because setup times are not referred to machines.

The only liable way, in order to not increase the cost of the product, is move a labor from the first workcenter represented in Figure 16 named 'cucitori' to the second one, overused, named 'riempitori/agganciatori'. Now the software displays a message telling us the calculations are complete.

This change did enable us to make our production targets.

5. CONCLUSION

The RMT technology that models the complex dynamics of manufacturing facilities in terms of queuing theory mathematical equations was applied, through the use of the MPX© software code, for the evaluation and optimisation of a manufacturing firm during a new product development. Using a fuzzy logic model for time prevision the MPX© utilisation allowed for the analysis and verification of the manufacturing system capability to meet predefined lead time reduction goals and the finding of opportunities for performance improvements in the production system.

REFERENCES

Beckman, S.L., 1990. "Manufacturing flexibility: The next source of competitive advantage", in: P.E. Moody (Ed.), Strategic Manufacturing, Dow Jones-Irwin, pp. 107-132.

Capaldo, G., Iandoli, L., Raffa, M., Zollo, G., 2003. The Evaluation of Innovation Capabilities in Small Software Firms: A Methodological Approach, Small business economics : an internat. journal. - Dordrecht [u.a.] : Springer, ISSN 0921-898X, ZDB-ID 10245601. - Vol. 21.2003, 4, p. 343-354.

Chiocca, D., Guizzi, G., Murino, T., Revetria, R., Romano, E., 2012. A methodology for supporting lean healthcare. Studies in Computational Intelligence, 431, pp. 93-99.

Converso, G., Aveta, P., Santillo, L.C., Gallo, M., 2012. Planning of supply risks in a make-to-stock context through a system dynamics approach. IOS PRESS.

Converso, G, Santillo, L.C., De Vito, L., 2013. Sustainability of global Supply Chain network: the role of research and innovation. WSEAS Press.

D'Addona D., Teti R., Carbone R., 2008. Quick Response Manufacturing Approach for Lead Time Reduction in PCB Fabrication.
Danny J. Johnson, 2003. A framework for reducing manufacturing throughput time, Journal of Manufacturing Systems, Volume 22, Issue 4, 2003.
DeMeyer, A., Nakane, J., Miller, J.G., Ferdows, K., 1989. "Flexibility: The next competitive battle the manufacturing futures survey". Strategic Management J., vol. 10, pp. 135- 144.
Di Franco, R., Gallo, M., Guizzi, G., Zoppoli, P., 2009. Project risk management: A quantitative approach through simulation tecniques. *Proceedings of the 8th WSEAS International Conference on System Science and Simulation in Engineering, ICOSSSE '09*, pp. 326-333.
Gallo, M., Grisi, R.M., Guizzi, G., 2010. A vendor rating model resulting from AHP and the linear model. *International conference on System Science and Simulation in Engineering - Proceedings*, pp. 370-377.
Gallo, M., Guerra, L., Guizzi, G., 2010. Some considerations on inventory-based capacity scalability policies in RMSs. *International conference on System Science and Simulation in Engineering - Proceedings*, pp. 342-347.
Goldhar, J.D., Jelinek, M., 1983. "Plan for economies of scope". Harvard Business Rev., November-December, pp. 141-148.
Grisi, R.M., Guerra, L., Naviglio, G., 2010. "Supplier Performance Evaluation for Green Supply Chain Management. Business Performance Measurement and Management, Springer, Gennaio 2010. ISBN: 978-3-642-04799-2.
Guizzi, G., Chiocca, D., Romano, E., 2012. System dynamics approach to model a hybrid manufacturing system, Frontiers in Artificial Intelligence and Applications, 246, pp. 499-517.
Holusha, J., 1989. "Beating Japan at its own game". The New York Times, 16 July.
Iandoli L., Zollo G., 2007. Organizational Cognition and Learning, Building System for the Learning Organization. Information Science Pub, 2007.
MPX® User Manual, 1999, Network Dynamics Inc., MA, 01803, USA.
Murino, T., Romano, E., Santillo, L.C., 2011. Supply chain performance sustainability through resilience function. *Proceedings – Winter Simulation Conference*, art. no. 6147877, pp. 1600-1611.
Shaouta, A., Al-Shammari, M., 1998. Fuzzy logic modeling for performance appraisal systems A framework for empirical evaluation. Expert Systems With Applications 14, 323–328.
Suri R., 2003. QRM and POLCA: A Winning Combination for Manufacturing Enterprises in the 21st Century, Technical Report, Center for Quick Response Manufacturing, May 2003.
Upton, D.M., 1994. "The management of manufacturing flexibility", California Management Rev., Hass School of Business, University of California, Berkeley, Winter.
Zadeh L., 1965. Fuzzy sets, Information and Control, 8, 338-353.
Zadeh L., 1973. Outline of a new approach to the analysis of complex systems and decision processes, *IEEE Transactions on Systems*, Man and Cybernetics, 3(1), 28-44.
Zelenovic, D.M., 1982. "Flexibility - A condition for effective production systems", Internat. J. Prod. Res., vol. 20, no. 3, pp, 319-337.
Zollo, G., Cannavacciuolo, A., Capaldo, G., Ventre, A., Volpe, A., 1996. "The organizational evaluation process: a fuzzy model", Fuzzy Economic Review, Vol. 1, n° 1, pp. 3÷30, 1996.

AUTHORS BIOGRAPHY

Piera Centobelli studied at the University of Naples Federico II where she received with honors the M.Sc. Degree in Management Engineering in 2013. Currently she is a PhD student at the Department of Materials and Production Engineering, University of Naples Federico II. The PhD programme is entitled 'Production Technology and Systems', with a particular focus on Innovative Materials, Processes and Systems.

Teresa Murino is researcher in Department of Materials Engineering and Operations Management University of Naples "Federico II". She teaches "Industrial Logistics" at the University for students in Logistics&Production Engineering (3rd year) and "Manufacturing System Management" for students in Mechanical Engineering (4th year) degree courses. The research interest include Advanced Model and Applications of Logistics&Manufacturing, simulation with system dynamics and optimization problems, data analysis.

Doriana D'Addona works as Assistant Professor at the Dept. of Chemical, Materials and Industrial Production Engineering, University of Naples Federico II. She has taken part in a significant number of regional, national and international research projects. She is member of national and international scientific associations in the field of production engineering: (CIRP) and (AITEM). Her main research interests are focused on manufacturing processes and automation, intelligent computation for manufacturing technology and systems.

Giuseppe Naviglio is a PhD in Production Systems and Technologies at the Department of Materials Engineering and Operations Management of the University of Naples Federico II. He has a master degree in management engineering from the University of Naples"Federico II. His research field is related to modeling and simulation of production systems and on Lean Manufacturing . Now he is a project manager of a Research & Development radar laboratory.