Laboratory for Responsible Manufacturing

Research Summary

1997 - 1998

Laboratory for Responsible Manufacturing

Department of MIME, College of Engineering, Northeastern University, Boston, Massachusetts 02115

LRM
Engineering solutions for evolving customer and environmental needs

LRM Director's Message

The idea of creating the Laboratory for Responsible Manufacturing (LRM) dates back to the early 1995. However, it was not until the late 1996, with the advent of the newly built Egan Research Center, that the idea became a reality.

In the last two years, we have made substantial progress. Today, in addition to Dr. Kamarthi and myself, our research group consists of about a dozen research associates working on their Master's, Doctoral and post Doctoral research. In the last two years this group has published about 30 papers in journals, 22 papers in conference proceedings, and two book chapters. In addition, the members of this group have made numerous presentations about their research at International and National conferences as well as LRM seminars.

At LRM, we have been able to create an intellectual environment where our researcher can come together and exchange ideas on a continuous basis. In addition, we hold weekly seminars in which members of our group make presentations about their research. After the presentation, the floor is open for discussions, commenting on the presentation, giving advice to the presenter and generating new ideas and directions for new and existing research.

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.

We are committed to continue the same level of productivity as in the past in research and publications as well as bring visibility to LRM and Northeastern University. In the next two years our priority is to strengthen our partnerships with industries and seek funding from governmental agencies such as NSF and DARPA.

Surendra M. Gupta

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 which 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 consumer's 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 is 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 customization systems and identified different technologies useful for supporting them. We have also been developing functional and

information models of mass customization 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 customization systems assist a company in determining what type of mass customization 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 customization system for the company. We also offer to build intelligent computer tools for operating mass customization 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 is DfE 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 millions of dollars of savings per year in 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 for different product designs. The index offers designers with an important measure to help improve future products.

MONITORING AND DIAGNOSIS 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. Diagnosis usually accompanies the process monitoring activities. Diagnosis 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 diagnosis 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 which 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 which 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 finish 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 a 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 nondeterministic 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 analyze 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 on MRP performance of a variety of probabilistic demand and lead times scenarios. 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 125 technical papers presented at various national & international conferences and published in numerous 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, 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", editor of the *Industrial Engineering 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*. In addition, he is a regular reviewer for more than a dozen major journals in the field of Production/ Manufacturing Systems and Operations Research and has regularly reviewed proposals for *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 in the State of Massachusetts and a member of ASEE, DSI, IIE, INFORMS and POMS.

He has taught a variety of undergraduate and graduate courses in the areas of Production/Manufacturing Systems and Operations Research. He has more than 25 years of teaching experience and has consistently received high student ratings.

He has been elected to memberships and chairmanships of dozens of University, College and Department Committees.

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 results 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

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. 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 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 Engineering & Management Institute, 1985-1990). She is a member of Sigma Xi (National Research Honor Society) and Tau Beta Pi (National Engineering Honor Society).

PRATAP S. S. CHINNAIAH, B. TECH., M. TECH.

Mr. Chinnaiah's research interests are in the areas of agile manufacturing, quality engineering, lean production, mass customization, and supply chain management. He is currently a research assistant in the MIME Department at Northeastern University, Boston. 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

Mr. Gungor's research interests are in the areas of graph theory, scheduling and sequencing, combinatorial optimization, heuristics, and disassembly systems. He has been 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) and Institute for Operations Research and the Management Sciences (INFORMS).

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).

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).

OMCA KORUGAN, BS, MS

Ms. Korugan's research interests are software development for remanufacturing and transportation systems. She is a member of Alpha Pi Mu (National Industrial Engineering Honor Society).

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

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 Labratory for Responsible Manufacturing.

PITIPONG VEERAKAMOLMAL, BS, MS

Mr. Veerakamolmal's research interests are in the areas of disassembly systems, theory of scheduling and sequencing, linear programming, and simulation. He has a Teaching Assistantship from Northeastern University, MIME Department. He is a member of Alpha Pi Mu (National Industrial Engineering Honor Society).

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, fuzzy logic, machine learning & reasoning, and rapid cost estimation.

