Laboratory for Responsible Manufacturing

Research Activity Report

1998 – 1999

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LRM

Engineering solutions for evolving customer and environmental needs

LRM Director's Message

We have made substantial progress here at the Laboratory for Responsible Manufacturing (LRM) since its inception in the late 1996. Today, in addition to Dr. Kamarthi and myself, our research group consists of a dozen plus research associates working on their Master's, Doctoral and post Doctoral research. In the last two years this group has published 27 papers in journals, 27 papers in conference proceedings, seven books/book chapters or edited volumes and six dissertations. In addition, the members of this group have made numerous presentations about their research at International and National conferences as well as conducted LRM seminars.

The objective of LRM is to develop and asses strategies and methodologies for competitive and agile manufacturing technologies in response to evolving environmental and customer needs as well as legislative and ethical standards while maintaining profitability.

Recently we received a major grant from the U.S. Department of Education for a period of three years (starting September 2000) worth about $848000 (including NU's cost-share) to fund up to eight new graduate (doctoral) students to carry out interdisciplinary research in the areas of Manufacturing and Information Systems. We had applied for this reputed grant in October 1999 under the U.S. Department of Education's Graduate Assistance in Areas of National Need (GAANN) Program.

The key people listed on the proposal are Dr. Surendra Gupta, Dr. Jacqueline Isaacs, Dr. Sagar Kamarthi and Dr. Ibrahim Zeid. Dr. Gupta will direct the GAANN Program and will work closely with the co-directors, Dr. Isaacs, Dr. Kamarthi and Dr. Zeid, to oversee all aspects of the project. For effective administrative purposes, the project will have four divisions. Dr. Gupta will coordinate the multidisciplinary research activities. Dr. Zeid will coordinate recruitment activities in conjunction with Graduate School of Engineering, NUPRIME, Connections Program, and the Women in Engineering Program for recruiting GAANN students. Dr. Kamarthi will oversee the industrial internship activities with the help of the Division of Technology Transfer, the Office of Industrial Relations and faculty in the Department of Cooperative Education. Dr. Isaacs will manage the teaching internship activities in cooperation with the Center for Effective University Teaching and faculty mentors from within the College of Engineering.

We, at the Laboratory for Responsible Manufacturing, are very pleased to be recognized with this award, not only from its reputation point of view but also in bringing notoriety to LRM, MIME Department, College of Engineering and Northeastern University. It will help us continue to raise the standard and the quality of work that is generated at LRM.

We are committed to continuous improvement and maintaining the same high level of productivity as in the past in research and publications as well as in bringing visibility to LRM and Northeastern University.

Surendra M. Gupta, Ph.D. PE

Contents

Research & Development Capabilities of LRM

Laboratory for Responsible Manufacturing (LRM)

Laboratory for Responsible Manufacturing (LRM) in the College of Engineering at Northeastern University is dedicated to conducting basic as well as applied research in manufacturing which covers areas such as Environmentally Conscious Manufacturing, Mass Customization, and Sensor-assisted Monitoring and Diagnosis. The modeling techniques used range from Neural Networks, Multi-agents, Stochastic models, Multi-criteria Optimization, Petri-nets and Graph Theory. The group members have expertise in different areas of research and are capable of working on research and developmental projects in collaboration with the industrial partners and governmental agencies. The following is a compendium of research and development capabilities of the group.

DISASSEMBLY AND RECOVERY OF END OF LIFE PRODUCTS

Industrialized countries all over the world are facing serious aftermath of the rapid development that has taken place in the last few decades. For example, there has been an appalling rate of depletion of natural resources in recent years. This is a direct result of an ever-increasing demand for consumer goods coupled with shortened lifetimes of many products. Although the products are more durable, they are not kept for long because of the rapid change in the state of the art and the consumers' appetite for latest models of products. This phenomenon coupled with serious shortage of landfills and incinerating facilities has led to an environmental threat.

It is widely recognized that the most ecological way to dispose of products at the end of their lives is to reuse, remanufacture or recycle them. In general, it is neither economical nor possible to recycle a product as a whole. Instead, the effort is to maximize the proportion of the product that can be recycled or reused, and minimize ecological devastation by reducing the mass of the product that is sent to the landfills or incinerators. The best way to achieve this is to disassemble the product, so that individual components and materials can be reused or recycled.

Our group has done extensive and seminal work in the area of disassembly scheduling, disassembly process planning, disassembly leveling, cost-benefit analysis of disassembly-related processes and product recovery at the end of life of products. Our experience in these areas puts us at the forefront of disassembly and recovery research.

DESIGN AND MANUFACTURING IN MASS CUSTOMIZATION

As markets reach their saturation limits for many products, and customers grow more demanding, manufacturing industries are forced to enter into the production paradigm of mass customization in which products are designed, manufactured, tested and delivered to satisfy the customers' exclusive requirements. This kind of concentration on the individual customer is taking place in consumer products, automobiles, telecommunications, computer hardware, and a wide range of other products.

We have made good progress into identifying the principles of mass customization and the different factors that influence this customer-oriented business strategy. We have developed a typology of mass-customized production systems and identified different technologies useful for supporting them. We have also been developing functional and

information models of mass-customized production systems to address the issues related to cost implications, operations planning, systems integration, and information management in mass customization environment.

Our work in mass customization helps industrial practitioners in several ways. Our classification of mass-customized production systems assist a company in determining what type of system it should adapt taking into account its existing production capabilities. Using the set of influential factors identified by us, the company can plan, design and implement an appropriate mass-customized production system for the company. We also offer to build intelligent computer tools for operating mass-customized production systems.

PRODUCT REALIZATION FOR RECYCLABILITY AND REUSABILITY

Product designers are usually required to satisfy numerous but often contradicting demands. Those demands not only include designing for appeal or cost efficiency, but also for assembly, manufacturing, and environmentally benign products, also known as the "Design for Environment" (DfE) (or *Green Design*). Conceptually, DfE denotes designing products such that their environmental impact is as small as possible. With proper design, not only can DfE be made more cost efficient, in many cases it could actually generate positive income in the long run. Moreover, it is necessary because of competition, consumer demand and the prevailing laws.

Major manufacturing companies have taken proactive steps towards the greening of products by emphasizing on reducing parts, rationalizing materials, and reusing components. These steps have resulted in savings of millions of dollars per year as reported by many companies.

We have developed various analysis tools to assist and/or evaluate different aspects of product designs. For example, we recently developed a Design for Disassembly Index that enables a designer to measure disassembly and recycling potential of different product designs. The index offers designers with an important measure to help improve future products.

MONITORING AND DIAGNOSTICS OF MANUFACTURING PROCESSES

Manufacturing process monitoring is the activity of identifying characteristic changes of a process without interrupting the normal operation by evaluating the process signatures. Diagnostic activities usually accompany process monitoring. Diagnostics refers to the identification of causes for the change or failure of the process.

