POLITECNICO DI MILANO

PhD Yearbook | 2007

MANUFACTURING AND PRODUCTION SYSTEMS

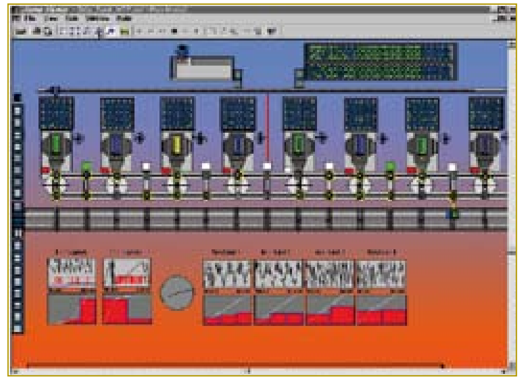
Chair:
Prof. Bianca Maria Colosimo

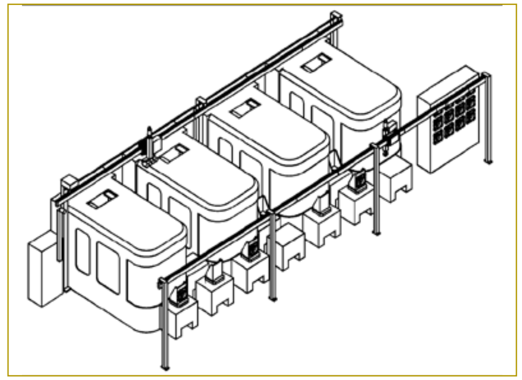
DOCTORAL PROGRAM IN MANUFACTURING AND PRODUCTION SYSTEMS

Manufacturing is a leading sector of the European economy since European Manufacturing is a dominant force in international trade. As an example, the EU's share of total global manufacturing trade was 18% in 2004, while the US had 12% and Japan 8%. (Manu*future* Strategic research Agenda – September 2006 – European Commission).
In some key sectors such as machine-tool, robot, and automation industry, Italy has even achieved a global leadership, accounting for about 10% of the total export (acting as the third in the world) and Lombardia is playing a dominant role, hosting 48.2% of the Italian companies (Report 2005 of the *Association of Italian Manufacturers of Machine Tools, Robots, Automation Systems – Ucimu*).
In this competitive scenario, Politecnico di Milano has the fundamental role of providing people with specific training in Manufacturing and Production Systems engineering, by strengthening their research skills in the industrial and academic context. Therefore, the PhD programme in Manufacturing and Production Systems focuses on the optimal transformation of raw materials into final products, addressing all the issues related with the introduction, usage, and evolution of technologies and production systems, during the entire product life cycle.

The professional skills acquired in the degree program give the competence for managing and solving problems related with product and/or service realization. In particular, issues of continuous improvement and integration of all the activities ranging from conception to realization are emphasized.
A Ph.D. in Manufacturing and Production Systems acquires her/his knowledge through the activities of study, research, lab experience, development in cooperation with industries, foreign institutions and international research groups. Using her/his background, the PhD candidate will be able to blend the exactness of scientific knowledge with the ability to deal with practical industrial problems. The outlined skills are of great interest to industrial companies devoted to: i) continuous improvement of technologies and processes; ii) strong integration of product-process-system design; iii) complete product lifecycle management; iv) optimal design of production, logistic and service systems. In this view, a Ph.D. in Manufacturing and Production systems can eventually aim at prestigious positions at national and international level within industrial companies, consulting companies, universities and research institutions.
Ph.D. activities can specifically focus on one of the following topics:

- Manufacturing Processes: This research area is aimed at studying both conventional and innovative manufacturing processes. The study can specifically deal with: developing new processes for innovative applications or for innovative materials; evaluating the application constraints of new and existing manufacturing processes; performing economic optimization of the process performances; investigating on the relationship between process parameters and process results. The research area is therefore very wide, with activities ranging from basic to industrial research.
- Production Systems: The research activities carried out in this area are concerned with the design and management of integrated production systems. The research activities encompass innovative and traditional system architectures in different sectors (machine tools manufacturing, production of mechanical components, services). Studies and research activities are based on real cases and underline the deep relations amongst products, processes and production systems.
- Quality in Manufacturing: Quality has a relevant role in the new competitive scenario in which European manufacturing is pushed toward high-value products. Research activities in this area focus on studying and developing new approaches, methods and tools for quality management, process monitoring, control and optimization and metrological issues (design and verification of geometric product specifications).
- Product Lifecycle Management (PLM): This area provides the methodologies and tools related to computer-based product lifecycle management, with emphasis on the automation and integration of product design and process planning.