Publications - Journals

1998

- 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.

- 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.

1997

- Gungor, A. and Gupta, S. M. (1997). "An Evaluation Methodology for disassembly Processes", *Computers and Industrial Engineering (An International Journal)*, Vol. 33, No. 1-2, pp. 329-332.

Abstract– Disassembly is a systematic process that allows reusable, non-recyclable, and hazardous subassemblies to be selectively separated from recyclable ones. In this paper, we present a methodology to evaluate different disassembly strategies so that the best one could be chosen. Since the identification of all possible disassembly sequences of complex products is not an easy task, we also propose a disassembly sequence generation heuristic which gives a near optimum disassembly sequence for a product. The application of the methodology is illustrated by considering an IBM PS/2 Model 30 computer base.

- Gupta, S. M. (1997). "Machine Interference Problem with Warm Spares, Server Vacations and Exhaustive Service", *Performance Evaluation (An International Journal),* Vol. 29, No. 3, pp. 195-211.

Abstract– We consider the machine interference problem with warm spares in which the server takes a vacation of random duration every time the repair facility becomes empty. We address the cases of multiple vacations, single vacation and hybrid multiple/single vacation schemes with exhaustive service. Vacation models that have been studied in the past generally assume infinite population. In this paper, we provide new, transform free, closed form expressions for the probability distribution of the number of machines in the repair facility and the performance measures for machine interference problem with warm spares and server vacations. By adjusting the parameters, closed form expressions for machine interference problem with cold spares, machine interference problem without spares, finite capacity and infinite capacity vacation models can also be derived. An extremely powerful and efficient algorithm is presented to determine the steady state probability distribution of the number of customers in the system as well as the performance measures for all these models. An example is considered and some insight is also provided.

- Gupta, S. M. and Al-Turki, Y.A.Y. (1997). "An Algorithm to Dynamically Adjust the Number of Kanbans in a Stochastic Processing Times and Variable Demand Environment", *Production Planning and Control (An International Journal)*, Vol. 8, No. 2, pp. 133-141.

Abstract– In a real life environment, the Just-In-Time (JIT) system is subjected to various types of uncertainties such as stochastic processing times and variable demand. Since, JIT was only meant to operate in a deterministic environment, its performance is seriously affected by variations in processing times and demand. In this paper, a newly developed Kanban system is presented 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 uncertainties during a production cycle. The new system is termed a Flexible Kanban System (FKS). The steps of the algorithm are detailed and the effectiveness of FKS is demonstrated using an example model. For the example model, the solution procedure, results and a discussion are presented.

- Gupta, S. M. and Isaacs, J. (1997). "Value Analysis of Disposal Strategies for Automobiles", *Computers and Industrial Engineering (An International Journal)*, Vol. 33, No. 1-2, pp. 325-328.

Abstract– Alternative disposal strategies for vehicle design with varying relative proportions of materials, are explored using goal programming to analyze the tradeoffs between technological, economic, and environment factors. Two vehicle designs - one based on a steel unibody and the other more intensively designed with polymer materials - were selected for investigation. The preliminary results indicate that if properly controlled, the current automobile recycling infrastructure in the U.S. can remain economically viable while improving with respect to environmental considerations.

- Isaacs, J. and Gupta, S. M. (1997). "Economic Consequences of Increasing Polymer Content on U.S. Automobile Recycling Infrastructure", *Journal of Industrial Ecology,* Vol. 1, No.4, pp. 19-33.