This research is concerned with the development of generic methodologies for sensor-assisted intelligent integrated monitoring and diagnostics of manufacturing processes and machine tools. These methodologies emphasize investigating sensor data representation schemes, sensor data fusion techniques, and neural network models, artificial reasoning methods for a variety of industrial applications.

We have developed a methodology for on-line flank wear estimation in turning processes. The results indicate that the methods investigated provide accurate on-line flank wear estimation. Our current plan is to extend the methodology for on-line tool wear estimation in milling and drilling, and in-process workpiece surface roughness assessment in turning, milling, and drilling.

JUST-IN-TIME PRODUCTION AND FLEXIBLE KANBAN SYSTEMS

The Just-In-Time (JIT) philosophy evolved from a number of principles such as the elimination of waste, reduction of production cost, total quality control and recognition of employees' abilities. The objective of JIT is the production of defect free goods in the required amount at the right time. The Kanban system, an element of the JIT system, has many advantages that include ability to control production, simplicity in production scheduling, reduced burden on operators, ease of identification of parts and substantial reduction in paper work.

Since the JIT system was designed for a deterministic environment (e.g., constant processing times and smooth and stable demand), its performance is optimum in that environment. However, once implemented, JIT is fraught with numerous types of uncertainties such as processing time and demand variations, breakdowns and other types of planned or unplanned interruptions.

To address the above-mentioned problems, we have developed a new and systematic design called the Flexible Kanban System (FKS). FKS capitalizes on the strength of JIT and, at the same time, overcomes the problems interjected by uncertainties. We have also focused on implementing JIT in small manufacturing companies which is more challenging because of their susceptibility to fluctuations.

NEURAL NETWORKS AND KNOWLEDGE-BASED SYSTEMS

Neural networks and knowledge-based systems are the intelligent computer tools useful for building powerful decision making systems which can emulate the capabilities of a human expert in a given domain of expertise. In industry, they can be used for several purposes that include interpretation, selection, prediction, monitoring, diagnosis, fault detection, design, planning, control, scheduling, maintenance, etc.

We have developed neural networks and knowledge-based systems for several applications such as form work selection in construction, undergraduate course selection, computer-aided process planning and cost estimation for a sheet metal company, cost reduction in purchasing for the Naval aviation supplies office, and tool wear estimation.

PROCESS MONITORING FOR PRODUCT QUALITY CONTROL

A major goal of process monitoring for product quality control is to detect any special disturbances in the process as early as possible, so that investigation of the process and corrective actions can be taken before many nonconforming products reach the final stage of production. The direct benefits of having a properly designed monitoring system include improved product quality, better plans for maintenance, more effective control of operating machines, and better manufacturing decisions with process and workload plans.

In process monitoring for product quality control, any observed variation in a process variable such as the diameter, length, or surface roughness of a part is attributable to either random causes or assignable causes. From the process control viewpoint, the tendency of any arbitrary pattern to repeat itself should cause concern for investigation into potential assignable causes.

We have developed a general-purpose scheme for process improvement that detects all systematic repetitive patterns from measured data. This new method automatically identifies all repetitive patterns of any structure, even if their length is relatively small. Once these symptomatic patterns are correctly identified, the results can be used to

identify the underlying reasons and to plan preventive control actions. Some of the numerous possible reasons can be found in voltage fluctuation of a power source, shift changes of operators, unfavorable humidity or temperature changes, and machine tool behavior under different operating conditions. Our pattern recognition-based method is very effective and could lead to an effective process monitoring and diagnosis for quality control.

STOCHASTIC MODELS

Modern manufacturing/ production systems continue to grow in complexity and size. A manufacturing/ production system can be considered as a collection of various service areas where jobs arrive at different rates and demand services with unequal processing times. Due to their non-deterministic behavior, stochastic models are best suited to analyze such systems. The analysis can be performed using either analytical or simulation techniques. Our work has extended the state of the art and developed many analytical techniques to study several types of manufacturing/ production systems. Similarly, we have developed capabilities to use simulation techniques to analyze large and complex systems.

MATERIALS MANAGEMENT

Materials management deals with all aspects of materials passing through a company beginning with the purchase of raw materials to the delivery of finished products. Within the company, it is necessary to determine when and in what quantities to order raw materials from various vendors, produce subassemblies and finished products, and ship finished products to clients. A methodology called the Material Requirements Planning (MRP) does just that. MRP, nonetheless, was designed to operate in a relatively static and predictable environment. However, there are times when these ideal conditions do not mimic the real-life situations.

We have done a lot of work to explore the effect of a variety of probabilistic demands and lead times scenarios on MRP performance. Understanding of such behaviors can lead to the development of strategies to maximize MRP performance in a real-life environment.

DATABASE SYSTEMS FOR PRODUCTION ENVIRONMENT

We can develop high quality customized database systems that can support group technology, design data retrieval, computer-aided process planning, cost optimization and estimation, just-in-time inventory management, etc.

LRM Members

Director

DR. SURENDRA M. GUPTA

Dr. Surendra M. Gupta is the director of the Laboratory for Responsible Manufacturing and is on the faculty in the Department of Mechanical, Industrial and Manufacturing Engineering at Northeastern University in Boston. He received his BE in Electronics Engineering from Birla Institute of Technology and Science, MBA from Bryant college and MSIE and Ph.D. in Industrial Engineering from Purdue University.

His research interests are in the areas of Production systems and Operations Research. He has authored and co-authored more than 150 technical papers presented at various national & international conferences and published in numerous books, proceedings & prestigious journals. He has traveled widely and presented his work at international conferences on six continents viz., Africa, Asia, Australia, Europe, North America and South America. The journals where his publications have appeared include *Annals of Operations Research, Computers and Electrical Engineering, Computers and Industrial Engineering, Computers and Mathematics with Applications, Computers and Operations Research, International Journal of Computer Integrated Manufacturing, International Journal of Flexible Automation and Integrated Manufacturing, International Journal of Industrial Engineering, International Journal of Operations and Production Management, International Journal of Production Economics, International Journal of Production Research, Journal of Electronics Manufacturing, Journal of Engineering Sciences, Journal of Fire Technology, Journal of Industrial Ecology, Journal of Intelligent Manufacturing, Journal of Operational Research Society, Journal of the American Society of Information Science, Microelectronics and Reliability, Opsearch, Perception and Psychophysics, Performance Evaluation, Performance Evaluation Review, Production and Inventory Management Journal, Production Planning and Control, and Transactions of Operational Research.*

He is the editor for the special issue of *Journal of Electronics Manufacturing* on "Environmental, Recycling and End of Life Issues in the Electronics Industry", senior editor of the *Industrial Engineering Applications and Practice: Users' Encyclopedia*, co-editor for the special issue of *Computers and Industrial Engineering* on "Operational Issues in Environmentally Conscious Manufacturing" and serves on the editorial boards of *IIE Transactions* on Design and Manufacturing, *Journal of Electronics Manufacturing*, *International Journal of Industrial Engineering* and *International Journal of Product and Process Development*. He has served as a member of several Technical Committees including that of *IEEE* on *ISEE'98, ISEE'99, ISEE'2000, DYCONS99, GT/CM'2000, RETBE'2000 and ICMFMDI'2000.* He is a regular reviewer for more than a dozen major journals in the field of Production/ Manufacturing Systems and Operations Research and *National Research Council*. He has been elected to the memberships of several honor societies and is listed in various Who's Who publications. He is a registered Professional Engineer and a member of ASEE, DSI, IIE, INFORMS and POMS.

