PRODUCTION AND OPERATIONS MANAGEMENT

POMS

Vol. 14, No. 4, Winter 2005, pp. 450–467
ISSN 1059-1478 | 05 | 1404 | 450$1.25

Manufacturing Operations Manuscripts Published in the First 52 Issues of *POM*: Review, Trends, and Opportunities

Panos Kouvelis • Chester Chambers • Dennis Z. Yu
Olin School of Business, Washington University, St. Louis, Missouri 63130, USA
Cox School of Business Southern Methodist University, Dallas, Texas 75275, USA
Olin School of Business, Washington University, St. Louis, Missouri 63130, USA
kouvelis@wustl.edu • cchamber@mail.cox.smu.edu • yuz@wustl.edu

We review the manuscripts accepted for publication by the Manufacturing Operations Department of *Production and Operations Management (POM)* over 13 years (1992–2004). The manuscripts managed by this department deal with topics including scheduling, manufacturing systems management, inventory control and capacity management, maintenance management, and teaching and applications. In the process of this review, we highlight the significant contribution of *POM* to the field of operations management and illustrate how this body of work has served to further the mission of the journal and department. We then offer comments regarding characterizations of these manuscripts and a few ideas on how to expand this body of work in the future to further the mission of the journal.

Key words: OM Research; Journals in OM; literature review; trends and directions in OM research
Submissions and Acceptance: Accepted by Kalyan Singhal.

1. Introduction

The initial 13 years of *Production and Operations Management* (*POM*) saw the publication of 335 papers between 1992 and 2004. Roughly 30% (108) of these manuscripts are in the area of Manufacturing Operations Management. In this sense, Manufacturing Operations Management is the largest department of *POM*. Submissions managed by this department include manuscripts addressing a wide variety of topics including (but not limited to) scheduling, planning and control systems, manufacturing system management, inventory and capacity management, maintenance and reliability issues, operations management practice and applications, and teaching operations management. This paper will provide a brief review of these works. In the process, we hope to illustrate how these works have served to further the mission of the journal, and use this background as the foundation of a discussion concerning promising areas for future efforts. The organization of this work is entirely straight-forward. In Sections 2 to 7, we review prior works in scheduling; manufacturing system management; inventory, lead-time and capacity management; maintenance and reliability management; operations management practice and applications; and teaching operations management. In Section 8, we highlight several works to illustrate trends, and we preface our discussion of research directions in Section 9.

2. Scheduling

Scheduling is one of the largest research areas in traditional manufacturing operations management. Papers focused on scheduling are particularly prevalent in the earlier volumes of *POM*. The dominant theme was that scheduling was a resource allocation problem, especially when this resource constrains the capacity of the production system. The objective of scheduling problems is typically to determine the sequence of jobs to be processed by one or more 'machines' or production resources, to optimize system performance. Traditionally, the scheduling problems are classified as single machine, parallel machines, job shop, and flow shop problems. We review papers on each of these topics in turn. In Table 1, we give an overview of all manuscripts published on scheduling.

2.1. Single Machine

The objective of single machine scheduling is to find the best schedule, either for individual jobs or batches, to be processed by a single resource. In this context, 'best' typically means a schedule that minimizes some performance metric(s), such as total earliness and/or tardiness, number of jobs late, or total completion time. When the objective is to minimize earliness and tardiness (costs), the problem is sometimes called an "early/tardy problem." The first treatment of this problem in *POM* was a short note by Coleman (1992). This paper presents a simple Mixed Integer Programming (MIP) formulation for the early/tardy problem. This work was significant in that it was among the first to include sequence-dependent setup times.

Woodruff and Spearman (1992) contribute to the field through the consideration of two classes of jobs simultaneously. Some jobs reflect firm commitments and the manufacturer faces deadlines as well as holding costs if a job is finished early. The chief contribution of this work stems from the fact that it also considers 'filler' jobs that can be added to the schedule as well as switch-over costs, which vary depending on whether a following job is in the same family as the earlier job. The authors develop a tabu search procedure that serves to maximize net revenue and endogenizes decisions about which 'filler' jobs to accept.

Alidaee (1994) considers a single machine problem with job-specific costs for both earliness and tardiness. The author shows that when these penalties are proportional to the processing times, the problem is mathematically equivalent to the total weighted tardiness problem studied frequently in earlier works. Once this is proven, it becomes clear that algorithms for the weighted tardiness problem can be profitably adapted to this apparently more complex problem. Chand, Chhajed, and Traub (1994) use dynamic programming to solve a problem in which the scheduler is given a fixed order of delivery for n jobs and no tardiness is allowed, but the scheduler may choose the delivery dates. Performance measurement involves earliness penalties in the form of holding costs, and lead time penalties arising from discounts given to customers that are proportional to the lead times. Dessouky, Kijowski, and Verma (1999) present an application of batch processing in the chemical industry. A mixed integer nonlinear programming model is introduced to help make batching and scheduling decisions with the objective of minimizing total earliness and tardiness penalties.

Uzsoy and Yang (1997) consider a machine which is capable of processing a number of jobs simultaneously as a batch. The processing time of each batch is given by the longest job in the batch. The objective is to minimize the total weighted completion time. They discuss the complexity of the resulting problem and develop a branch and bound algorithm which generates an optimal schedule.

Cheng, Yan, and Yang (1998) consider the production of a set of products with constant demand. They find the cost minimizing schedule including both setup and backlog costs. The contribution of the work lies in its inclusion of production rates as a decision variable. This results in an optimal cyclic schedule in which the plant spends much of its time at a reduced production rate for a critical product.

One important generalization of the early/tardy problem arises when a set of jobs are to be delivered in a common due window. Krämer and Lee (1993) address this problem and assume that the earliness and tardiness cost factors are constants (α, and β per unit time, respectively) and the size of the window is given. They show that the problem is polynomial when the location of the due window is a decision variable and develop a dynamic programming algorithm to generate an optimal schedule when the location of the window is given and fixed. A note by Weng and Ventura (1996) builds on this work and shows that even if the location of the due window is given, the problem is still polynomial provided the location is 'unrestricted'. The term 'unrestricted' is related to the makespan of the jobs involved. They also develop a more efficient dynamic programming algorithm to solve the problem when the window location is restrictive.

2.2. Parallel Machines

The problem of parallel machines focuses on the allocation of jobs to be processed by some specific machines while minimizing makespan, total processing time, or operational cost. Campbell (1992) considers a multi-product lot-sizing problem with parallel machines and dynamic demands for each product. He uses a Lagrangian relaxation-based approach to create a schedule that minimizes total costs. This approach allows setups to be done during idle times. It also allows machines to remain setup for a product across multiple periods even if the machine is idle for one or more of these periods. Alidaee and Kochenberger (1996) develop a modeling framework to study controllable processing time problems for both single machine and parallel machine settings. They show that both problems can be re-stated as transportation problems and solved efficiently. Liu (1992) considers a flexible manufacturing system with N identical, parallel machines and a single type of job with dynamic feeding, uncertain processing times, and rework. The author provides an algorithm which creates close to