Relevance is also given to the impact of process design on production-system design, both at single-plant level and at network-enterprise level.

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Prizes and awards

Laura Catellani
Best paper award - young researchers for the paper: Catellani L., Colosimo B.M., Semeraro Q. "Detecting Outlying Samples in Customers' Satisfaction Surveys Analysis: the Effect of Scaling the Ordinal Data." 4th International Working Conference Total Quality Management - Advanced and Intelligent Approaches, sponsored by CIRP, Belgrade, Serbia & Montenegro, 27-30 May 2007

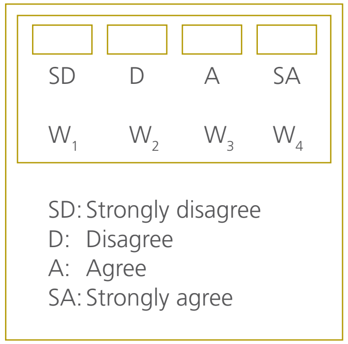
Marcello Colledani
Best Young Author award for the paper: Colledani M., Tolio T. "Performance Evaluation of Production Systems Monitored by Statistical Process Control and Offline Inspections", Proceedings of the INCOM 12th IFAC Symposium on Information Control Problems in Manufacturing, Saint Etienne, France, May 2006, pp. 329-334.

QUALITY IN UNIVERSITY DIDACTIC: IDENTIFICATION AND DIAGNOSIS OF OUTLIERS IN STUDENT RATING ANALYSIS

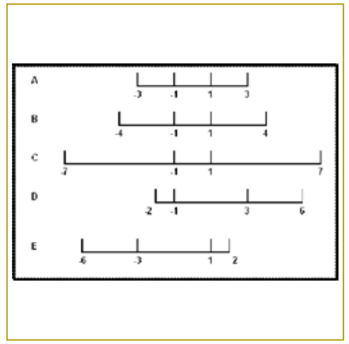
Laura Catellani

Introduction

Student satisfaction is commonly monitored by using questionnaires containing many questions related to different characteristics of the attended courses (e.g., organization, faculty skills, and overall satisfaction). For each question, the student must express her/his level of satisfaction by using an ordinal scale. The analyst usually adopts a scaling procedure that consists in associating a numerical value w_i to each possible i-th outcome of each question. This work focuses on identifying courses which are different from the others, i.e., which are outliers, with reference to some specific criteria. The courses offered in a Faculty of Engineering and the four-points ordinal scale shown in figure 1 were taken as reference throughout the work.



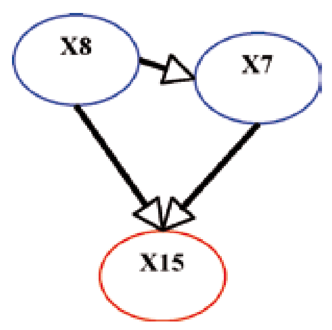
1. The ordinal scale related to the real case



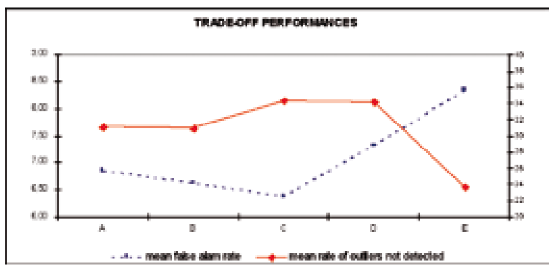
2. The ordinal scale (A,B,C,D,E) system used for the simulation study

Methodology

In order to realize how students' requirements can be met and satisfaction improved, a model that specifies the relative importance of each attribute in creating the overall satisfaction was identified. Traditional regression analysis can not be adopted in this case because of multicollinearity (answers related to different questions were highly correlated); therefore Partial Least Squares Regression was firstly applied, considering the mean level of satisfaction (for each question and for each course) as response. The usual weights 1, 2, 3, 4 were further assumed as points of the scale in figure 1.
In order to discover the courses that are different from the others, a Bayesian Network was further considered as second tool. In particular, it was used to derive a general model aimed at describing the statistical dependences between the overall satisfaction and the other characteristics of the courses. With reference to this network, an indicator of discrepancy between each specific course and the general model was defined. In particular, the courses associated to high values of this discrepancy index were considered as "outliers". For each outlying course, a specific Bayesian Network model was eventually derived for diagnostic purposes (i.e., to detect the specific course's issues which were causing student satisfaction/ dissatisfaction).
Finally, a simulation study focused on evaluating whether different scaling/weighting procedures can better aid the detection of the outlying services, i.e., services which are somehow different from the others. Figure 2 shows the scaling systems used in this simulation study. In this case, only the (mean) overall satisfaction (the final question of the questionnaire) was considered by using an Xbar control band (where the term band is used to distinguish it from the "control chart", where the points plotted on the chart are sequentially obtained with respect to time; in this case, the term band is more appropriate since courses are contemporarily offered and judged).



