The International Journal of Flexible Manufacturing Systems, 16, 5–9, 2004

Introduction: Modeling and Analysis for Complex Production Systems. Position Statement

DARIUSZ CEGLAREK darek@engr.wisc.edu
Department of Industrial Engineering, The University of Wisconsin-Madison, 1513 University Avenue, Madison, WI 53706-1572, USA

JUDY JIN jhjin@sie.arizona.edu
Department of Systems & Industrial Engineering, The University of Arizona, Tucson, AZ 85721-0020, USA

Introduction

Modern manufacturing system is experiencing the emergence of a new paradigm wherein increased customization, product proliferation, heterogeneous markets, shorter product life cycle and development time, responsiveness, and other factors are increasingly taking center stage (Bollinger, 1998). For example, in Japan, Toyota was reportedly offering five-day delivery from the time the client designed a customized car on a CAD system (from modular options) to actual product delivery.

A characteristic feature of a number of manufacturing industries is the frequency of model change and the considerable amounts of time and cost required to make a changeover. This trend has steadily gone up in the last two decades. For example, since 1980s, US car market's total demand has essentially remained stable, however, the number of nameplates has increased by 35% from 139 to 183, respectively. This increase continued during the 1990s essentially creating a shift in the automotive industry.

The newly emerging manufacturing paradigm is characterized by the so-called time-based competition (TBC). The time to market for a new product or service responsiveness of a company is becoming the cutting edge in global market competition (Ulrich, Sartorius, Pearson, and Jakiela, 1993). Taking time as the yardstick, the new standard has further pushed the limits of cost and quality strategies, competing on speedy results in both quality and cost improvement. The advantages of this new strategy are widely recognized to be (1) use of newer technology than that of competitors in a newly developed product; (2) capturing new market niche earlier than that of a competitor; (3) higher customer satisfaction; and (4) better integration of the entire enterprise. In addition, the company can parallelly achieve higher quality, lower cost, and leaner organization (Suri, 1998).

To take full advantage of the TBC strategies, new techniques such as quick response manufacturing (Suri, 1998), reconfigurable manufacturing system (Koren et al., 1999; Mehrabi et al., 2000), agile manufacturing and the like have been developed and applied to support the aforementioned shifts in the last decade.

Due to rapid changes in recent market demands, reducing product cycle and improving quality is inevitably becoming the prevailing trend. For instance, in the automotive industry, a product life cycle will be shortened to 2–3 years in a few years when compared to the current 4–7 years and 9–12 years from a few years ago. Additionally, market requirements demand significantly shorter new product realization cycles. Currently, it takes 24 months for the world's top auto manufacturers to develop a new car, with development time expected to reduce to 12–18 months within the next five years. Similar trends are also apparent in the electronics, appliance, and consumer goods industries. As a result, flexible and reconfigurable manufacturing systems (RMS) and quick response manufacturing (QRM) are increasingly being adopted in industrial practices. Still, due to the lack of confidence in predicting system performance (ramp-up time, expected yield, and relatively long time necessary to reach it), there is tremendous resistance towards implementing advanced technology or innovations in new product/process development (CIRP, 2000).

The most significant obstacles towards reducing new product realization time can be categorized into (1) design phase wherein, large numbers of design/engineering changes have to be made after the product has been designed and at times even after it has been built (6,000 changes on average for a new automotive body development); (2) preproduction phase which entails long ramp up time, especially for complex systems such as flexible machining transfer lines (up to 12–14 months) and automotive assembly lines (3–5 months) (Ceglarek and Shi, 1995); and (3) full production phase involving low production yield (below design intent expectations: 65–70% for flexible machining line).

These challenges are related to manufacturing system failures and quality problems during the ramp-up phase. They can be often summarized as (1) lack of accurate methodologies for predictability of process performance during early product development stages; (2) system failures and long fault recovery during a ramp-up phase; and (3) lack of advanced maintenance and system evaluation methodologies of the complex FMS/RMS.