He has been elected to memberships and chairmanships of dozens of University, College and Department Committees and is currently serving as an elected member of the Faculty Senate representing the College of Engineering.

Associate Director

DR. SAGAR V. KAMARTHI

Dr. Sagar V. Kamarthi is the associate director of the Laboratory for Responsible Manufacturing and is on the faculty of the Department of Mechanical, Industrial and Manufacturing Engineering at Northeastern University, Boston. He received his BS in Chemical Engineering from the Sri Venkateswara University, Tirupati, India, and MS and Ph.D. in Industrial Engineering from the Pennsylvania State University.

His research interests are in the areas of mass customization. The current research plan includes the development of metrics of agility and formulation of principles for mass customization, and creation of intelligent information systems for customer interaction. Since he joined the department four years ago, he has taken the responsibility of teaching both undergraduate and graduate level courses in the area of manufacturing system/engineering and establishing a research focus in the department on agile manufacturing for mass customization. At present he is developing an integrated research, education and industrial partnership plan modeled on the concept of knowledge supply chains. As key a feature of this model, he will use the experience, information and data that result from the industrial partnerships for driving his research and educational activities.

He has been supervising Dr. Stefan Pittner, Postdoctoral Research Associate, for the past three years. At present, he has been advising four doctoral students and five master students on different topics related to his research interests.

He has written several technical papers and been actively seeking collaboration with several industrial partners. The journals where his publications have appeared include *ASME Transactions on Manufacturing Science and Engineering, IEEE Transactions on Pattern Analysis and Machine Intelligence, IIE Transactions*, and *International Journal of Production Research*.

He has been serving as an Associate Editor of the *International Journal of Agile Manufacturing*, Associate Editor of the *Industrial Engineering User's Encyclopedia*, and Editorial Board Member of the *International Journal of Industrial Engineering -- Applications and Practice*.

He is the recipient of several prestigious awards. In 1998 he won the Dell K. Allen Outstanding Young Manufacturing Engineer Award. This award is conferred by the Society of Manufacturing Engineers (SME) and ranks in stature with the SME International Honor Awards and the SME Award of Merit. In 1996 he won the Pritsker Doctoral Dissertation Award given by the Institute of Industrial Engineers (IIE) to the outstanding doctoral dissertation research in the areas related to industrial and manufacturing engineering. In 1989, he won the First Prize in the Fourth Annual Graduate Research Exhibition at the Pennsylvania State University. In 1982 he won the First Prize in the National Student's Design Competition conducted by the Indian Council for Science Museums, Bangalore, India.

He is a member of the SME, ASME, IIE, IEEE, and ASEE. Since 1996, he has been serving Boston IIE Senior Chapter as the Director for NEU Representation.

Research Associates

MUHTAR BURAK AKBULUT, BS, MS, MSIE

Mr. Akbulut's research interests are in the area of distributed information systems and their applications to manufacturing related problems. He holds a BS and an MS in Mechanical Engineering from the Middle East Technical University, Ankara, Turkey and an MS in Industrial Engineering from Northeastern University. He is a member of ASME and Phi Kappa Phi (Interdisciplinary Honor Society).

HASAN KIVANC AKSOY, BS, MS

Mr. Aksoy's research interests are in the areas of stochastic processes, optimization and applied probability. He has a BS in Statistics from the Middle East Technical University, Ankara, Turkey and an MS in Industrial Engineering from Northeastern University. He has been awarded a full scholarship to pursue graduate studies in the United States by Osmangazi University, Eskisehir, Turkey. He is a member of Alpha Pi Mu (National Industrial Engineering Honor Society).

JANE E. BOON, BS, SM

Ms. Boon's research interests are in the areas of life cycle cost assessment and industrial ecology. Ms. Boon has received the following academic awards: Keil Fellowship (MIT, 1990); Natural Sciences and Engineering Research Council Award for Post-graduate Study (1992); Magna International Corporate Sponsorship (GMI Institute, 1985-1990). She is a member of Sigma Xi (National Research Honor Society) and Tau Beta Pi (National Engineering Honor Society).

PRATAP S. SUNDAR, B. TECH., M. TECH.

Mr. Sundar's research interests are in the areas of agile manufacturing, quality engineering, lean production, mass customization, and supply chain management. He is a member of, IIE, INFORMS, and Alpha Pi Mu (National Industrial Engineering Honor Society).

SHAHZAD DAD, BS, MS

Mr. Dad's research interests are in the areas of indirect sensing, neural network methods for fault prediction and machine performance enhancement. He was awarded 4th prize for the senior Design Project by ASME.

MEHMET DINCER, BS, MS

Mr. Dincer's research interests are in the areas of production planning and control in disassembly systems. He has been awarded a full scholarship for his graduate studies by Kocaeli University, Izmit, Turkey. He is a member of Alpha Pi Mu (National Industrial Engineering Honor Society).

QINGLAN GAO, BS, MS

Ms. Gao's research interests are in the area of sensor-assisted monitoring and diagnosis of manufacturing processes. She has a BS in Engineering Thermal Physics from the

University of Science and Technology, Hefei, China. She completed her MS degree in June 1998 from Northeastern University.

ASKINER GUNGOR, BS, MS, PH.D.

Mr. Gungor's research interests are in the areas of graph theory, scheduling and sequencing, combinatorial optimization, heuristics, and disassembly systems. He was awarded a full scholarship for his graduate studies by Pamukkale University, Denizli, Turkey. He is a member of Alpha Pi Mu (National Industrial Engineering Honor Society), Sigma Xi (National Research Honor Society) and Institute for Operations Research and the Management Sciences (INFORMS). He obtained his Ph.D. degree from Northeastern University in September 1999.

WILAIRAT IMTANAVANICH, BS, MS

Ms. Imtanavanich's research interests are in the areas of design for manufacturing processes of multi-lifecycle materials, multi-lifecycle polymer product, environmental-conscious alternative materials, and production and investment analysis of alternative material industry. She has a BS degree in chemical engineering from King Mongkut's Institute of Technology, Thailand, and an MS degree in Engineering Management from Syracuse University.

ELIF AYSE KIZILKAYA, BS, MS

Ms. Kizilkaya’s research interests are in the areas of production planning and control, operations research, just in time systems, disassembly inventory control and systems. She is a recipient of General Electric Women in Research Fellowship and the Sears B. Conduit Award. She has been listed in the Who’s Who Among Student’s in American Colleges and Universities and currently has a Teaching Assistantship from Northeastern University, MIME Department. She is also a member of Tau Beta Pi (National Engineering Honor Society) and Alpha Pi Mu (National Industrial Engineering Honor Society).