3.
X15: Are you overall satisfied with this course?
X8:Does the teacher explain the arguments clearly?
X7:Does the teacher motivates/ stimulates the interest?
The Bayesian Network related to the relationships with overall satisfaction (X15)



4. Trade off between performance indicators (on the abscissa, the different scaling systems are shown)

Discussion of the results obtained

The Partial Least Squares Regression approach results (193 courses, 8245 questionnaires filled in), allowed us to conclude that students' overall satisfaction is mainly influenced by: the teacher's clearness (X8) and the teacher's ability in motivating students' interest (X7).
In a similar manner, the Bayesian Network [Fig. 3] obtained for a different set of courses (144 courses, 3925 questionnaires) showed that the overall satisfaction of the "typical" or "average" student is mainly affected by the same two teacher's abilities.
With respect to the effect of different scaling/weighting systems (weights w_i), we observed that both the ability of detecting specific type of outlying samples and the false alarm probability (i.e., the probability that an "in-control" course is actually judged as outlier) depends on the specific weighting system assumed within the *Xbar* approach. In particular, the two performance indicators (ability to detect outliers and false alarm rate) resulted in trade-off [Fig.4]. The main conclusion of the present study is that the selection of a proper weighting/scaling system should be driven by specific issues which can be summarized in: i) what type of outliers have to be detected; ii) what are the costs associated to not detecting outliers; iii) what are the costs incurred by false alarms.

INTEGRATED ANALYSIS OF PRODUCTION LOGISTICS AND QUALITY PERFORMANCE IN MANUFACTURING SYSTEMS

Marcello Colledani

Introduction and description of objectives

In the last three decades, the increasing competitiveness of the global market has caused an ever increasing pressure on both quality of products and productivity of the systems. However, quality and productivity have always been considered by researchers and practitioners as two very separate fields. Considering production logistics, the Manufacturing Systems Engineering research area has been developed for understanding the behavior of production system and for designing efficient factories. On the other hand, Statistical Process Control, Total Quality Management and Six Sigma have been developed for a better control of manufacturing processes and higher product quality. The link between these two areas has been very rarely considered at a production system level, even if industrial experience has evidenced the need for jointly considering quality and productivity performance measures while designing the system, as recently pointed out by the General Motors Corporation on the basis of problems identified in their productive plants.
Moreover, the technological progress has provided several possibilities for a better control of production plants. Advances in sensors technology has provided the possibility of rapidly inspect several product characteristics with high accuracy. In addition, machine data collection systems have found wide application in real systems for monitoring the machine states. The results of this technological revolution for manufacturing is that a huge amount of data is day by day collected with the aim of having reliable feedbacks from the shop floor in real time. However, this enormous amount of data is rarely opportunely used to derive knowledge regarding the system behaviour.
The relation among quality and productivity is evident: there is a strong impact of decisions taken while designing the production system on the performance of the quality control system and viceversa. For instance, the production system architecture affects the performance of the quality control system in identifying quality problems. As an example, in a production line with 15 machines the number of bad parts produced by the system if inspection stations are poorly allocated can be the 15% higher than the number of bad parts produced with a good allocation of the same number of inspection stations. Since producing bad parts means cost for industries, there is need for investigating the impact of the production system configuration on the quality of products. On the other hand, the corrective actions on the machines decided as a consequence of signals generated by the quality control system have an impact on the productivity of the system. A common practice in real systems is to see quality control perfectly designed and optimized for quality, without considering the fact that stopping a machine for quality problems also affects the system production rate.
These examples motivate the research activity and give an idea of its high impact in terms of knowledge on production systems behavior and cost reduction for companies.
The proposed research aims at investigating the interactions existing among quality and productivity performance measures in production lines, providing quantitative methodologies to support the decision making process of production system designers.