Abstract– Environmental awareness regarding resource use and emissions over the life cycle of the automobile has heightened the concerns for end-of-life (EOL) vehicle disposal. With increasing use of lighter materials to enhance fuel economy, the steel-dominated content of automobiles is changing to include a greater fraction of polymers. This change may substantially impact vehicle disposal. In light of impending regulations, various alternatives for remanufacturing and reuse of components and material disposal are under investigation. For example, if shredder operations are used to reclaim metallic materials, then the extent of disassembly will significantly impact profitability as well as the environment. Therefore tradeoffs between technological and economic feasibility, and the degree of environmental detriment must be identified for disposal scenarios of interest. Using goal programming, changes to the current US vehicle recycling infrastructure are explored for their effects on dismantler and shredder profitabilities. To investigate the effect of lightweighting on the profitability of the recycling infrastructure, two specific vehicle designs are compared: a steel unibody and a polymer intensive vehicle. Other scenarios examine the outcomes for mandating removal of polymer materials during disassembly, and for increasing the disposal cost of scrap polymer to that of hazardous waste. Goal programming addresses multi-objective problems involving linear multiple criteria and linear constraints, and allows the exploration of the vehicle recycling infrastructure profitability for prescribed target profits under varying conditions. These results indicate that if properly controlled, the current automobile recycling infrastructure in the US can remain economically viable while improving with respect to environmental considerations. Alternatively, implementation of certain policies that reduce profitability could cause disastrous consequences, resulting in the economic collapse of the infrastructure.

- Kamarthi, S. V. and Pittner, S. (1997). "Fourier and wavelet transform for flank wear estimation - a comparison", *Journal of Mechanical Systems and Signal Processing*, Vol. 11, No. 6, pp. 791-809.

Abstract– The aim of this article is to present potential sensor data representation schemes for force and vibration signals in the context of flank wear estimation in turning processes. In particular, we compare the performance of methods based on fast Fourier transforms (FFTs) and fast wavelet transforms (FWTs) using data from turning experiments. This research, for the first time, studies the performance of these modern sensor data representation schemes for flank wear estimation on a common platform and provides a useful insight into their merits and drawbacks. The flank wear estimates are computed continually from the features extracted through each representation

scheme by using a simple recurrent neural network architecture. The results can be used for choosing right data representation schemes for flank wear estimation.

- Kamarthi, S. V., Pittner, S., and Bukkapatnam, T. S. (1997). "Foundations for Analytical Models of Staircase Traversal of Convex Polygonal Surfaces", *International Journal of Production Research*, Vol.35, No.7, pp. 2009-2024.

Abstract– In this paper, we present the analytical foundations for modeling the staircase traversal of convex polygonal surfaces by a tool in the form of a circular disk. Based on these foundations, we next develop a mathematical model and an algorithm for a near optimal tool path in a staircase traversal of convex polygonal surfaces. We compare this algorithm---which is called OPTPATH---with two existing algorithms. This comparison confirms that OPTPATH performs better than the other two test algorithms. The OPTPATH algorithm can be used for staircase traversal with or without overlap between successive sweep passes and with or without rapid traversal in edge passes. This generality of OPTPATH allows its application to several manufacturing problems such as face and pocket milling, robotic deburring, rapid prototyping, and robotic spray painting. The results of the theorems presented in the paper can be helpful in designing new algorithms as well as in improving some of the existing algorithms for optimizing tool path in staircase traversal of convex polygonal surfaces.

- Karaesmen, F. and Gupta, S. M. (1997). "Control of Arrivals in a Finite Buffered Queue with Setup Costs", *Journal of the Operational Research Society,* Vol. 48, No. 11, pp. 1113-1122.

Abstract– We consider finite buffered queues where the arrival process is controlled by shutting down and restarting the arrival stream. In the absence of holding costs for items in the queue, the optimal (s,S) policy can be characterized by relating the arrival control problem to a corresponding service control problem. With the inclusion of holding costs however, this characterization is not valid and efficient numerical computation of the queue length probability distribution is necessary. We perform this computation by using a duality property which relates queue lengths in the controlled arrival system to a controlled service system. Numerical results which analyze the effect of setup and holding costs and the variability of the arrival process on the performance of the system are included.

- Karaesmen, F. and Gupta, S. M. (1997). "Duality Relations for Queues with Arrival and Service Control", *Computers and Operations Research (An International Journal),* Vol. 24, No. 6, pp. 529-538.