Table 1 An Overview of Papers on Scheduling

Papers	Classes: *Single machine*	*Parallel machines*	*Job shop*	*Flow shop*	Performance measure	Topic/issues	Complexity/algorithms	Simulation/ experiment
Aggarwal et al. (1992)		•			Total costs	Lumber drying operations	LP relaxation	
Alidaee (1994)	•				Weighted early/tardy	Early/tardy cost functions	NP-hard, heuristic	
Alidaee & Kochenberger (1996)	•	•			Compression costs	Controllable processing time	Transportation problem	
Barman & LaForge (1998)			•	•	Tardiness, flow time	Different priority rules		√
Bowman (2002)			•		WIP holding cost	Cyclic schedule in JIT system	Cyclic critical path	√
Bowman & Muckstadt (1995)			•		Overtime/holding cost	Demand and process variability	Greedy	√
Campbell (1992)		•			Total costs	Lot size, short-term dedication	Lagrangian	√
Chand et al. (1994)	•				Earliness, due date	Fixed-interval delivery	DP algorithm	
Cheng et al. (2000)				•	Makespan	Flow shop with no-wait	Polynomial time or NP-complete	
Coleman (1992)	•		•		Weighted early/tardy	Sequence-dependent setup		LP solver
Dessouky & Leachman (1994)				•	Inventory/backorders	Release policy		√
Dessouky et al. (1999)	•				Weighted early/tardy	Fixed and identical batch size	Heuristic	√
Herrmann et al. (1995)			•		Makespan	Semiconductor test area	Generic algorithm	√
Jin et al. (2002)				•	Makespan	Hybrid flow shop of PCB lines	Generic algorithm	√
Kanet & Zhou (1993)	•		•		Tardiness	DT approach to priority rules		√
Kim & Bobrowski (1995)			•		Costs, WIP, flow time	Sequence-dependent setup		√
Krämer & Lee (1993)	•				Weighted early/tardy	Common due-window	$O(n \log(n))$	
Litchfield & Narasimhan (2000)			•		Flow time, lateness	Modified SPT rule		√
Liu (1992)		•			Total costs	Stochastic parallel processing	DP algorithm	
Melnyk et al. (1994)			•		Capacity utilization	Job release time distribution		√
Morton et al. (1995)			•		Resource & delay cost	Bottleneck dynamics		
Rohleder & Scudder (1993)	•		•		Weighted early/tardy	Order release & dispatch rule		√
Uzsoy & Yang (1997)	•				Completion time	Batch processing	Branch & bound	√
Weng & Ventura (1996)	•				Weighted early/tardy	Common due-window	DP algorithm	
Williams et al. (1997)				•	Makespan	Optimal sub-lot sizing	$O(m^2)$, heuristic	√
Woodruff & Spearman (1992)	•				Profit maximization	Jobs with deadlines and setups	Tabu search	√

optimal schedules to minimize the sum of the costs associated with waiting time, idle time, material handling, and rework. Aggarwal, Vemuganti, and Fetner (1992) present applications of parallel machine scheduling in the U.S. timber industry when two parallel drying processes are considered. They develop an MIP model to serve as a decision support system for scheduling lumber drying operations.

2.3. Job Shops

Job shop scheduling considers the problem of a set of jobs and a finite number of machines. Each job involves a sequence of operations to be processed on some subset of all machines with each operation involving a single machine. The objective is to find a schedule specifying when each operation is to be performed and by which machine while minimizing some system performance measures such as mean flow time, earliness and tardiness cost, or operational cost. Job-release mechanisms (which determine when jobs are sent to the shop floor), and priority dispatching rules (which select among jobs at a machine queue), are the major concerns in job shop control.

Several papers in *POM* focus on job release rules. Melnyk, Denzler, Magnan, and Fredendall (1994) use an experimental model and simulation to show that shop performance is significantly influenced by the release time distribution when setup times are sequence-independent. By holding the work content of each set of jobs, and shop utilization constant, they develop results that focus on the parameters of a variety of release time distributions. Their results imply that release policies have greater impact on job shop performance than do dispatching rules in these environments. Kim and Bobrowski (1995) extend earlier works by considering dispatching approaches and sequence-dependent setup times. They show that in these settings the dispatching rules become critically important.

Some job shops produce a mix of items that is stable over a short term. In these settings, a cyclic schedule may be optimal. Bowman (2002) considers such a setting. This environment realizes a cyclic critical path rather than a single machine as the bottleneck. This work develops a simulation-based tool to control job release in order to achieve a desired throughput while minimizing the level of work-in-process inventory. Bowman and Muckstadt (1995) develop a stochastic cyclic scheduling policy where demand is variable. A production control algorithm is developed using task criticality estimates to time material release.

Kanet and Zhou (1993) focus on the dispatch rules and suggest a novel approach. They devise a method to estimate the impact of placing job i at the front of the queue. The rule is to select the job with the smallest impact on total cost. The approach seems to perform well, but the computational requirements may be high. Herrmann, Lee, and Hinchman (1995) take a similar approach in that they develop a genetic algorithm that uses global information to devise real-time dispatching rules for a test area in semiconductor manufacturing that behaves as a job shop.

In some settings the relationships between release rules and dispatch rules is more complex. Rohleder and Scudder (1993) develop a novel rule for both work release and dispatching. They use simulation to test the performance of the proposed approach in comparison with combinations of common release and dispatch rules. The rule introduced here generally outperforms several common combinations. Litchfield and Narasimhan (2000) consider a job shop problem in which transfer batch sizes may differ from process batch sizes. For these settings they develop a modified SPT rule that minimizes mean flow time, flow time variance, and mean lateness.

2.4. Flow Shops

Flow shop scheduling problems deal with the planning and control of jobs that visit a sequence of machines in the same order. It is sometimes assumed that the processing times are identical at each machine. The objective function is typically to minimize the overall completion time for all of the jobs—makespan and/or the WIP inventory levels. Cheng, Gupta, and Wang (2000) provide a state of the art review of manuscripts on flow shop scheduling with setup times. They point out biases of the current research efforts and suggest several avenues for useful and worthy future works.

Williams, Tüfekçi, and Akansel (1997) study a flow shop in which a job or lot can be split into n sub-lots, processing times differ at each machine, and the objective is to minimize makespan. They review the optimal policy when $n = 2$, develop an algorithm to optimally solve the problem when $n = 3$, and develop a heuristic for cases where $n > 3$. The complexity of the two or three stage flow shop problem with no-wait processing is investigated by Cheng, Sriskandarajah, and Wang (2000). In their model, each job must be processed continuously from its start on the first machine to completion on the last machine, and the objective is to minimize makespan. They identify several specific problem types solvable by known algorithms and prove the complexity of several additional problems as well.

Dessouky and Leachman (1994) study the job release schedule in both classic job shops and flow shops by experimental analysis with the objective of reducing work-in-process inventory. An application of flow shop scheduling in printed circuit board assembly lines is presented by Jin, Ohno, Ito, and Elmaghraby (2002). They propose a global procedure using a genetic algorithm to minimize makespan. Most job shop or flow shop scheduling research investigating the performance of priority rules has been based on using the same rule on all machines. Morton, Narayan, and Ramnath (1995) translate the job priorities into resource prices by sequencing priorities according to a cost/benefit ratio. They consider dual resource prices which stem from delay cost and describe how these prices can be approximated and how lead times can be computed. Barman and LaForge (1998) construct a hybrid shop containing characteristics of both flow shops and job shops which is comprised of three stages: gateway, intermediate, and finishing. They allow a combination of priority rules (FCFS, SPT, EDD, COVERT) at different stages of the system, and explore resulting system performance.

3. Manufacturing System Management

Several works in this area are closely related to the research on scheduling discussed earlier, but with a somewhat different focus. For example, the planning model of Fuxman (1998) seeks to deduce the minimum amount of total buffer space and its allocation to individual work stations to maximize throughput on a flow-line using a cyclic production schedule. The emphasis is not on scheduling each machine per se, but on allocating buffer space to benefit the system as a whole. Similarly, throughout this section, we are focused on topics which focus on multiple resources or the system as a whole. Specifically, this section gathers manuscripts focused on control systems, Flexible Manufacturing Systems (FMS), Just-in-Time production (JIT), cellular production systems, Materials Requirements Planning (MRP), and factors that complicate production planning.

3.1. Comparison of Control Systems

Buzacott and Shanthikumar (1992) introduce a general framework for future researchers to consider a wide range of approaches to coordinate and control material and information flows in manufacturing systems. They create a general model which can mimic a wide variety of planning and control approaches on the plant floor. The model is formulated in such a way as to find an 'optimal' approach given the model's parameter values. This suggests an infinite array of 'hybrid' strategies. The authors propose a solution procedure to the general problem, but leave the determination of parameter values as an open question.

Yang (2000) uses simulation to rigorously compare three different manufacturing control systems for managing a multi-product flow line: Single-Kanban, Dual Kanban or CONWIP (constant work-in-process). The author shows that CONWIP consistently produces the shortest mean customer waiting time and lowest work-in-process inventory levels but may result in a higher number of trips between stations.

3.2. Flexible Manufacturing System (FMS), Just-in-Time (JIT), Cellular Manufacturing

Recent developments in manufacturing technology and automation led to the introduction of a variety of FMS's. An FMS consists of a set of versatile, numerically controlled machines, integrated by automated material handling devices. A central computer coordinates and controls the activities of the system. The research problems most often studied in this area are related to earlier works on machine and job-shop scheduling. However, the automation of the tool loading aspects of FMS introduce a new layer of complexity to the problem.