Methodology and discussion of obtained results

In order to achieve the overall objective, the new problem addressed in the work has been properly formalized, basing on the analysis of real cases as well as on the available literature.
In particular, a taxonomy to model complex manufacturing

systems in which quality control is implemented has been developed, in order to formally describe the system features. Furthermore, the problem of analyzing the performance of complex production systems monitored by SPC has been considered. New system performance measures have been introduced, which jointly take into account quality and production logistics aspects. The System Effective Throughput, E^{eff} (number of conforming parts produced in a time unit), the System Total Throughput, E^{tot} (the total number of parts produced by the system) and the System Yield, Y^{system} (the fraction of conforming parts produced) have been considered in the performance analysis.
An approximate analytical method has been proposed, to rapidly estimate the system performance. Given the complexity of the systems to be analyzed, a new approach, named *Two-Level Decomposition*, has been developed. This approach is based on the Markovian analysis of the complex machines behaviour.
Both on-line and off-line inspections have been taken into account. The machines composing the systems have been considered to be subject to random events like operational failures, which simply stop the machine instantaneously, and out of controls, which reduce the quality of the produced parts, without immediately stopping the machine. In particular, out of controls justify the presence of inspection stations in the system, which provide measured data to the quality control tools, i.e. control charts. These tools generate signals whenever out of controls of machines are identified.
The developed method has been implemented and provided results have been compared with simulation, which requires high computational effort. Several system layouts and parameters have been tested, proving high accuracy of the developed method (Errors lower then 1% in the estimation of E^{eff}). Moreover, Design of Experiments (DOE) has been used to identify possible directions of improvement of the developed methodology.
Given the good accuracy of the method, it has been used to investigate the system properties. This knowledge can support production managers both in the phase of design and management of these systems. A new dependency of the system effective throughput on the capacity of the buffer has been identified and scientifically explained: the number of conforming parts produced by the system is maximized for a particular buffer capacity, if remote quality control is adopted. Moreover, the impact of the location of inspection stations on quality and productivity has been investigated. It has been shown that the correct location of a very limited number of inspection stations provides the big improvement in the performance, while additional inspection stations just slightly increase the effective throughput. Finally, it has been shown that local actions performed with the aim of increasing the machine performance in terms of quality or productivity may have negative impact on the global performance, at the system level.
Based on the developed analytical method, a new approach for the optimization of manufacturing systems has been proposed. This method aims at providing the optimal configuration of buffers and sampling plans, by jointly considering for the first time quality and productivity implications. The optimization has been carried out with the objective of minimizing the cost of the configuration which allows meeting the desired demand rate. The approach shows that configurations obtained without considering the relations among quality and productivity measures in details are only sub-optimal.
Finally, two real cases, one in the automotive sector and one in the white goods sector, have been analyzed, providing high added value for companies, derived by the used of the developed methodology in real systems. The possibility of exploring a new research area based on the integrated analysis of quality and production logistics performance of systems is shown, providing evidence that there are high benefits from an integrated production system design approach.