ELIF KONGAR, BS, MS

Ms. Kongar’s research interests are in the areas of disassembly systems, production planning, goal programming and simulation. She received both her BS and MS degrees from Yildiz Technical University, Istanbul, Turkey. She has been awarded a full scholarship for her Ph.D. study by Yildiz Technical University.

AYBEK KORUGAN, BS, MS

Mr. Korugan’s research interests are in the areas of queueing networks, inventory management in remanufacturing environments, and control and optimization of manufacturing systems. He has been awarded a full scholarship for his graduate studies by Canakkale University, Canakkale, Turkey. He is a member of Alpha Pi Mu (National Industrial Engineering Honor Society).

KENDRA E. MOORE, BA (*MAGNA CUM LAUDE*), MA, MS, PH.D.

Ms. Moore’s research interests include Petri nets, discrete-event simulation, stochastic modeling of Kanban-based production systems, disassembly systems, and command/control systems. Ms. Moore has received the following academic and business

awards: Curator's Scholarship (full academic scholarship, Stephens College, Columbia, MO); Curator's Award for Outstanding Sophomore (Stephens, College); NCAA Division III Outstanding Scholar Athlete; Entrepreneur of the Year (ALPHATECH, Inc.). Ms. Moore is a member of the Institute for Electrical and Electronics Engineers, the Institute for Industrial Engineers, the Institute for Operations Research and Management Science, the Society for Computer Simulation, and Alpha Pi Mu (National Industrial Engineering Honor Society). She obtained her Ph.D. degree from Northeastern University in September 1998.

STEFAN PITTNER, PH.D.

Dr. Pittner's research interests are in the areas of optimization and automation of manufacturing processes, mass customization, intelligent agents, and neural networks. He received his MS in Computational Mathematics and his Ph.D. in Applied Mathematics, both from the Vienna University of Technology. He has been working as a Postdoctoral Research Associate in the Laboratory for Responsible Manufacturing.

KISHORE POCHAMPALLY, B.E.

Mr. Pochampally's research interests are in data-driven systems. He obtained his B.E. degree (with distinction) from Regional Engineering College in India. He has a Teaching Assistantship from Northeastern University, MIME Department.

GUN UDOMSAWAT, BS, MS

Mr. Udomsawat's research interests are in the areas of stochastic processes, production planning, design and control, system optimization, multi-lifecycle product design and economical analysis, cost/benefit models for environmental-conscious product and system investment. He holds a BS degree from King Mongkut's Institute of Technology, Thailand, and an MS degree in Engineering Management from Syracuse University.

PITIPONG VEERAKAMOLMAL, BS, MS, PH.D.

Mr. Veerakamolmal's research interests are in the areas of disassembly systems, theory of scheduling and sequencing, linear programming, and simulation. He is a member of Alpha Pi Mu (National Industrial Engineering Honor Society), Sigma Xi (National Research Honor Society) and Phi Kappa Phi (Interdisciplinary Honor Society). He obtained his Ph.D. degree from Northeastern University in June 1999.

PIROJ WONGSIRIPATANAKUL, BS, MS

Mr. Wongsiripatanakul's research interests are in the areas of acoustic emission sensor, surface roughness estimation, fuzzy logic, neural networks, and learning systems. He has worked at the Ministry of Science, Technology, and Environment, Thailand since 1979. He has earned a scholarship from the Royal Thai Government to pursue a Ph.D. degree.

NAKEN WONGVASU, BBA, MS

Mr. Wongvasu's research interests are in the areas of mass customization, product representation & modeling, RFQ processing, neural networks, case-based reasoning, knowledge acquisition and rapid cost estimation.

Publications - Journals

1999

- Gungor, A. and Gupta, S. M., (1999). "Issues in Environmentally Conscious Manufacturing and Product Recovery: A Survey", *Computers and Industrial Engineering (An International Journal)*, Vol. 36, No. 4, pp. 811-853.

Abstract— Environmentally Conscious Manufacturing and Product Recovery (ECMPRO) has become an obligation to the environment and to the society itself, enforced primarily by governmental regulations and customer perspective on environmental issues. This is mainly driven by the escalating deterioration of the environment, e.g., diminishing raw material resources, overflowing waste sites, and increasing levels of pollution. ECMPRO involves integrating environmental thinking into new product development including design, material selection, manufacturing processes and delivery of the product to the consumers, plus the end-of-life management of the product after its useful life. ECMPRO related issues have found a large following in industry and academia who aim to find solutions to the problems that arise in this newly emerged research area. Problems are widespread including the ones related to life cycle of products, disassembly, material recovery, remanufacturing, and pollution prevention. In this paper, we present the development of research in ECMPRO and provide a state-of-the-art survey of published work.

- Gupta, S. M., (1999). "N-Policy Queueing System with Finite Source and Warm Spares", *Opsearch*, Vol. 36, No. 3, pp. 189-217.

Abstract— In this paper, a generalized queueing system with finite source, N-policy with startup time and warm spares is considered. A closed form stationary distribution of the number of customers in the system for such a system is not attainable. However, it is possible to derive closed form expressions for recursively calculating the stationary distribution. With some modification, this model can accommodate server vacations with exhaustive service discipline. To this end a generalized model to accommodate the cases of multiple vacations, single vacation and hybrid multiple/single vacation schemes is considered. Closed form expressions for the vacation models are achievable and are presented. An efficient algorithm is presented to find the stationary probability distribution of the number of customers in the system as well as the performance measures of these models. The algorithm is an extremely powerful generalized methodology which can solve dozens of standard and non-standard queueing problems. Several special cases are considered. Some previously published results are shown to be special cases of the more general results derived here. An example and some numerical results are also presented.

- Gupta, S. M., Al-Turki, Y. A. Y. and Perry, R. F., (1999). "Flexible Kanban System", *International Journal of Operations and Production Management*, Vol. 19, No. 10, pp. 1065-1093.

Abstract— Just-In-Time (JIT) systems were originally designed for deterministic production environments such as constant processing times and smooth and stable demand. However, once implemented, JIT is fraught with numerous types of uncertainties, including variations in processing time and demand, planned interruptions such as preventive maintenance and unplanned interruptions such as equipment failure. These uncertainties lead to lowered production throughput, decreased machine utilization, increased order completion time and greater backlogs and overtime

requirements. In this paper, we introduce a newly developed system, which we refer to as the Flexible Kanban System (FKS), to cope with uncertainties and planned/ unplanned interruptions. We demonstrate the superiority of the new system by considering four case examples covering various uncertainties, conducting numerous studies and comparing the overall performances of the FKS with that of the traditional JIT system. In all the cases considered, the performance of the FKS was, indeed, superior to that of the traditional JIT system.

- Kamarthi, S. V. and Pittner, S. (1999). "Accelerating Neural Network Training Using Weight Extrapolations", *Neural Networks*, Vol. 12, pp. 1285-1299.