Liang and Dutta (1993) present an MIP model dealing with tool loading along with the related problems of part-selection and machine-loading. They use a sequential bi-criteria approach to consider a primary objective such as the maximization of throughput as well as a secondary objective such as minimizing costs. They go on to develop a Lagrangian-Relaxation based solution approach that is suitable to this class of problems. Webster and Jacobs (1993) also deal with issues of tool configuration but allow for dynamic movement of tools within the context of a set of jobs that can be grouped into one or more product families. Denizel-Sivri and Erenguc (1993) present an MIP model of both single machine and multiple machine settings. The single machine problem considers part type selection and lot sizing with dynamic demand. This model is extended to also consider the machine loading problem in multiple machine settings. Chakravarty (1997) investigates the real time scheduling in an FMS. He suggests a DEA based approach in which real time data is used to select dispatching rules from a set of possibilities. The result is that the system would choose different rules for different situations based on an evolving set of data points.

The concept of JIT has been under development for many years, but no universal agreement regarding its definition is available. Sakakibara, Flynn, and Schroeder (1993) use surveys and plant visits to develop a framework and measurement instrument describing JIT implementation. Their framework includes 14 dimensions for JIT practice including (1) setup time reduction, (2) small lot sizes, (3) JIT delivery from suppliers, (6) small group problem solving, (11) equipment layout, and (13) a Kanban system. (Numbers are quoted directly from the original text.) Berkley (1992) presents a literature review on Kanban research with an emphasis on research published after 1983.

The design and management of manufacturing cells has received ample attention in the pages of *POM*. Implementation of cellular manufacturing introduces two fundamental problems; how to group products into 'families' that make it attractive to dedicate a manufacturing cell to that group and how to group resources to create the associated cell. Mosier and Martin (1995) present a model which seeks to simultaneously address these questions by developing clustering algorithms to define both product groups and each cell's resources. Johnson and Wemmerlöv (1996) surveys prior research seeking answers to the questions of if, when, and why cellular layouts outperform functional layouts. They point out that the research findings in the studies they reviewed are inadequate in helping practitioners make specific layout choices. Johnson and Wemmerlöv (2004) uses survey results to identify the factors that cause firms to stop implementing cellular systems and the reason why firms have various degrees of cellularization. Their major finding is that once firms begin the move toward cellular manufacturing they will continue as long as they can identify product groups that make the benefits of creating one more cell outweigh its costs.

3.3. MRP and Master Production Schedules (MPS)

In MRP systems, a master production schedule (MPS) is utilized to translate independent demand for end items to dependent demand for components and raw materials. In its simplest form, an MRP system uses the MPS and lists of processing and/or lead times to work backwards to assign tasks to both internal resources and external suppliers. This set of assignments then must be modified to reflect capacity or delivery constraints.

Armentano, Berretta, and Franca (2001) uses the concept of echelon inventory to develop a lot sizing heuristic to convert the MPS into a feasible schedule which seeks to minimize the sum of inventory, production, and setup costs. Adenso-Díaz and Laguna (1996) consider a setting in which the delivery schedule is fixed and overtime is used to overcome capacity constraints. They present a technique to search for feasible production plans while minimizing overtime by adjusting the lot sizing rules that the system employs. Metters and Vargas (1999) consider a stochastic MPS model with a rolling planning horizon. By applying results from research on periodic review stochastic inventory systems, they develop a dual-buffer MPS policy and demonstrate that the proposed approach is superior to existing MPS policies.

Venkataraman (1996) presents a case study of a paint company which considers how often the firm should develop a new MPS in a rolling horizon based planning system. They determine that the schedule should be 'replanned' every two months for this particular setting and give guidelines regarding how this decision should be made in other instances. Zhao, Xie, and Jiang (2001) use simulation to investigate the impact of policies related to freezing the MPS and the selection of lot-sizing rules on system performance. Their contribution stems from the fact that they consider multiple products and capacity constraints.

3.4. Manufacturing Network Management

A large portion of products is produced in batches in discrete manufacturing systems. Such systems can often be represented by queueing network models where the nodes correspond to manufacturing stations and arcs connecting the nodes indicate the flows between stations. Bitran and Morabito (1999) consider the use of 'tradeoff curves' which show the relationship between capacity and WIP in job shops modeled as open queueing networks. The authors review the use of such curves as well as algorithms to derive them. Rao and Suri (2000) present an algorithm to estimate the throughput and mean queue lengths of an assembly line with input from multiple fabrication lines. The inherent difficulty of the problem lies in the fact that the assembly line cannot begin the next unit unless output is available from each fabrication line, and processing times are stochastic and independent.

Kulkarni, Magazine, and Raturi (2004) address questions of network configuration by comparing two alternate approaches. A process configuration involves separate facilities for each common component. This can buy economies of scale, but it also pools the stores of component inventory to be allocated to products as needed. A product configuration makes all of the components for a product under one roof. This buys focus and eliminates cross-plant shipments but fixes the production volume of each product earlier. They detail these tradeoffs and provide guidance on estimating the costs involved.

3.5. Additional Topics in Manufacturing System Control

Here, we gather works which deal with the complications that arise in remanufacturing as well as the impacts of learning, forgetting, and resource failures. Ferrer and Whybark (2001) present a model of a material planning system for the management of a remanufacturing facility. These settings present unusual difficulties due to the uncertainty of orders for remanufactured goods, the supply of used components, and the yields of the disassembly process. Ketzenberg, Souza, and Guide (2003) compare configurations in a remanufacturing operation. They detail when it is optimal to have assembly and disassembly operations running in parallel as opposed to mixed line configurations with these activities done at stations capable of both tasks. Surprisingly, the parallel configuration outperforms the mixed line in some settings when the variability of both arrivals and processing times are high.

Production scheduling is often complicated by the presence of experience-based learning. Chao and Graves (1998) present an application study based on an internship in Boeing. They discuss how learning effects may be targeted as a way to reduce flow times as opposed to head count or direct costs. Chakravarty and Shtub (1992) propose a heuristic that seeks to minimize the total cost of a mixed-model assembly line which produces several models of the same product. The contribution of this work stems from the fact that it includes learning at different rates on each task and occasional re-balancing of the assembly line.

A near-optimal, forward dynamic programming algorithm is developed by Chiu, Chen, and Weng (2003) to study the lot-sizing problem with learning and forgetting in both setups and production. Smunt and Meredith (2000) compare the total costs of flexible automation and labor-intensive manufacturing processes with consideration of learning and forgetting. In a batch production system with a single machine and a single product, the authors show that intuition is a weak guide in estimating the cost savings from flexible automation, particularly when lot sizes are selected to be optimal for each approach.

Yet another complication arises from the failure of elements in the production system. Elhafsi and Bai (1997) study a dynamic production scheduling problem in which there is a single machine which produces two types of products with random failure points and repair times. They apply optimal stochastic control to solve the scheduling problem when the objective is to match output to demand while keeping the work-in-process low. They also develop a heuristic which approximates the optimal policy well under normal conditions. Krämer, Elhafsi, and Bai (1997) extend the model to an FMS consisting of two unreliable machines with a finite buffer.

4. Inventory, Lead-Time, and Capacity Management

Decisions about inventory and capacity levels are classic topics in Operations Management. Each of these topics has received ample attention in *POM*. Papers in inventory management include those that analyze order quantities in the presence of learning in both production and setup activities. Decisions about capacity management include analysis of expansion decisions and the management of a key capacity constraint. The strategic emphasis on lead times as a competitive weapon is more recent but has received some attention in the pages of *POM* as well.

4.1. Minimizing Inventory Related Costs

Li and Cheng (1994) develop a dynamic programming approach to lot sizing for a single-product. They modify the assumptions of the classic EOQ framework by including learning effects for both production and setup costs. They also include a forgetting effect on setup times. Kim, Hayya, and Hong (1995) use an economic production quantity (EPQ) model to investigate the effects of investments to reduce setup time for a single machine producing multiple products. They show that setup reduction not only reduces the total inventory cost, but also increases the available machine capacity for a variety of investment cost functions. Li, Erlebacher, and Kropp (1997) study an EOQ/reorder point model with opportunities to invest to reduce setup cost, lead time, or variance of demand forecast errors. They develop a simple search procedure to obtain the optimal values of batch sizes and investment levels in these three alternatives.