Historically methods for quality improvements are primarily based on statistical analysis of measurement data, which focuses on the detection of process change rather than determining fault root cause as reported in recent papers (Hu and Wu, 1992; Ceglarek, Shi, and Wu, 1994; Ceglarek and Shi, 1996; Ding, Ceglarek, and Shi, 2002). Neither such methods are effective for complex manufacturing systems nor are they applicable towards new product/process launches. On the other hand, current diagnostics methods do not integrate statistical information and have limited definition of fault condition as fault/no fault (1/0), which is insufficient for quality improvement of complex manufacturing systems. Additionally, current productivity and quality requirements place high emphasis on efficient system-based approaches for the design of products and manufacturing systems (Ceglarek and Shi 1995; Hu, 1997; Jin and Shi, 1999). Reconfigurability requirements of production lines for mixed part-types create additional complexity to the problem.

This special issue is the second on *Quality and Reliability: Modeling and Analysis for Complex Production Systems* and focuses on some of the aforementioned challenges relevant to quality and productivity in electronics and automotive industries as well as on generic methods for root causes identification of quality problem and evaluation of FMS.

Both special issues bring together a number of experts from around the world who have worked extensively in the area of quality and reliability. The reader is provided insight into current approaches and issues relevant for improving quality.

The first special issue was published in the Volume 15, No. 2, April 2003 and focused on addressing the following areas:

(i) Modeling strategies for quality improvement in electronics industry (Ho, Xie, and Goh, 2003). The paper specifically addresses the surface mount assembly quality with emphasis on autocorrelation and process degradation.
(ii) Holistic approach for FMS performance and maintenance modeling (Rupe and Kuo, 2003). The presented approach goes beyond examining the working and failed states of a FMS system and common reliability matrices to create the measure of system effectiveness. This approach can help in current efforts towards reducing a new FMS system ramp-up time as well increase system utilization.
(iii) Approach of identifying root causes of dimensional variation/quality problems in multistation assembly systems (Carlson and Soderberg, 2003). This is especially important during design and launch of new assembly systems used in automotive assembly.
(iv) ANOVA method for variance component decomposition and diagnosis in batch manufacturing processes (Jin and Guo, 2003) which can effectively use production observation data rather than rely on special test data through design of experiments (DOE).

The current second special issue on *Quality and Reliability: Modeling and Analysis for Complex Production Systems* focuses on:

(i) Overview of the time-based competition in manufacturing based on the stream-of-variation analysis (SOVA) methodology (paper by Ceglarek et al.). This paper discusses the concept of time-based competition in manufacturing and design based on the review of on-going research related to stream-of-variation (SOVA) methodology. The SOVA methodology focuses on development of modeling, analysis, and control of dimensional variation propagation in complex multistage assembly processes (MAP) such as in automotive, aerospace, appliance, and electronics industries. The presented methodology can help in eliminating costly trial-and-error fine-tuning of new-product assembly processes attributable to the unforeseen dimensional errors throughout the assembly process from design through ramp-up and production.
(ii) Methodology for diagnosing manufacturing variation using second-order and fourth-order statistics (paper by Ho and Apley). This paper discusses a method that can aid in diagnosing root causes of product and process variability in complex manufacturing processes, when large amounts of multivariate in-process measurement data are available. The presented methodology builds on the SOVA methodology in the area of root cause identification.
(iii) Methodology for enhancing SOVA simulation of multistation production system by introducing the number theory net (NT-net) approach (paper by Huang et al.). Recent development in modeling stream of variation in multistage manufacturing system along with the urgent need for yield enhancement in the semiconductor industry has led to complex large-scale simulation problems in design and performance prediction, thus challenging current Monte Carlo (MC) based simulation techniques. The paper proposes a new method founded on number theory (NT-net) to reduce the computing effort and the variability of MC's results in tolerance design and circuit performance

simulation. The sampling strategy is improved by introducing NT-net that can provide better convergent rate over MC.

(iv) Methodology of availability analysis for multitask production systems (paper by Seward and Nachlas). In the paper, new models of the operational reliability and of the availability of multitask systems are developed. A multitask production system is a part of the multistation manufacturing system. It can be described as a system in which different subsets of the components can be used to perform distinct functions or tasks. For such a system, some of the components are used intermittently and some may be used continuously. This type of operational protocol is often applied to flexible manufacturing systems.