Abstract— The backpropagation (BP) algorithm for training feedforward neural networks has proven robust even for difficult problems. However, its high performance results are attained at the expense of a long training time to adjust the network parameters, which can be discouraging in many real-world applications. Even on relatively simple problems, standard BP often requires a lengthy training process in which the complete set of training examples is processed hundreds or thousands of times. In this paper, a universal acceleration technique for the BP algorithm based on extrapolation of each individual interconnection weight is presented. This extrapolation procedure is easy to implement and is activated only a few times in between iterations of the conventional BP algorithm. This procedure, unlike earlier acceleration procedures, minimally alters the computational structure of the BP algorithm. The viability of this new approach is demonstrated on three examples. The results suggest that it leads to significant savings in computation time of the standard BP algorithm. Moreover, the solution computed by the proposed approach is always located in close proximity to the one obtained by the conventional BP procedure. Hence, the proposed method provides a real acceleration of the BP algorithm without degrading the usefulness of its solutions. The performance of the new method is also compared with that of the conjugate gradient algorithm, which is an improved and faster version of the BP algorithm.

- Kavusturucu, A. and Gupta, S. M., (1999). "Analysis of Manufacturing Flow Lines with Unreliable Machines", *International Journal of Computers Integrated Manufacturing*, Vol. 12, No. 6, pp. 510-524.

Abstract— We develop an analytical methodology for the analysis of a tandem manufacturing flow line with finite buffers and unreliable machines. The flow line is modeled using Open Queueing Networks. The methodology uses decomposition, isolation and expansion methodologies to calculate the throughput of the flow line. The methodology is tested rigorously. In order to cover a large experimental region, orthogonal arrays are used to design the experiments. The results of these experiments are compared to their corresponding simulation results. t-test is carried out to investigate the differences between the simulation results and the results of the methodology. The results show that the methodology is robust and remarkably accurate over a wide range of parameters.

- Kavusturucu, A. and Gupta, S. M., (1999). "Expansion Method for the Throughput Analysis of Open Finite Manufacturing/Queueing Networks with N-Policy", *Computers and Operations Research (An International Journal)*, Vol. 26, No. 13, pp. 1267-1292.

Abstract— In this paper we consider arbitrary topology open manufacturing (queueing) systems with finite buffers and N-policy. N-policy involves a queueing system in which the machine (server) is assigned to alternative jobs when it becomes idle and becomes available only after the queue builds up to a predetermined level of N jobs. We use the decomposition, isolation and expansion methodologies to calculate the throughput of the system. The methodology is tested rigorously by

using orthogonal arrays to design the experiments in order to cover a large experimental region. The results of the methodology are compared to simulation results. To this end, we also develop a simulation model (which in itself is quite challenging). The differences in the two results are investigated using t-tests. Based on the results, the methodology proves to be remarkably accurate and robust over a broad range of parameters.

- Kavusturucu, A. and Gupta, (1999). S. M., "Manufacturing Systems with Machine Vacations, Arbitrary Topology and Finite Buffers", *International Journal of Production Economics*, Vol. 58, No. 1, pp. 1-15.

Abstract— We consider a manufacturing system with finite buffer and arbitrary topology where a machine takes a vacation (i.e. is unavailable for processing due to the processing of secondary jobs or maintenance of machines) of random duration every time the machine becomes idle. To this end, we develop an approximation (analytical) methodology to calculate the throughput of the system using queueing networks together with decomposition, isolation and expansion methodologies. The methodology was tested rigorously covering a large experimental region. We used orthogonal arrays to design the experiments in order to keep the number of experiments manageable. The results obtained using the approximation methodology were compared to simulation results. The t-tests carried out to investigate the differences between the two results showed that the proposed methodology is very accurate as well as robust.

- Moore, K. E. and Gupta, S. M., (1999). "Stochastic Colored Petri Net (SCPN) Models of Traditional and Flexible Kanban Systems", *International Journal of Production Research*, Vol. 37, No. 9, pp. 2135-2158.

Abstract— Modeling and analysis of JIT under realistic assumptions presents a number of challenges, including the ability to model blocking and starvation, the ability to conduct both qualitative and quantitative analysis, and the ability to model control policies. Petri nets (PNs) have recently emerged as a promising approach for modeling manufacturing systems. PNs are a graphical and mathematical technique useful for modeling concurrent, asynchronous, distributed, parallel, nondeterministic, and stochastic systems. PN models can be analyzed to determine both their qualitative and quantitative properties. In this paper, we use stochastic, colored PNs (SCPNs) to model JIT system and analyze the impact on system performance of two different kanban control policies: a traditional kanban system (TKS) and a recently introduced flexible kanban system (FKS) policy. In TKS, the number of kanbans is fixed throughout the production cycle; the control problem is to determine the optimal number of kanbans. In FKS, the number of kanbans is systematically manipulated during the production cycle to improve system performance; the control problem is to determine the minimal number of kanbans and when and by how much to manipulate the kanbans. The resulting models are shown to be live and bounded, and their performance compared for a variety of operating scenarios. The model can be extended to build models of arbitrary size.

- Pittner, S. and Kamarthi, S. V. (1999). "Feature Extraction from Wavelet Coefficients for Pattern Recognition Tasks", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 21, No. 1, pp. 83-88.

Abstract— In this paper, a new efficient feature extraction method based on the fast wavelet transform is presented. Especially, this paper deals with the assessment of process parameters or states, in a given application, using the features extracted from the wavelet coefficients of measured process signals. Since the parameter assessment using all wavelet coefficients will often turn out to be tedious or leads to inaccurate results, a preprocessing routine that computes robust features

correlated to the process parameters of interest is highly desirable. The method presented divides the matrix of computed wavelet coefficients into clusters equal to rowvectors. The rows that represent important frequency ranges (for signal interpretation) have a larger number of clusters than the rows that represent less important frequency ranges. The features of a process signal are eventually calculated by the euclidean norms of the clusters. The effectiveness of this new method has been verified on a flank wear estimation problem in turning processes and on a problem of recognizing different kinds of lung sounds for diagnosis of pulmonary diseases.

- Veerakamolmal, P. and Gupta, S. M., (1999). "Analysis of Design Efficiency for the Disassembly of Modular Electronic Products", *Journal of Electronics Manufacturing*, Vol. 9, No. 1, pp. 79-95.

Abstract— In this paper, we present a technique for analyzing the design efficiency of electronic products, in order to study the effect of end of life (EOL) disassembly and disposal on the environment. The design efficiency is measured using a Design for Disassembly Index (DfDI). DfDI uses a disassembly tree (DT) which relies on the product's structure. The DT can be used to identify the precedent relationships that define the hierarchy of the product's structure (which in turn, represents the order in which components can be retrieved). DfDI can be used to analyze the merits and drawbacks of different product designs. The index offers designers with an important measure to help improve the future products. We provide a comprehensive procedure for developing the index and demonstrate its application through an example.