It is usually assumed that the demand quantity is normally distributed in the study of optimal inventory control policies. Alfaro and Corbett (2003) use Monte Carlo simulation to examine the value of pooling under non-normally distributed demands and suboptimal inventory policies. They show that there exits a range of inventory levels within which pooling is more beneficial and beyond which optimizing the inventory policy is better. Lee and Kim (1998) consider an inventory control problem integrating order quantity and pricing decisions. A downward sloping demand function is assumed for the products of a monopolist where the retailer aims to find both the profit-maximizing selling price and order quantity for a single product.

Bylka and Sethi (1992) consider a discrete time, undiscounted, dynamic lot sizing model. The setting modeled is one in which the decision maker needs to state the production schedule for the next n periods; his decision horizon. This paper proves the existence of, and defines the number of periods that must be forecasted; the forecast horizon, to deduce the schedule for the decision horizon under very common conditions. Heady and Zhu (1994) use a similar planning horizon theorem along with the Economic-part-period concept to create a more efficient implementation of the Wagner-Whitin algorithm. The execution time of the resulting approach is roughly linear in the length of the planning horizon.

Bradley and Conway (2003) consider a two-stage production network with the first stage as a single-machine multiple-product system and the second stage as a multi-machine multi-product (one to one) system. They determine schedules for the first stage that minimize the inventory between the two production stages while providing for the continuous operation of the second stage. Their results demonstrate the principles of cyclic inventory and show that cyclic inventory is directly proportional to cycle length, which is in turn directly proportional to total changeover time, and inversely proportional to machine utilization.

Leschke and Weiss (1997) investigate the impact on performance resulting from an allocation of investments in setup cost reduction in a multi-item, capacity constrained manufacturing system with competing setup reduction opportunities. They compare the results using six different allocation rules and show that the amount and nature of the benefits achieved by setup reduction can be significantly different depending on the way that setup reduction investments are prioritized.

4.2. Capacity Expansion

In the face of demand growth and/or uncertainty, capacity expansion is a major strategic decision. There are quite a few papers published in *POM* which address this topic. Sethi, Taksar, and Zhang (1992) present a paradigm of hierarchical decision making in production planning and capacity expansion problems under uncertainty. They consider decisions about the purchase time of a new machine at a given fixed cost and production plans before and after the purchase. The objective is to minimize the discounted costs of investment, production, inventories, and backlogs. Chaouch and Buzacott (1994) consider capacity expansion with a known time to build and an uncertain pattern in the growth of demand. Their results show that it is economically attractive to delay plant construction beyond the time when existing excess capacity becomes exhausted if the construction lead time is relatively short. Wang (1995) considers a capacity expansion sequencing problem in which a finite number of discrete projects to increase capacity by known amounts will be timed to minimize discounted costs when demand grows exponentially. Learning effects can also influence the capacity expansion decision. Gaimon and Burgess (2003) introduce a model to study capacity expansion decisions when learning may reduce lead time or the cost required to complete an expansion. As a consequence of the learning effect on the cost of capacity expansion, the incentive for larger-sized expansions to obtain economies of scale is reduced. Therefore, it becomes optimal to invest in a series of relatively small expansion projects.

Two additional works must also be noted here. Bordoloi, Cooper, and Matsuo (1999) present a capacity expansion model to illustrate and clarify notions of flexibility, adaptability, and efficiency in a manufacturing system. Their work is an effort to provide a unifying concept which helps to differentiate and highlight these notions. Matta and Miller (1996) consider a related problem in which capacity exceeds demand and the producer seeks an optimal strategy to manage the options of temporarily shutting lines down or simply making lines idle for short periods of time. The objective is to minimize costs while serving all remaining customers.

4.3. Bottleneck Management

In a production network, a common phenomenon seen after a capacity expansion is shifting production bottlenecks. The original bottleneck disappears after capacity expansion but a new bottleneck appears elsewhere. Lawrence and Buss (1994) run simulation experiments in a Jackson queueing network model to examine production 'bottleneck shiftiness' in the system. At any given moment, the bottleneck is defined as the station with maximal queue length. They calculate the percentage of time that each work center will be a bottleneck and develop a measure of 'bottleneck shiftiness' which reflects the likelihood that the bottleneck appears to move from place to place. Their results show that shiftiness is higher in a balanced shop and declines when the capacity of non-bottleneck resources is increased.

Within the larger area of research centered on management of constraining resources, *POM* has offered a number of insights regarding ideas on capacity management promoted by Eliyahu Goldratt in his book *"The Goal"* and the corresponding commercial software. Fry, Cox, and Blackstone (1992) describe the structure and modules of the software and elaborate on how it interfaces with management. This work also describes various algorithms imbedded within the software package. Simons and Simpson (1997) provide additional discussion on some of the algorithms implemented in related software. This work also discusses a comparison between the performance of these algorithms with that of alternative approaches (such as CONWIP). Short commentaries by Conway (1997) and Pinedo (1997) note the considerable difficulties that arise in comparing scheduling approaches when all of the details of the logic are not made explicit because seemingly subtle differences can lead to notably different performance. These works call for a more complete exposition of the elements and logic behind the system and point out several reasons to be careful not to overstate the power of the approach without more rigorous performance comparisons. Spearman (1997) points out several additional issues regarding both the contribution and limitations of Goldratt's approach. One step in the direction of more rigorous comparisons is found in the work of Atwater and Chakravorty (2002) who present a simulation experiment to study the performance of a drum-buffer-rope (DBR) scheduling system. They investigate the capacity utilization of two heavily utilized resources in a system and demonstrate that 100% utilization of the primary constraint is not optimal. They also show that DBR responds well to relatively low levels of increased capacity at the less utilized resource.

4.4. Production Lead Times

Lead time reduction is quickly becoming a dominant competitive factor in many business environments. In most research, lead time is treated as a constant or a random variable with known distribution. For manufacturers, the cost of reducing lead time is often easy to determine but the benefits are much less clear. Consequently, modeling this tradeoff has great managerial value. Hill and Khosla (1992) develop a conceptual framework within which the costs and benefits of lead time reduction can be compared. They also present mathematical models to decide optimal lead time reduction levels within this framework. They model a make-to-order system in which lead time reduction leads to increased demand and a make-to-stock system in which lead time reduction results in reduced safety stock. Tang and Tang (2002) study the use of dynamic lead time pricing for a make-to-order manufacturer when the customer's utility for the product is decreasing over time. This work considers two discounting approaches: a common price to all vs. a customer-specific discount when customer sensitivities to lead times are normally distributed. They derive the optimal lead time and pricing policies under each approach.

5. Maintenance and Reliability Management

Many firms need to develop a schedule for preventive maintenance which balances maintenance costs with repair costs and the opportunity costs from disruption. Mckone and Weiss (1998) present a literature review which describes the basic elements of total productive maintenance (TPM) programs and identifies the gaps between practice and research. Several *POM* papers address these gaps. Traditional procedures to determine the optimal schedule of preventive maintenance are based on the assumption that the time-to-failure (TTF) is random and follows some specific distribution. A distribution-free procedure is developed by Shore (1996). The proposed model provides solutions to the classic optimal replacement problem and only requires partial distribution information such as the first two moments of the distribution or certain maximum likelihood estimates. In a related work, Shore (1998) uses Monte Carlo simulation to evaluate heuristics for the optimal replacement problem that yield highly accurate solutions for cases when the moments are known as well as for cases where they have to be estimated from sample data.

Several works in *POM* focus on the optimal replacement problem in richer contexts. For example, it is often necessary to consider maintenance activities as part of an integrated quality improvement effort. Sahin and Polatoglu (1996) considers this setting via a model which links manufacturing quality, machine reliability, and preventive maintenance policies to total cost. Based on an application in semiconductor manufacturing, Sloan and Shanthikumar (2000) develop a Markov decision process model that combines production and maintenance scheduling problems in a single decision process for a multiple-product, single-machine production system.