Abstract– We consider finite buffered queues with service or arrival control. In the case of service control, service may be stopped and restarted depending on the queue length. In the case of arrival control, the arrival stream can be turned off and on or arrivals may be rejected depending on the queue length. We give duality relations for various systems with arrival and service control that enables us to relate their stationary queue length distributions. We use physical coupling arguments which imply the stochastic coupling necessary to relate the queue lengths. We also discuss special cases for which queue length relationships can be obtained by analyzing the underlying Markov process. Two examples are provided to demonstrate the application of the duality property. The first example is a case where the existing queue length distribution for a given model can be used to obtain the queue length distribution of another model. In the second example, we obtain the previously unknown queue length distributions for two related models at once.

- Moyer, L. and Gupta, S. M. (1997). "An Efficient Assembly Sequencing Heuristic for Printed Circuit Board Configurations", *Journal of Electronics Manufacturing,* Vol. 7, No. 2, pp. 143-160.

Abstract– This paper proposes a sequencing approach to develop an efficient feasible path for the printed circuit board assembly process. Determining the component placement sequence, also referred to as the placement path, is an NP-complete problem that best resembles a Traveling Salesman Problem (TSP) for which a heuristic is developed. The heuristic approach is tested against a previously published subproblem as well as a real-life working board configuration. This heuristic is intended to provide a good, feasible component placement sequence for the assembly of a batch of printed circuit boards with an assembly type configuration consisting of a moveable X-Y positioning table and a tape-and-reel sliding feeder rack. Even with high speed assembly machines placing in excess of 40,000 components per hour (cph), process improvements are possible by increasing the efficiency of the planned placement sequence. This heuristic is developed to identify an improved component placement sequence in a reasonable computational time to allow for future implementation of the methodology in applied situations where time constraints are unavoidable.

- Moyer, L. and Gupta, S. M. (1997). "Environmental Concerns and Recycling/ Disassembly Efforts in the Electronics Industry", *Journal of Electronics Manufacturing*, Vol. 7, No. 1, pp. 1-22.

Abstract– This paper reviews the problems that many electronics manufacturers are facing in a society of rules and regulations that are becoming increasingly environmentally conscious. The effect of electronics assembly, disassembly, and disposal on the environment is reviewed and the potential hazards of continuing the present trends in electronics parts disposal is discussed. The paper contains a comprehensive survey of previous work related to environmentally conscious manufacturing practices, recycling, and the complexities of disassembly in the electronics industry. Interest in this area has intensified in the recent years due to an increased awareness of the problem in a world of high technology, where electronic products dominate. Industrial applications of recycling programs are presented and existing methodologies and evaluation systems are discussed. In order to promote and support this new environmental ethic in electronics assembly and disassembly, the need for improved methods of electronics reuse, minimization of life-cycle scrap, development of planning tools, and an increase in research activity in this area is also highlighted.

- Taleb, K. and Gupta, S. M. (1997). "Disassembly of Multiple Product Structures", *Computers and Industrial Engineering (An International Journal),* Vol. 32, No. 4, pp. 949-961.

Abstract– In this paper, we address the problem of scheduling the disassembly of discrete parts products characterized by well defined product structures. We allow for the existence of multiple product structures as well as the existence of common parts and/or materials which makes the problem very complex. To this end, we present two companion algorithms which can be applied to obtain a disassembling scheme for such problems. Specifically, the algorithms determine the quantity and operations schedule of disassembly for all product structures (including the ordering of the roots and the disassembly schedule for the roots and the subassemblies) in order to fulfill the demand for the various parts. An example is presented to illustrate the use of the algorithms.

- Taleb, K., Gupta, S. M. and Brennan, L. (1997). "Disassembly of Complex Products with Parts and Materials Commonality", *Production Planning and Control (An International Journal)*, Vol. 8, No. 3, pp. 255-269.

Abstract– This paper addresses the issue of parts and materials commonality when scheduling disassembly. In a disassembly environment, inventory management is complex due to the presence of multiple demand sources at the component level of the product structure. Commonality introduces a new layer of complexity by creating alternative procurement sources for the common component items. A novel scheduling algorithm is presented, followed by an example.

- Zeid, I., Gupta, S. M., and Bardasz, T. (1997). "A Case-Based Reasoning Approach to Planning for Disassembly", *Journal of Intelligent Manufacturing,* Vol. 8, No. 2, pp. 97-106.