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- Chinnaiah, P. S. S. and Kamarthi, S. V. (1998). "Automation of Library Reshelving Operations", *International Journal of Industrial Engineering - Theory, Application and Practice*, Vol. 5, No. 4, pp. 308-315.

Abstract— The book circulation process in a library broadly consists of two tasks: (1) the data processing task which keeps track of the books and (2) the reshelving task which includes activities such as collection of returned books, holding, sorting, and reshelving. In this paper a model for automating the reshelving operations is presented applying the concept of automated storage and retrieval system (AS/RS). Although a fully automated reshelving system is technically feasible, such a system is prohibitively expensive. Therefore a practical system which is a combination of automated and manual operations is proposed to place a user returned book in its appropriate location and carry out the associated data processing work. Experiments on a simulation model demonstrate that a drastic reduction in the reshelving lead time is possible. The proposed system will significantly improve the performance of the reshelving operations and hence the customer service in a library.

- Chinnaiah, P. S. S., Kamarthi, S. V., Cullinane, T. P. (1998). "Characterization and Analysis of Mass-Customized Production Systems", *International Journal of Agile Manufacturing*, Vol. 2, No. 1, pp. 93-118.

Abstract— During the 1980s many industries began focusing more intensely on individual customer needs. This trend has led to the beginning of mass-customized production systems in which products are designed, manufactured, tested, and delivered according to a customer's exclusive requirements. Concentration on the individual customer is taking place in consumer goods, automobiles, telecommunications, information services, computer hardware, software, and a wide range of other products. Mass-customized production systems vary widely in their architectures. In these varying architectures the technology and personnel requirements of mass-customized production systems depend on a variety of factors. This paper establishes a formal definition for mass-customized production systems, provides a comprehensive review of the literature, classifies different types of mass-customized production systems, identifies several technologies useful for supporting these systems, and discusses various factors that influence them. A table comparing all variants of mass-customized production systems with respect to these factors of influence is presented. The present study has been formulated to help industrial practitioners to plan, design, and implement appropriate mass-customized production systems.

- Gungor, A. and Gupta, S. M. (1998). "Disassembly Sequence Planning for Products with Defective Parts in Product Recovery", *Computers and Industrial Engineering (An International Journal)*, Vol. 35, No. 1-2, pp. 161-164.

Abstract— Recycling and remanufacturing are important forms of product/material recovery which involve product disassembly to retrieve the desired parts and/or subassemblies. Disassembly is a systematic method for separating a product into its constituent parts, components or other groupings. Efficient disassembly requires development of disassembly sequence plans (DSPs). Generating DSPs describing the sequence of parts during disassembly is not a trivial problem since DSP generation is described to be NP-complete. Further complicating matters is the presence of a high degree of uncertainty due to upgrading/downgrading of the product during its use by the customers and defects occurring either when in use or during disassembly. In this paper, we address the uncertainty related difficulties in disassembly sequence planning. To this end, we present a

methodology to develop a framework for dealing with uncertainty in DSP implementation and demonstrate it using a simple example.

- Gupta, S. M. and Al-Turki, Y. A. Y. (1998). "Adapting Just-In-Time Manufacturing Systems to Preventive Maintenance Interruptions", *Production Planning and Control (An International Journal)*, Vol. 9, No. 4, pp. 349-359.

Abstract— The Just-In-Time (JIT) system is designed to operate in an ideal environment such as constant processing times, smooth and stable demand and uninterrupted processing. However, in a real life environment, the JIT system is subjected to various uncertain factors including stochastic processing times, variable demand and process interruption due to planned preventive maintenance. These factors seriously compromise the performance of JIT. In this paper, we present a newly developed JIT system which uses an algorithm to dynamically and systematically manipulate the number of Kanbans in order to offset the blocking and starvation caused by the said factors during a production cycle. We refer to the new system as the Flexible Kanban System (FKS). We provide steps of the algorithm and demonstrate the effectiveness of FKS using a case example. For the case example, we present the solution procedure, results and discussion.

- Gupta, S. M. and Al-Turki, Y. A. Y. (1998). "The Effect of Sudden Material Handling System Breakdown on the Performance of a JIT System", *International Journal of Production Research*, Vol. 36, No. 7, pp. 1935-1960.

Abstract— In this paper we explore the impact of sudden breakdown of the material handling system on the performance of a Traditional Kanban System (TKS). TKS, which is an element of the Just-In-Time system, is designed to operate in an ideal environment such as constant processing times and uninterrupted processing. However, in a real life environment, the TKS could be subjected to various unpredictable factors including stochastic processing times and process interruption due to equipment failure. These factors would seriously strain the performance of TKS. We consider a TKS in which some stations are dependent on a material handling system to move parts between them. We study the effect of a sudden breakdown of such a material handling system on the performance of the TKS. In addition, we also study a newly developed Kanban system (which dynamically and systematically manipulates the number of Kanbans in order to offset the blocking and starvation caused by these factors during a production cycle) under the same conditions. We refer to the new system as the Flexible Kanban System (FKS). We compare the overall performances of the TKS and FKS by considering a variety of cases. We present the solution procedure, results and discussion for these cases.

- Gupta, S. M. and Kavusturucu, A. (1998). "Modeling of Finite Buffer Cellular Manufacturing Systems with Unreliable Machines", *International Journal of Industrial Engineering*, Vol. 5, No. 4, pp. 265-277.

Abstract— We develop a methodology for the analysis of finite buffer manufacturing systems with unreliable machines and arbitrary topology. We model the system using Open Queueing Networks. Decomposition, isolation and expansion methodologies are used to calculate the throughput of the system. The methodology is tested rigorously. Orthogonal arrays are used to design the experiments in order to cover a large experimental region. The results of these experiments are compared to their corresponding simulation results. In order to investgate the differences between the simulation results and the results of the methodology, t-tests are carried out. When tested over a wide range of parameters, the results show that the methodology is remarkably accurate and robust.

- Karaesmen, F. and Gupta, S. M. (1998). "Service Control in a Finite Buffered Queue with Holding and Setup Costs", *Transactions on Operational Research*, Vol. 10, No. 1, pp. 1-20.

Abstract— We consider a finite buffered queue where the queue length is controlled by shutting down and restarting the server. In particular, we analyze the problem with the inclusion of holding costs for customers (or items) whereas previous research concentrated on the case without holding costs. To study the effect of holding costs, we first establish some stochastic comparisons that permit us to compare different operating policies. In addition to these structural results, we also present new results on the queue length distribution for the system. Our methods enable us to obtain the queue length distribution in closed form for phase type service distributions. As a consequence, we provide extensive numerical examples over a range of the problem parameters which uncover some intriguing properties of the optimal revenue depending on the service time distribution.

- Kavusturucu, A. and Gupta, S. M. (1998). "A Methodology for Analyzing Finite Buffer Tandem Manufacturing Systems with N-Policy", *Computers and Industrial Engineering (An International Journal)*, Vol. 34, No. 4, pp. 837-848.