6. Operations Management Practice and Applications

This department has presented several studies on operations management practice and applications in various industries. For example, in semiconductor manufacturing the major operations management task is to schedule the production capacity of fabrication facilities. Deuermeyer, Curry, and Feldman (1993) presents a modeling framework to analyze semiconductor fabrication facilities. They develop an approach in which users can efficiently describe the production environment. This is combined with both analytic approximations and simulations to create a hybrid technique that may be useful in facility planning.

Inman and Leon (1993) consider output data at stages in an auto assembly plant to test the common assumption that output rates are independent for nonoverlapping intervals. They find that when the interval is one shift this assumption holds up quite well, but must be more carefully considered when using time buckets of one hour.

We are all familiar with high bay warehouses where pallets are stacked in aisles and equipment moves through the aisles to place and retrieve merchandise. The space between two or more aisles can be eliminated to create deep lane storage systems. This arrangement has the advantage of better space utilization but the problem that it may be necessary to move one (or more) pallet(s) to reach the desired items. Thus it is a challenge for deep lane storage systems to provide high throughput rates at high rack utilization levels. Stadtler (1996) introduces a collection of algorithms for more efficient use of deep lane storage systems.

Munson and Rosenblatt (1998) present a study on both practice and research on quantity discounts. They start with a survey of the literature on quantity discounts regarding when they should be offered and how they should be managed. They also conduct interviews with 39 companies to determine how discounts are used in practice. They suggest that researchers need to develop techniques and models that will be both realistic and user friendly since their findings show that companies in general do not adopt the techniques and models suggested by academicians.

In a survey study of several hundred automotive suppliers in North America, Lieberman, Helper, and Demeester (1999) evaluate the determinants of inventory levels for high-volume parts manufacturers. Their data show that inventory levels are influenced by setup and holding costs, production lead times, the extent of customer communication, and the involvement of employees in problem solving. Surprisingly, they find that low inventories are not characteristic of the Japanese parts makers in North America. Within the same industry, Ittner and MacDuffie (1995) consider the relationships between structural and executional cost drivers by comparing metrics across 62 auto-assembly plants worldwide. They find that scale, is correlated with reduced overhead per unit, but that the links between automation and product mix complexity with costs are more complex. They also find that executional factors including the reduction of buffers, multi-skilled workers and the use of teams are correlated with reduced costs. The authors also argue that these factors may be more difficult for competitors to replicate, creating a more sustainable advantage.

Blocher, Garrett, and Schmenner (1999) study the relationship between throughput time, WIP and customer service in a pharmaceutical manufacturing company (Eli Lilly). They present a paradox that some WIP can reduce the effect of variation in a process, but too much WIP can actually increase the variation because of the rescheduling and expediting behavior that often follows.

Jack and Raturi (2003) examine the effect of volume flexibility in the capital goods industry. They posit four metrics of volume flexibility which reflect variability in sales as well as inventory, cost and profitability levels. They suggest that prior results are in need of much refinement and that our understanding must not lose sight of the fact that there is a clear distinction between the capability of a firm to respond to variation in sales and its ability to do so profitably. Moreover, managers are more concerned with the ability to offer a profitable response then with the ability to meet demand at all cost.

Due to the complexity of real-world environments, simulation is a common tool to study and experiment with a variety of policies. Several efforts in *POM* combine simulation with the analysis of current practice in a number of settings. For example, Petersen (2000) develops a simulation model to investigate order picking policies for mail order companies using labor requirements, processing times, and customer service as performance measures. In a similar vein, Yan, Lou, and Sethi (2000) use simulation to compare the robustness of several different production control policies in semiconductor manufacturing. Their results suggest that control policies which consider both upstream and downstream conditions are somewhat less impacted by unexpected changes to the setting.

Hartl (1995) presents a rarity in *POM*. This paper investigates how optimal production rate and price levels react to the introduction of an environmental tax on emissions. He finds that under perfect competition, a linear tax has no effect, while in a monopoly case, the optimal production and emissions rates decrease given any tax structure. He also deduces that in a competitive environment a progressive tax is required if the objective is to cut peak emission levels.

The transformation of a company into a computer-integrated manufacturing enterprise can offer the company a significant competitive advantage in today's global marketplace. Garza, Golub, Luper, and Neebe (1992) report on the implementation of computer-based decision support systems in R. J. Reynolds Tobacco USA (RJR), which is used to optimize the selection of patterns for loading cases of finished product into truck trailers at a central distribution center. McAfee (2002) studies an ERP implementation at a high tech manufacturer. Plant level data indicate that the implementation led to a short term drop in performance, followed by a period of improvement where several performance metrics exhibit a pattern akin to a learning curve. The author argues that the data clearly shows the impact of ERP investment and calls for similar studies involving multiple sites.

Hsu and Rattner (1992) argue that there is a need for a theory-based model to identify the information requirements for integrated manufacturing. Veeramani, Bernardo, Chung, and Gupta (1995) argue that the transformation of manufacturing companies into computer-integrated enterprises has been limited due to the lack of understanding of the scope and implications of computer-integrated manufacturing (CIM). They present a taxonomical framework for defining key integration elements in CIM design and identify fundamental research issues that need to be addressed. Tempelmeier (2002) develops a heuristic for dynamic order sizing and supplier selection with time varying data. Suppliers offer all units and/or incremental quantity discounts. The heuristic is implemented as a part of the Advanced Planner and Optimizer (APO) software of SAP AG.

7. Teaching Operations Management

Several papers published in *POM* have contributed to the state of the art in teaching Operations Management. Schwarz (1998) introduces a teaching paradigm which is called the information/control/buffer portfolio (I/C/B). The author shows how the portfolio is effective in introducing students to what managing operations is all about. The proposed I/C/B framework provides a consistent way to organize information about operations management systems. Leschke (1998) reviews the frameworks most commonly used in introductory textbooks as well as the guiding concepts used in several 'non-traditional' texts. He then introduces a new framework for teaching introductory production/operations management which he argues overcomes the most common shortcomings of earlier approaches. The framework is composed of four major elements: the product-process matrix, the operations planning and control cycle, a business process model of the firm, and a model of the information flows. Machuca (1998) argues that there is a need for systems thinking in operations management, and also the need for new teaching tools. The author introduces the transparent-box business simulation system developed by the research group GIDEAO and offers insights regarding its use. Ebert, Tanner, and Tuturea (1998) 'internationalize' the discussion somewhat in their consideration of the educational needs arising from the ongoing experiences in Eastern European countries which are in transition from controlled economies to open-market competition. They present a survey of manufacturing professionals in Romania and provide recommendations concerning Operations Management curriculum in university systems in Eastern Europe.

There are significant operational differences between managing operations that are located within a country and managing operations that cross borders. As the world moves toward a global economy, it is increasingly important that operations management courses address globalization issues. Lawrence and Rosenblatt (1992) present a survey of operations management academicians worldwide to investigate how international topics are incorporated into operations management curricula. They develop a list of topics, materials, and approaches to teaching about international OM. Starr (1997) suggests that the introductory courses for MBAs should consist of a traditional OM course emphasizing domestic operations and a separate international OM course. Interestingly, Whybark (1997) notes that many feel that it is difficult to justify the idea of international OM as a separate discipline. However, it does appear that this distinction is consistent with the attitudes of U.S.-based managers and students. Consequently, it seems that continuing to treat international operations management separately may be necessary (at least in the short term) to help reduce the startup cost for American managers entering into firms that compete globally.

8. Highlighted Works and Trends

While the broad overview of manuscripts within this department is useful, we also see some value in highlighting several specific works at this time. This is done to add depth to the readers' understanding of the breadth of work in the pages of *POM*, and to highlight novel aspects of the underlying work we would like to see more of in the pages of the *POM* journal and especially of this department. Furthermore, it serves to set the stage for our discussion of directions for future work in the final section.

Buzacott and Shanthikumar (1992) create a general model of a production environment which includes a family of parameters as inputs. Depending upon the parameter values, the model can represent different approaches to the planning and control of a production process. This type of modeling suggests possibilities rarely considered in academic research. In effect, this approach allows a firm to consider an infinite array of 'hybrid' approaches. For example, the model can mimic a system with characteristics of both JIT and MRP based control systems in the same shop. This allows a study of tradeoffs between such choices in a richer context. It may often be easier to select a specific environment, create a simple abstraction of it, and seek some optimal policy within this virtual reality. However, this typically skips the initial question of 'what should the environment look like?' It may be impossible to answer such questions optimally, but there is no question that insights derived from their study have value to practitioners, while at the same time opening up the modeling horizons for production planning researchers.