Abstract– With recycling regulations, resource conservation needs and an increased awareness of the state of the environment by both the consumer and the producer, many companies are establishing disassembly plants and developing product designs which specifically facilitate disassembly. Once disassembled, the items can be reused, recycled or discarded. One can identify two distinct aspects of the disassembly problem, viz., design for disassembly (DFD) and planning for disassembly (PFD). The goal of DFD is to design products that are easy to disassemble. On the other hand, the objective of PFD is to identify efficient sequences to disassemble products. This paper focuses on the PFD aspect of disassembly. Due to the fact that there could be many ways to disassemble a given product, the PFD knowledge is accumulated by experience. Such knowledge is valuable and should be captured, saved and re-used to solve similar problems that arise in the future. In this paper, we propose Case-Based Reasoning (CBR), as an approach, to solve PFD problems. CBR is based on the fundamental principle that problem solving can benefit from solutions to past problems that have been attempted. The technique and issues related to the application of CBR to PFD are presented.

Forthcoming

- Gungor, A. and Gupta, S. M., “Issues in Environmentally Conscious Manufacturing and Product Recovery: A Survey”, *Computers and Industrial Engineering (An International Journal)*.
- Gupta, S. M. and Kavusturucu, A., "Production Systems with Interruptions, Arbitrary Topology and Finite Buffers", *Annals of Operations Research*.
- Gupta, S. M., Al-Turki, Y. A. Y. and Perry, R. F. "Flexible Kanban System", *International Journal of Operations and Production Management*.
- Kamarthi, S. V., Bukkapatnam, S. T. S., and Hsieh, H. S. "An Algorithm for a Near Optimal NC Path Generation in Staircase Traversal of Convex Polygonal Surfaces", *Journal of Manufacturing Science and Engineering*.
- Kamarthi, S. V., Kumara, S. R. T, and Cohen, P. H. "Flank Wear Estimation Through Wavelet Representation of Acoustic Emission Signals", *Journal of Manufacturing Science and Engineering*.
- Kamarthi, S. V., Kumara, S. R. T, and Cohen, P. H. "On-Line Tool Wear Estimation in Turning Through Sensor Data Fusion and Neural Networks", *IIE Transactions*.
- Kavusturucu, A. and Gupta, S. M., "Analysis of Manufacturing Flow Lines with Unreliable Machines", *International Journal of Computers Integrated Manufacturing*.
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- Pittner, S., and Kamarthi, S. V. "Feature Extraction from Wavelet Coefficients for Pattern Recognition Tasks", *IEEE Transactions on Pattern Analysis and Machine Intelligence*.
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- Cullinane, T. P., Chinnaiah, P. S. S., and Kamarthi, S. V. (1998). "Factors That Influence the Design of Mass-Customized Production Systems", *Proceedings of the 7th Industrial Research Conference (IERC8)*, Banff, Alberta, Canada, May 9-10, CD-ROM.
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SUMMER 1998

- “Design of A1 type agile systems” by Pratap Chinnaiah.
- “Disassembly flexible kanban model experimentation & comparison to traditional kanban model” by Elif Kizilkaya.

SPRING 1998

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- “Compatibility oriented product modeling,” by Naken Wongvasu.
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- “Generation of disassembly sequence plans (DSPs) in the presence of uncertainty” by Askiner Gungor.
- “Recycle disassembly planning” by Mehmet Dincer.
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- “Multi-echelon inventory systems with return flows” by Aybek Korugan.
- “Neural networks in disassembly” by Pitipong Veerakamolmal.
- “Optimal disassembly sequence planning: progress report" by Askiner Gungor and Kendra E. Moore.
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- “A multiobjective model for disassembly process with multiple products and parts/materials commonality” by Hasan.K. Aksoy.
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- “Disassembly and recycling management” by Mehmet Dincer.
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WINTER 1997

- “Disassembly process planning II” by Pitipong Veerakamolmal.
- “Inventory of a recycle oriented production system” by Aybek Korugan.
- “Petri Net models of pull production systems: single- and multi-product systems” by Kendra E. Moore.

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