We would like to thank all of the authors who contributed to this special issue, and the referees for their critical reviews. We also gratefully acknowledge the support and assistance provided by Professor Kathryn Stecke, for encouraging and supporting this special issue series. Last but not least, we would like to thank Kluwer Academic Publishers for sponsoring this special issue.

References

Bollinger, J. E. (Ed.) *Visionary Manufacturing Challenges for 2020*, Committee on Visionary Manufacturing Challenges, National Research Council, National Academy Press, Washington, DC (1998).

Carlson, J. S. and Soderberg R., "Assembly Root Cause Analysis: A Way to Reduce Dimensional Variation in Assembled Products," *International Journal of Flexible Manufacturing Systems*, Vol. 15, No. 2, pp. 113–150 (2003).

Ceglarek, D. and Shi, J., "Dimensional Variation Reduction for Automotive Body Assembly Manufacturing," *Manufacturing Review*, Vol. 8, No. 2, pp. 139–154 (1995).

Ceglarek, D. and Shi, J., "Fixture Failure Diagnosis for Auto Body Assembly Using Patter Recognition," *ASME Transactions, Journal of Engineering for Industry*, Vol. 118, No. 1, pp. 55–65 (1996).

Ceglarek, D., Shi, J., and Wu, S. M., "A Knowledge-Based Diagnosis Approach for the Launch of the Auto-body Assembly Process," *Transactions of ASME, Journal of Engineering for Industry*, Vol. 116, No. 4, pp. 491–499 (1994).

CIRP, 2000, "Flexible Automation—Assessment and Future," *CIRP Scientific Technical Committee Survey in USA, Europe and Japan* (January 27, 2000).

Ding, Y., Ceglarek, D., and Shi, J., "Fault Diagnosis of Multistage Manufacturing Processes by Using State Space Approach," *ASME Transactions, Journal of Manufacturing Science and Engineering*, Vol. 124, No. 2, pp. 313–322 (2002).

Ho, S. L., Xie, M., and Goh, T. N., "Process Monitoring Strategies for Surface Mount Manufacturing Processes," *International Journal of Flexible Manufacturing Systems*, Vol. 15, No. 2, pp. 95–112 (2003).

Hu, S. and Wu, S. M., "Identifying Root Causes of Variation in Automobile Body Assembly Using Principal Component Analysis," *Transactions of NAMRI*, Vol. 20, pp. 311–316 (1992).

Hu, S. J., "Stream-of-Variation Theory for Automotive Body Assemblies," *Annals of CIRP*, Vol. 46, No. 1, pp. 1–6 (1997).

Jin, J. H. and Guo, H. R., "ANOVA Method for Variance Component Decomposition and Diagnosis in Batch Manufacturing Processes," *International Journal of Flexible Manufacturing Systems*, Vol. 15, No. 2, pp. 167–186 (2003).

Jin, J. and Shi, J., "State Space Modeling of Sheet Metal Assembly for Dimensional Control," *ASME Transactions, Journal of Manufacturing Science & Engineering*, Vol. 121, pp. 756–762 (1999).

Koren, Y., Heisel, U., Jovane, F., Moriwaki, T., Pritschow, G., Ulsoy, G. A., and Brussel, H., "Reconfigurable Manufacturing Systems," *Annals of CIRP*, Vol. 50, No. 2 (1999).

Mehrabi M. G., Ulsoy A. G., and Koren Y., "Reconfigurable Manufacturing Systems: Key to Future Manufacturing," *Journal of Intelligent Manufacturing*, Vol. 11, No. 4, pp. 403–419 (2000).

Rupe, J. and Kuo, W., "An Assessment Framework for Optimal FMS Effectiveness," *Internationl Journal of Flexible Manufacturing Systems*, Vol. 15, No. 2, pp. 151–165 (2003).

Suri, R., *Quick Response Manufacturing: A Companywide Approach to Reducing Lead Times*, Productivity Press (1998).

Ulrich, K., Sartorius, D., Pearson, S., and Jakiela, M., "Including the Value of Time in Design-for-Manufacturing Decision-Making," *Management Science*, Vol. 39, No. 4, 429–447 (1993).