Johnson and Wemmerlöv (1996) address a question of particular importance to researchers. Specifically, they note a collection of normative models which suggest that the impact of moving from a functional layout to a cellular layout should be relatively minor. They also survey a body of anecdotal evidence and empirical results which imply that the improvements resulting from a move to cellular manufacturing can be quite dramatic. This raises an obvious question of why this apparent discrepancy exists. The authors attempt to address this question by highlighting factors that seem to determine whether a shift to a cellular layout will or will not produce major results. This type of analysis builds bridges between communities of researchers engaged in differing styles of work. It can also help practitioners learn how to evaluate scholarly work for the benefit of their firms. Furthermore, it attempts to answer the question of when and why lean approaches to low-to-mid-volume high-variety environments are appropriate and generate benefits. This work does not close the topic, but that can be looked as a valuable attribute. It openly invites new contributions that can reinforce or contradict the theoretical and empirical findings of an important question not adequately studied.

Sakakibara, Flynn, and Schroeder (1993) use surveys and plant visits to address questions such as 'why do firms who begin a move toward cellular manufacturing seem to stop before converting the entire environment?' Such questions can only be answered by the people making the decisions. It is very difficult to see how researchers can uncover insights regarding the actual thinking of managers without approaching them directly. This style of work is another way to identify factors making the implementation of cellular manufacturing attractive. Of course, this also relates to the larger question of when and why the results of academic research have real impact on managerial practice. Such works have particular value to young scholars working to develop an understanding that will help them to identify promising research topics and styles. It also seems fair to say that the work is a refreshing addition to the manufacturing process reengineering literature in that it goes beyond the usual question of what type of process change is needed, and asks how such process change can be effected within particular environments.

Bitran and Morabito (1999) present algorithms that may be used to produce 'tradeoff curves' which show the relationship between capacity and WIP (or lead times) in job shops modeled as open queueing networks. The decomposition method employed to produce the curves is of interest to researchers. However, the presentation of the findings is centered around questions such as 'Should I invest in additional capacity or the reduction of variability in processing times?', or ' Is it better to reduce WIP (or lead times) by cutting the throughput rate or by adding capacity?' The work is novel in the recognition of the fact that it is these types of questions that are at the forefront of a manager's decision setting. Of course, the authors must wrestle with questions regarding the accuracy of their selected modeling method, but they also present the analysis in a way that makes its applicability to the manager's environment very clear.

Kulkarni, Magazine, and Raturi (2004) address questions of network configuration by comparing a process configuration in which each facility focuses on a single component, with a product configuration in which all of the components for a product are produced and assembled under one roof. Obviously, the two cases are stylized versions of two extremes. However, the rigorous comparison of the two approaches produces a collection of insights that are applicable across a broad array of settings. In other words, instead of describing an optimal policy under a very specific set of assumptions, the authors work to uncover and deliver a collection of insights that may guide the decision making process. Thus, the link between the rigor of normative modeling and the understanding needed to manage on a day to day basis is most transparent. Also, from a thematic perspective, this work offers a rigorous modeling effort to clarify issues of manufacturing "focus," and the corresponding notions of product versus process. This work also helps form the debate on how to design manufacturing network configurations by providing arguments that go beyond abstract discussions of focus and flexibility, by presenting a reasonable quantification of the relevant tradeoffs.

Leschke and Weiss (1997) consider the allocation of investment funds in setup cost reduction. They use simulation to compare the impacts of a variety of allocation rules on system performance. Some of the rules considered are those suggested by the academic literature. Other rules are applications of ideas expressed in the popular literature, such as Shingo's recommendation to prioritize setups that take the longest time. In this sense, the work bridges a divide between theoretical modeling that seeks 'optimal' decisions and common practice that often applies heuristics that are easy for the managers to understand. In the process, the authors apply the rigor of the OM scholars to managerial questions in a way that is easy for practitioners to understand and appreciate. From a thematic perspective, this work contributes to our understanding of lean process reengineering initiatives as investment decisions that have to be carefully thought out as opposed to oncepts that must be dogmatically accepted.

Bordoloi, Cooper, and Matsuo (1999) present a capacity expansion model to illustrate and clarify notions of flexibility, adaptability, and efficiency in a manufacturing system. This work presents a review of prior works that serves to organize that work in a way that may be useful to other readers. Rather than simply focusing on how this work is slightly different than similar, prior offerings, the authors propose definitions of terms that are often ambiguous and organize prior works in accordance with these definitions. This helps to identify research questions and to unify a large body of prior work. The work is similar to the work of Kulkarni, Magazine, and Raturi (2004) on notions of manufacturing network focus, in that it attempts to formalize previously vague notions in the operations strategy literature, such as flexibility and adaptability of manufacturing systems.

The scarcity of empirical research that leverages hard data is notable in the pages of *POM*. The work of Lieberman, Helper, and Demeester (1999) stands out in the use of data regarding inventory levels for high-volume manufacturers of parts for the U.S. automobile industry. The work combines hard data with survey responses to draw conclusions about both technologies and managerial practices as they relate to inventory levels. Their results serve to clarify links between structural elements, such as investments in new machines or setup time reduction, and inventory. However, they also highlight the impacts of infrastructural policies and tactics, such as training in problem solving. This type of research provides ample motivation of future modeling efforts and raises additional empirical questions while suggesting approaches for these questions as well.

The work of Munson and Rosenblatt (1998) is unique in the pages of *POM* in that it combines a survey of prior literature on the use and predicted impact of volume discounts with an empirical study that focuses on the actual impacts and use of such discounts. They combine an extensive review with data drawn from interviews with 39 companies to determine how discounts are used in practice. This combination of approaches, considering a central question provides an enlightening link between academic research and industry practice. This type of research implicitly addresses questions about whether the work presented in scholarly journals such as *POM* actually affects practitioners in the manner that we generally hope it will. This type of research has particular importance to young scholars who are working to develop a sense of what useful research is and how to identify problems and approaches that will benefit the larger community.

POM has included seven papers which explicitly focus on teaching OM. The work of Schwarz (1998) stands out in that it does not limit itself to one small segment of the material that must be covered or to a single tool. This work attempts to provide a broad framework that may guide an entire course, or even a collection of courses. The unifying logic suggested is that all operations management systems do basically the same thing: they plan and control production. Planning and controlling is the role of the planning and control system. Information is required in both making and implementing decisions. Capturing and communicating this information is the role of the information system. Finally, since real-world information systems and control systems are seldom perfect, something must cope with their imperfections. That is the role of the buffer system. Thus a teaching paradigm such as the information/control/buffer portfolio (I/C/B) can be adapted to a wide variety of OM topics. Each teacher's implementation of the idea will be unique but the insights behind the framework can be leveraged by the entire community of OM instructors.

9. Future Research Directions

The mission statement for the manufacturing management department states that the goal is to publish work of the highest scientific rigor related to the management of production systems. The topics suggested include planning and control, capacity planning, layout, quality, and inventory. It seems quite safe to say that the body of work reviewed in Sections 2 to 8 does much to fulfill this mission and is consistent with the objectives of the department and journal. On the other hand, several research questions, methodologies, and insights are notable by their scarcity among the 108 papers reviewed earlier. For example, there is a striking absence of empirical work, other then a few uses of survey based investigations. A wide array of questions regarding current practice, emerging trends, technology diffusion, and strategic responses to changing environments (just to name a few) lend themselves well to empirical investigations. As this is also part of the mission of this department, its absence is quite noticeable.

It is also clear that the vast majority of the works published in this set focus on cost minimization. Very little work is presented that discusses ways to manage production to increase revenues. For example, little attention is given to topics such as the impact of reducing lead times, or the value of locating facilities closer to customers for benefits other then reduced transportation costs. Similarly, it also seems reasonable to classify the vast majority of the problems addressed in these works as tactical in nature as opposed to strategic. Very little discussion is provided on strategic questions other than capacity expansion, and almost no content is provided related to making better use of information technologies, or strategic flexibility. There is also a great deal of insight provided regarding the use, purchase, maintenance, and placement of machines, but almost no comment on issues specific to human assets in the production system.