AN APPROACH TO DESIGN FOCUSED FLEXIBILITY MANUFACTURING SYSTEMS CONSIDERING EVOLVING MARKET NEEDS

Anna Valente

Frequent production changes force companies, which want to be competitive in a dynamic market, to be quick-responsive with the minimum economical effort. In such an environment, products need to be frequently modified or even replaced and production volumes change considerably from one time period to another. The research is centred on the production of metal components made by highly automated machine tools. Main features of this production context are related to: high levels of demand volumes of products, possible future technological and volume modification of products and a high pressure on costs. While typically high levels of demand volumes of products lead to the design of rigid manufacturing systems, product modifications and uncertainties related to forecasted product evolutions tend to force the adoption of flexible manufacturing systems. Indeed, manufacturing flexibility represents a strategic mean a company may use to cope with frequent production changes of the part families. However, form an economical perspective, uncertainties which affect forecasted production problems may lead the system designer to make too expensive and risky investments which may jeopardize the profitability of the company. Therefore, in order to reach the optimal trade-off between system flexibility and productivity, system designers should focus system flexibility on current and forecasted production problems. The claim is that the customization of system flexibility on the specific production problems leads to the minimization of system cost during system lifecycle.
Manufacturing systems designed by focusing the flexibility degree are defined Focused Flexibility Manufacturing Systems – FFMSs. FFMSs are hybrid systems, in the sense that they can be composed both by general purpose and dedicated resources. This innovative architecture derives from the consideration that system flexibility is related both to the flexibility of each single selected resource and to interaction among the resources which compose the system. For instance, a flexible system can be composed by dedicated machines and highly flexible carriers. The aim of the research is to provide an approach to design FFMSs considering market evolving needs.
The FFMS design problem consists of selecting the type and number of resources which satisfy production requirements with the minimum economical effort during system lifecycle. Since FFMS selected resources strongly depend on the considered production context, the proposed FFMS design approach starts from a deep analysis of production problem on hand. For this reason, the FFMS design approach has been developed considering two phases: Phase 1 consists of analyzing and formalizing the information on current and future production problem; in Phase 2 the proposed FFMS design method is applied to the information collected during Phase 1, providing in output the FFMS optimal configuration.
Input information collected within Phase 1 are heterogeneous: in fact, data concerning products which compose the part family as well as data concerning feasible devices which can be selected during the system configuration must be considered at the same time. Moreover, since the analyzed production context is characterized by products which can undergo technological and volume changes, information concerning the part family must be analyzed in an evolutionary perspective. Since the system lifecycle is normally longer than product lifecycle, the designed production system during its life must undergo many production changes. In this sense, production problems can be characterized by a combination of many products which evolve during the considered horizon.

Since managing input information in an evolutionary perspective can be hard, a Scenario Tree representation has been adopted to simplify the problem representation. Herein, it has been considered that the production system during its lifecycle has to face short-term and long-term production problems. On the one hand, it must cope with a set of daily, or in general short-term, production problems which must be satisfied. On the other hand, long-term production problems have been represented by forecasted production nodes in the Scenario Tree and, because of their nature, have been considered uncertain. Afterward, collected and analyzed information have been formalized. In fact, one of the main problems during the FFMS configuration phase is the need of managing and organizing all the required information which are very different in their nature. Another critical aspect is that input information must be managed dynamically in order to consider the evolutionary perspective of the FFMS design problem. Therefore, the whole family of information have been formalized according to the Formalization Framework proposed in (Tolio et al, 2007). The second phase of the FFMS design approach consists of applying the developed design method which provides the production system configuration characterized by the minimum level of flexibility required by the production problem. The FFMS design phase consists of the selection of the number and type of resources (machines, load/unload stations and carriers) that must be purchased during the configuration phase in order to face the production requirements with the minimum expected economical effort. As previously described, production problems are affected by uncertainty and during the system design phase, which must be considered in order to design cost-effective system configurations. An approach to model problem uncertainty is Stochastic Programming technique in which the problem stochasticity is discretized through scenarios. In particular, the FFMS design model has been formulated as a Two Stage Linear Stochastic Programming Problem.
To test the advantages of the FFMS design approach three main testing objectives have been identified: a) evaluation of the FFMS competitiveness by comparing FFMSs and parallel machine FMSs in terms of investment costs for given production problems; b) analysis of the system morphology (in terms of typology of selected machines) in relation to the difference between the cost of dedicated machines and general purpose machines; c) assessment of how the different types of production variability impact on the FFMS profitability and architecture. A Design of Experiment (DoE) has been developed in order to study if the variability of the production problems affect the FFMS profitability in comparison to the highest flexible system design. Experiments have been developed looking at real production contexts. For instance, experiments characterized many products which during their lifecycles undergo many technological changes and high levels of demand disturbances or experiments characterized by few products whose technological features are affected by few changes, during their lifecycles, and whose production volumes are quite stables. The FFMS design approach has been applied on a case study gently provided by IMAS TRANSFER S.p.A. (Industria Meccanica Applicazioni Speciali), an Italian Machine Tool Builder. The part family considered is composed by four parts of an Hydraulic Primary Chain Tensioner for the automotive sector, i.e. an hydraulic actuator which constantly keeps the chain in tension. The analysis of results coming from the FFMS design approach testing emphasize production contexts in which FFMS are more competitive than other production system architectures. In particular, best results concerning FFMS profitability are obtained in relation to production contexts in which the considered part family is composed by few part types produced in quite stable production volumes and affected by few technological changes. Moreover, from experimentation results it is also possible to individuate a set of rules which characterize the FFMS behaviour in relation to changes in production contexts and which can support Mavhine Tool Builders who want to rationalize the system flexibility during the system design phase: i.e. for instance technological changes of products basically lead to increase the system flexibility levels while demand changes lead to design FFMS mainly composed by dedicated resources.

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