Abstract— We develop a methodology for the analysis of a finite buffer tandem manufacturing system where the machines follow N-policy. We model the system using Open Queueing Networks. The throughput of the system is calculated using decomposition, isolation and expansion methodologies. The methodology is tested rigorously by using orthogonal arrays to design the experiments. t-test is used to investigate the differences between the results of the methodology and their corresponding simulation results. The comparison shows that the methodology is robust and remarkably accurate over a wide range of parameters.

- Kavusturucu, A. and Gupta, S. M. (1998). "Tandem Manufacturing Systems with Machine Vacations", *Production Planning and Control (An International Journal)*, Vol. 9, No. 5, pp. 494-503.

Abstract— This paper develops a methodology for the analysis of tandem manufacturing systems where a machine takes a vacation (i.e. becomes unavailable for some reason such as processing secondary jobs or being repaired) of random duration every time the corresponding station becomes empty. The system is modeled using a queueing network in which decomposition, isolation and expansion methodologies are used to calculate the throughput. The methodology was rigorously tested by designing experiments using orthogonal arrays to cover a large experimental region. The results are compared with benchmark results obtained through simulation. The differences between the two results are investigated using t-tests. The methodology developed proved to be robust and very accurate.

- Kizilkaya, E. and Gupta, S. M. (1998). “Material Flow Control and Scheduling in a Disassembly Environment”, *Computers and Industrial Engineering (An International Journal)*, Vol. 35, No. 1-2, pp. 93-96.

Abstract— This paper presents a technique to control the material flow in a disassembly environment using the Flexible Kanban System (FKS). The implementation and effectiveness of the FKS is demonstrated using a case example.

- Korugan, A. and Gupta, S. M. (1998). “A Multi-Echelon Inventory System with Returns”, *Computers and Industrial Engineering (An International Journal)*, Vol. 35, No. 1-2, pp. 145-148.

Abstract— This paper considers a two-echelon inventory system with return flows, where demand and return rates are mutually independent. An open queueing network with finite buffers is used to model the system. The model is analyzed using the expansion methodology.

- Mak, R., Lam, K. and Gupta, S. M., (1998). "A Practical Algorithm for Cyclic Hoist Scheduling in a PCB Manufacturing Facility", *Journal of Electronics Manufacturing*, Vol. 8, No. 3-4, 1998, pp. 193-207.

Abstract— Electroplating is a major process in the manufacturing of printed circuit boards. Scheduling the movement of material handling hoists for electroplating processes is generally known as the Hoist Scheduling Problem (HSP) and has been proven to be NP-complete. The objective of HSP is to find a cyclic sequence of hoist moves that maximizes the production throughput. For the past two decades, various optimization and heuristic techniques have been proposed to solve the problem. However, these methods are often limited to the elementary problems. Recently, artificial intelligence (AI) approach using constraint logic programming has been applied to solve the cyclic HSP but did not consider problems with duplicated process tanks. In this paper, we apply constraint satisfaction to solve HSP with duplicate process tanks. A binary search procedure is proposed and a tighter bound to the cycle length is introduced to reduce the computation effort. The proposed algorithm can be easily implemented on any personal computer with reasonable performance so as to be useful on the shop floor. Finally we present results for several benchmark examples.

- Moore, K. E., Gungor, A. and Gupta, S. M. (1998). “A Petri Net Approach to Disassembly Process Planning”, *Computers and Industrial Engineering (An International Journal)*, Vol. 35, No. 1-2, pp. 165-168.

Abstract— Recycling and remanufacturing involve product disassembly to retrieve the desired parts and/or subassemblies. Disassembly is a systematic method for separating a product into its constituent parts, components, or other groupings. Disassembly process planning is critical in minimizing the amount of resources (e.g., time and money) invested in disassembly and maximizing the level of automation of the disassembly process and the quality of the parts (or materials) recovered. We propose an algorithm which automatically generates a disassembly Petri net (DPN) from a geometrically-based precedence matrix. The resulting DPN can be analyzed to generate all feasible disassembly process plans (DPPs), and cost functions can be used to determine the optimal DPP; alternatively, heuristic methods may be used to generate near-optimal DPPs.

- Moyer, L. and Gupta, S. M. (1998). "Development of the Surface Mount Assembly Process Through an Angular Board Orientation", *International Journal of Production Research*. Vol. 36, No. 7, pp. 1857-1881.

Abstract— This paper proposes a methodology to improve the process time required for the component placement process of the printed circuit board assembly with an X-Y positioning table. The methodology is applied to a previously published subproblem as well as a real-life working board configuration. Even with high speed assembly machines placing in excess of 40,000 components per hour (cph), process improvements are possible. Concentrating on the path planning portion is a valid method to increase efficiency, but as the problem approaches optimality, the planning process essentially becomes counterproductive due to the time and effort required. This

paper presents an algorithm for system time improvement for use after a board placement path is established. In order to take advantage of the machine's capability to move the positioning table along each axis simultaneously, the board is physically rotated with respect to the positioning table. This paper steps through the theoretical development of a method to determine the proper angle of rotation, first for a regular "rectangular" board configuration, and then for a more applicable "general" configuration.

- Pittner, S., Kamarthi, S. V., and Gao, Q. (1998). "Wavelet Networks for Sensor Signal Classification in Flank Wear Assessment", *Journal of Intelligent Manufacturing*, Vol. 9, No. 4, pp. 315-322.

Abstract— It is known that the vibration sensor signals in a turning process are sensitive to the gradually increasing flank wear. Based on this fact, this paper investigates a flank wear assessment technique in turning through vibration signals. Mainly to reduce the computational burden associated with the existing sensor-based methods for flank wear assessment, a a so-called wavelet network is investigated. The basic idea in this new method is to optimize simultaneously the wavelet parameters (that represent signal features) and the signal interpretation parameters (that are equivalent to neural network weights) to eliminate the feature extraction phase without increasing the computational complexity of the neural network. A neural network architecture similar to a standard one-hidden-layer feedforward neural network is used to relate sensor signal measurements to flank wear classes. A novel training algorithm for such a network is developed. The performance of this new method is compared with a previously developed flank wear assessment method which uses a separate feature extraction step. The posed wavelet network can also be useful for developing signal interpretation schemes for manufacturing process monitoring, critical component monitoring, and product quality monitoring.

- Veerakamolmal, P. and Gupta, S. M. (1998). "Optimal Analysis of Lot Size Balancing for Multi-Products Selective Disassembly", *International Journal of Flexible Automation and Integrated Manufacturing*, Vol. 6. No. 4.

Abstract— In recent years there has been an appalling rate of depletion of natural resources due to an ever-increasing number of consumer goods manufactured, in turn leading to an increase in the quantity of used and outdated products discarded. From an environmental point of view, it is not only desirable to disassemble, reuse and/or recycle the components and materials from the discarded products, in many cases it can also be economically justified. This paper presents a quantitative methodology for product disassembly and recycling by taking both operational and environmental factors into account. To this end, a mathematical programming model that provides a unique solution for planning component recovery from products with component commonality is presented. The objective of the component recovery model is to compute the number of products to disassemble, in order to fulfill the demand of the components, at the minimal disassembly and disposal costs. A case study is presented to illustrate the methodology.