Obviously, many of these topics are covered more extensively in other departments. But it may be wise for the largest department in *POM* to include works that (1) speak to managers about strategic issues, (2) are clearly differentiated from industrial engineering manuscripts, (3) have great relevance to revenues as well as costs, and (4) provide insights regarding the management of all assets (including the workforce and suppliers) useful in the production of physical goods. In short, the Manufacturing Management department of *POM* has a long history of presenting high quality works on a wide variety of relevant topics. Additionally, opportunities abound for the department to expand the nature of its contribution to the business and academic communities as we move forward. To be more concrete in regards to ideas for future research, we outline several open questions and research problems for some of the reviewed areas (scheduling, manufacturing systems management, and inventory/lead-time/capacity management). This discussion is intended to stimulate further research efforts and academic dialogue. The specific views expressed are those of the authors, and should not be interpreted as a statement of the research priorities or tastes of the journal.

9.1. Scheduling

The volume of scheduling research is unparalleled by most other sub-fields in manufacturing operations management. Much of that research is the modeling of rather simple stylized, deterministic environments. These models often overlook the complexity, uncertainty and involvement of intelligent agents (such as workers and managers) as well as other realistic attributes of the environments that industrial schedulers and production managers routinely face. Thus, it is obvious that research that attempts to deal with all of the "dirty hands" complexities and uncertainties of actual environments is needed. We do not mean to suggest that works of a very restricted nature, or interesting case studies are what we have in mind. Rather, we are suggesting that well motivated applications that stimulate interesting solution approaches with wider applicability are worthwhile research pursuits. It should be well understood by all, that pristine and rigorously proven optimal solutions will not be the primary outcome from such studies. But if we succeed at illustrating how insights from our "stylized environments" and rigorous theories can be used to generate robust heuristics, problem solving approaches and managerial insights for "real" environments, we will do much to serve both practitioners and our own research community.

There is a rather noticeable gap, some might even call it a warning sign, between what is taught in operations and manufacturing management courses in most business schools and even at some industrial engineering programs, and the scheduling theories and models that this vast literature has generated. We will defer an in-depth discussion of the relevance of most such research for practitioners. Our main point is simply that while most of this work is both relevant and well executed, we often fail to effectively convey its immediate relevance. That immediately brings up the question of why coverage of this material is so often thought to be unnecessary, or at least not given a high priority in core courses, on operations management. There are many plausible answers to this question, and it seems wise for someone to take the initiative to survey and document them.

Our intuition is that the emphasis in core OM courses is often on teaching performance evaluation models (such as queuing based models, or stochastic simulation constructs of operational environments) and using them to build a fundamental understanding of "rules," "natural laws," and derived insights about the performance of operational systems. However, many of the same topics could have been covered through the study of stylized scheduling models and their solutions. It seems fair to say that the scheduling research has failed to effectively advocate such an approach. We believe that the development of such an argument is an interesting research direction with a strong potential for impact on both teachers and practitioners.

9.2. Manufacturing Systems Management

The last 10 years have witnessed the explosive impact and fast paced evolution of information systems, especially Enterprise Resource Planning (ERP) software. This phenomenon has had a dramatic impact on the management of manufacturing systems. Surprisingly, this is hardly noticeable in the pages of top quality OM journals. ERP implementation leads to a vast array of managerial challenges, such as process structuring and control, decision making and the development of decision support systems, change management, and designing managerial incentives. Dealing with these issues often leads to monumental failures or heroic efforts for success. However, the current OM literature seems to reflect the thought that these issues are largely irrelevant. We have produced very little literature which documents, explains, and theorizes about future implementations of such information systems. Often our literature takes the perspective that the flow control principles behind the system is all that matters to us, and the subsequent organizational re-structuring, and the information and software infrastructure built around these principals is less important. It seems wise to revisit this thesis, given the plethora of examples which point in the opposite direction. We need models which explicitly account for the organizational and information requirements just as they do the material flows as we study production systems. This is particularly relevant for systems with predominant roles for human operators and managers behaving as rational economic agents motivated by their own agendas and instituted incentives. Optimal material flows might not be all that is needed for the effective organizational control of complex manufacturing processes with complex information flows and rationally acting agents. It might also be time to polish our understanding of organizational design and change theories, and to connect them with our ideas on what type of process change should be affected. In other words we need to connect our performance evaluation and control models with an expression of how and to what extent the organizational realities drive performance outcomes.

Another major development of the last twenty five years has been the movement towards more lean production. This philosophy has led to the transformation of a vast array of manufacturing processes in virtually all industries. During the first 10 to fifteen years of this movement, we were fascinated by many of these ideas for high-volume manufacturing environments, and developed all kinds of theoretical and empirical justifications to explain their success. Oddly, we see considerably less research concerning the transformations of batch processes that occurred over the last 10 years or so. A lot less theory has been produced to explain when and for what types of batch processes the "cellular/lean" approaches can be effective. We need more work which explains the economic and flow controls, the rationales driving them, and how their success and applicability relates to other environmental factors such as market demand and its uncertainty, accommodated variety and customization, technological and business criteria based similarities among grouped products etc. This is needed because managers need to know if/when such approaches will fail to produce the desired results. There appear to be many consulting advocates preaching lean manufacturing as the way to riches for all, claiming superior performance for lean cellular processes across all environments and systems. We all know that this is not the case for every setting, but we have often failed to produce the models and empirical data which allow managers to properly evaluate such claims. For all that continue to struggle with such issues, it becomes apparent that we do not offer sufficient guidance to allow managers to understand the complex effects of multi-product, multi-process complexity within manufacturing systems, and to carefully separate and balance the benefits of economies of scale, from the diseconomies of scope that arise in such settings. Our understanding of the management of batch processes still needs the development of more theory.

Clearly, the managers of low volume high-variety batch processes are looking for methods and approaches which are more effective and less vague than what they find in "the theory of constraints" and/or limited applicability dynamic priority rules and back-of-the-envelope buffering heuristics. Our favorite protagonist, Alex Rogo, of "The Goal" (Goldratt 2004) is still searching for concrete and theoretically documented answers. This is especially true as he manages his batch process in a fast paced environment with higher complexity, increased variety, and shorter product life cycles.

The limited research effort to date intended to deepen our understanding of and better formalize key concepts of operational strategy presents an obvious future research opportunity. While we have struggled in our literature with the question, "what is operational flexibility and how do we measure it," we still do not have a comprehensive answer for it. Furthermore, we have almost no answers about how to design/build-in such flexibility at a desirable (profit maximizing/cost minimizing/ long term strategically sought) level in our processes (in terms of facility design and equipment choices, layout configurations, cross training of workers, etc.), and how such design choices interact with other strategic decisions about capacity, the extent of vertical integration, supplier selection etc. Similarly, we often present the manager with the vague notions of "manufacturing focus," "product focused plants," and "process focused facilities." We routinely speak of these concepts as essential building blocks in the design of manufacturing networks and key elements of our process choice decisions. We are then surprised that the manager seems confused, even though we have difficulty in rigorously defining and measuring the terms that we introduce into the discussion. We must be more precise in order for phrases such as the "degree of focus," and the "changing nature of focus over time," to have coherent meaning. Only then can such concepts and measures be used to guide strategic process choice and design decisions.

As in the case of manufacturing flexibility, we clearly need ways to estimate and evaluate the benefits of focus to make the value of the concept apparent. Furthermore, we have often failed to explain how flexibility and focus provide competitive advantage while carefully considering the strategic interactions of competing manufacturers. The economics, strategy, game theory, and real options literatures together with our own performance evaluation tools and theories seem to contain all the needed tools for us to proceed with these research tasks, and the time and opportunity for that to happen is now.

9.3. Inventory, Lead-Time and Capacity Management

One of the richest research areas of our field continues to go strong with a lot of effort spawned by the excitement over lean approaches and supply chain management. These ideas have refocused corporate attention and highlighted the importance of careful inventory, lead-time and capacity management for competitive success in both cost and time competitive environments. Still, many of the traditionally studied problems continue to attract attention as their relevance and difficulty to solve remain intact. The increased product proliferation in variety strategies forces us to rethink the careful management of inventories of substitutable products, and to find ways to carefully account for substitution not only at the operational level but also as early as the product line design. It seems that the more we try to understand such issues the more we have to incorporate models of customer behavior and choice in selecting among products. This forces us to explore all relevant marketing/production interface issues behind such decisions. Some work has appeared along these dimensions, but more is needed as the tractability of such issues has proven to be a challenge.