- Veerakamolmal, P. and Gupta, S. M. (1998). “High-Mix/Low-Volume Batch of Electronic Equipment Disassembly”, *Computers and Industrial Engineering (An International Journal)*, Vol. 35, No. 1-2, pp. 65-68.

Abstract— This paper presents a procedure to disassemble electronic products with multiple subassembly modules. First, a partial schedule for each subassembly is obtained. The next step modifies the partial schedule in order to minimize the machine idle time at the retrieval process and, thus, the resulting makespan of the whole process. The procedure offers an optimal process

makespan according to the sequence in which the batch of products pass through the disassembly and recovery processes. Special emphasis is placed on applying variant process planning methodology for disassembly and retrieval.

Forthcoming

- Akbulut, M. B., Kamarthi, S. V. and Berry, N. M., "Applications of Agent- and Object-Oriented Approaches to Achieve Agility in Manufacturing", *Journal of Integrated Computer-Aided Engineering*.
- Gupta, S. M. and Kavusturucu, A., "Production Systems with Interruptions, Arbitrary Topology and Finite Buffers", *Annals of Operations Research*.
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- Moore, K. E., Gungor, A. and Gupta, S. M., "Petri Net Approach to Disassembly Process Planning for Products with Complex AND/OR Precedence Relationships", *European Journal of Operational Research*.
- Veerakamolmal, P. and Gupta, S. M., "Disassembly Process Planning", *Engineering Design and Automation (An International Journal)*.

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- Aksoy, K. and Gupta, S. M., (1999). "An Open Queueing Network Model for Remanufacturing Systems", *Proceedings of the International Conference on Computers and Industrial Engineering*, pp. 62-65.
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- Guide, Jr., V. D. R. and Gupta, S. M., (1999). "A Queueing Network Model for Remanufacturing Production Systems", *Proceedings of the International Seminar on Reuse*, pp. 115-128.
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- Korugan, A. and Gupta, S. M. (1998). "Analysis of a Two-Echelon Inventory System with Return Flows", *Fourteenth Conference on Operational Research and Industrial Engineering (YA/EM'98)*, Ankara, Turkey, June 25-26.

NU Research and Scholarship Poster Session

- Gupta, S. M., Veerakamolmal, P., Gungor, A., Aksoy, H. K., Kizilkaya, E., Korugan, A., Boon, J. and Dincer, M., (1999). "Disassembly and Recovery of End of Life Products", *Northeastern University Research and Scholarship Poster Session*, Egan Research Center, Northeastern University, May 10.
- Kamarthi, S. V., Sundar, P., Wongvasu, N. and Pittner, S., (1999). "Design and Manufacturing in Mass Customization", *Northeastern University Research and Scholarship Poster Session,* Egan Research Center, Northeastern University, May 10.

LRM Seminars

FALL 1999

- “Mathematical Programming Model for Remanufacturing” by Mehmet Dincer.
- “Performance Comparison of Pull and Push Systems for Disassembly Environment” by Elif Kizilkaya.
- "Buffer Allocation Plan for Cellular Remanufacturing Systems" by Hasan.K. Aksoy.
- “Price Policies for a Hybrid System with Disposals” by Aybek Korugan.

SUMMER 1999

- “CBR based cost and delivery time estimation for make-to-order production” by Naken Wongvasu.
- "Disassembly Traditional Kanban System" by Elif Kizilkaya.
- “Agility of a Cellular Manufacturing Shop” by Pratap Sundar.

- “The Kanban Control Model of a Two-Echelon Inventory System with Return Flows” by Aybek Korugan.
- "Buffer Allocation Problem for Remanufacturing Systems" by Hasan.K. Aksoy.

SPRING 1999

- “Application of Goal Programming to Remanufacturing Environment” by Elif Kizilkaya.
- “Economic Modeling of Electric Vehicle Recycling” by Jane Boon.
- “Reusable-Components Requirements Planning for the Integrated Remanufacturing System” by Pitipong Veerakamolmal.
- “Analysis of a Simple kanban Network with Merging at the Final Stage” by Aybek Korugan.
- “An Integrated Time and Cost Estimation Model for Make-to-Order Products” by Naken Wongvasu.
- "An Open Queueing Network Model for Remanufacturing Systems (Buffer Allocation Problem)" by Hasan.K. Aksoy.
- “Agility of a Manufacturing Cell” by Pratap Sundar.
- “Introduction to Mathematical Programming Model for Remanufacturing” by Mehmet Dincer.

WINTER 1999

- “Disassembly Planning with Fixed Disassembly Sequence” by Mehmet Dincer.
- ”Compatibility Matrix” by Naken Wongwasu.
- “Analysis of a Supplier Management System Using Generalized Stochastic Petri Net” by Kenichi Nakashima.
- “Agility Measures based on Changes in Product Mix, Production Volume and Delivery Time” by Pratap Sundar.
- “The Disassembly Line Balancing Problem” by Askiner Gungor.
- “A Kanban Control Approach for Multi-Echelon Inventory Systems with Return Flows” by Aybek Korugan.
- "An Analytical Model for Remanufacturing Systems" by Hasan.K. Aksoy.

SUMMER 1998

- "Analysis of remanufacturing systems: A simple open queueing model" by Hasan.K. Aksoy.
- “Design of A1 type agile systems” by Pratap Sundar.
- “Disassembly flexible kanban model experimentation & comparison to traditional kanban model” by Elif Kizilkaya.

SPRING 1998

- “Analysis of a two-echelon single item inventory system with returns” by Aybek Korugan.
- “Analysis of remanufacturing systems: a simple open queueing model” by Hasan.K. Aksoy.
- “Automation of library reshelving operations and an architecture for an agile library” by Pratap Sundar.
- “DBALANCE: Disassembly line balancing” by Askiner Gungor.
- “Design of an integrated component recovery system” by Pitipong Veerakamolmal.
- “Disassembly planning” by Mehmet Dincer.
- “Problem with representing product structure in a large variant environment” by Naken Wongvasu.
- “Surface roughness estimation” by Piroj Wongsiripatanakul.

WINTER 1998

- “A multi-echelon inventory system with return flows” by Aybek Korugan.
- “A strategic decision model for the selection of agility enablers” by Pratap Sundar.
- “An application of flexible kanban system to disassembly” by Elif Kizilkaya.
- “Compatibility oriented product modeling,” by Naken Wongvasu.
- “Disassembly Petri net generation in the presence of XOR precedence relationships" by Kendra E. Moore and Askiner Gungor.
- “Generation of disassembly sequence plans (DSPs) in the presence of uncertainty” by Askiner Gungor.
- “Recycle disassembly planning” by Mehmet Dincer.
- “Remanufacturing with stochastic reusable rate and its effects on production planning and inventory control” by Hasan.K. Aksoy.
- “Software implementation of remanufacturing issues” by Omca Korugan.

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