The Revenue Management literature (see Talluri and van Ryzin 2004 for a textbook exposition) was started by, and was initially mostly concerned with, airline reservations and other similar service environments (hotels, rental companies, restaurants, etc.) It quickly became apparent that much of this research has direct applicability to manufacturing systems management. The dynamic pricing of industrial capacities and inventories makes a lot of sense in many make-to-order environments, especially for industrial and logistical settings with multiple classes of customers with different preferences for quality, time and costs. Careful rationing strategies for capacity and inventories can prove to be an effective revenue management strategy when combined with dynamic pricing. The associated optimization problems remain challenging, but present a rich opportunity for researchers in our field. The real time enterprises of today fully armed with ERP/Internet/RFID technologies want to take advantage of their real time demand data and inventory/capacity visibility to accelerate the matching of demand and supply cycles producing previously unimagined levels of inventory velocity and corresponding turns. Agile enterprises seek to combine their manufacturing lead-time and inventory capabilities with the coordinated use of market control mechanisms (price, promotion, differentiated service) to increase profitability. Our capacity and inventory models were often passive in assuming exogenous (outside of our control) demand distributions, but that is far from being a satisfying assumption today. Our models have to account for customer choice, and our ability to influence such choice through not only our product offerings, but also through dynamic adjustments of our offered service in terms of quality, lead-times, and charged prices. That implies that our dynamically optimal capacity and inventory levels should reflect the complexities of customer behavior and competitor reactions, offering a host of new modeling opportunities. The study of inventories with substitution, dynamic pricing, rationing, strategic customers and competitors is just a small sample of a life time worth of research opportunities that this environment presents. It is particularly satisfying to realize that the relevance of such research questions is unquestionable as a hungry world of practitioners awaits such knowledge to translate it into software and managerial practices in a fast paced hypercompetitive environment of profitable growth and pressures for fiscal responsibility.

References

Adenso-Díaz, B., M. Laguna. 1996. A technique to minimize overtime in the capacitated MRP problem. *Production and Operations Management* 5(4) 357–370.

Aggarwal, A. K., R. R. Vemuganti, W. Fetner. 1992. A model-based decision support system for scheduling lumber drying operations. *Production and Operations Management* 1(3) 320–328.

Alfaro, J. A., C. J. Corbett. 2003. The value of SKU rationalization in practice (The pooling effect under suboptimal inventory policies and nonnormal demand). *Production and Operations Management* 12(1) 12–29.

Alidaee, B. 1994. Minimizing absolute and squared deviation of completion times from due dates. *Production and Operations Management* 3(2) 133–147.

Alidaee, B., G. A. Kochenberger. 1996. A framework for machine scheduling problems with controllable processing times. *Production and Operations Management* 5(4) 391–405.

Armentano, V. A., R. E. Berretta, P. M. Franca. 2001. Lot-sizing in capacitated multi-stage serial systems. *Production and Operations Management* 10(1) 68–86.

Atwater, J. B., S. S. Chakravorty. 2002. A study of the utilization of capacity constrained resources in drum-buffer-rope systems. *Production and Operations Management* 11(2) 259–273.

Barman, S., R. L. LaForge. 1998. The impact of simple priority rule combinations on delivery speed and delivery reliability in a hybrid shop. *Production and Operations Management* 7(4) 402–416.

Berkley, B. J. 1992. A review of the Kanban production control research literature. *Production and Operations Management* 1(4) 393–411.

Bitran, G. R., R. Morabito. 1999. An overview of tradeoff curves in manufacturing systems design. *Production and Operations Management* 8(1) 56–75.

Blocher, J. D., R. W. Garrett, R. W. Schmenner. 1999. Throughput time reduction: Taking one's medicine. *Production and Operations Management* 8(4) 357–373.

Bordoloi, S. K., W. W. Cooper, H. Matsuo. 1999. Flexibility, adaptability, and efficiency in manufacturing systems. *Production and Operations Management* 8(2) 133–150.

Bowman, R. A. 2002. Job release control using a cyclic schedule. *Production and Operations Management* 11(2) 274–288.

Bowman, R. A., J. A. Muckstadt. 1995. Production control of cyclic schedules with demand and process variability. *Production and Operations Management* 4(2) 145–162.

Bradley, J. R., R. W. Conway. 2003. Managing cyclic inventories. *Production and Operations Management* 12(4) 464–479.

Buzacott, J. A., J. G. Shanthikumar. 1992. A general approach for coordinating production in multiple-cell manufacturing systems. *Production and Operations Management* 1(1) 34–52.

Bylka, S., S. P. Sethi. 1992. Existence and derivation of forecast horizons in a dynamic lot size model with nondecreasing holding costs. *Production and Operations Management* 1(2) 212–224.

Campbell, G. M. 1992. Using short-term dedication for scheduling multiple products on parallel machines. *Production and Operations Management* 1(3) 295–307.

Chakravarty, A. K. 1997. A model for switching dispatching rules in real time in a flexible manufacturing cell. *Production and Operations Management* 6(4) 398–418.

Chakravarty, A. K., A. Shtub. 1992. The effect of learning on the operation of mixed-model assembly lines. *Production and Operations Management* 1(2) 198–211.

Chand, S., D. Chhajed, R. Traub. 1994. A single-machine scheduling model with fixed-interval deliveries. *Production and Operations Management* 3(4) 296–307.

Chao, J. S., S. C. Graves. 1998. Reducing flow time in aircraft manufacturing. *Production and Operations Management* 7(1) 38–52.

Chaouch, B. A., J. A. Buzacott. 1994. The effects of lead time on plant timing and size. *Production and Operations Management* 3(1) 38–54.

Cheng, F., H. Yan, J. Yang. 1998. Production scheduling of continuous flow lines: Multiple products with setup times and costs. *Production and Operations Management* 7(4) 387–401.

Cheng, T. C. E., C. Sriskandarajah, G. Wang. 2000. Two- and three-stage flowshop scheduling with no-wait in process. *Production and Operations Management* 9(4) 367–378.

Cheng, T. C. E., J. N. D. Gupta, G. Wang. 2000. A review of flowshop scheduling research with setup times. *Production and Operations Management* 9(3) 262–282.

Chiu, H. N., H. M. Chen, L. C. Weng. 2003. Deterministic time-varying demand lot-sizing models with learning and forgetting in setups and production. *Production and Operations Management* 12(1) 120–127.

Coleman, B. J. 1992. Technical note: A simple model for optimizing the single machine early/tardy problem with sequence-dependent setups. *Production and Operations Management* 1(2) 225–228.

Conway, R. 1997. Comments on an exposition of multiple constraint scheduling. *Production and Operations Management* 6(1) 23–24.

Denizel-Sivri, M., S. S. Erenguc. 1993. A branch and bound procedure for setup problems in flexible manufacturing systems. *Production and Operations Management* 2(4) 289–305.

Dessouky, M. M., R. C. Leachman. 1994. An optimization-based methodology for release scheduling. *Production and Operations Management* 3(4) 276–295.

Dessouky, M., B. Kijowski, S. Verma. 1999. Simultaneous batching and scheduling for chemical processing with earliness and tardiness penalties. *Production and Operations Management* 8(4) 433–444.

Deuermeyer, B. L., G. L. Curry, R. M. Feldman. 1993. An automatic modeling approach to the strategic analysis of semiconductor fabrication facilities. *Production and Operations Management* 2(3) 195–220.

Ebert, R. J., G. Tanner, M. Tuturea. 1998. Building the POM curriculum for a privatizing economy: An evaluation from manufacturers' perspectives. *Production and Operations Management* 7(2) 171–180.

Elhafsi, M., S. X. Bai. 1997. Optimal and near optimal control of a two-part-type stochastic manufacturing system with dynamic setups. *Production and Operations Management* 6(4) 419–438.

Ferrer, G., D. C. Whybark. 2001. Material planning for a remanufacturing facility. *Production and Operations Management* 10(2) 112–124.

Fry, T. D., J. F. Cox, J. H. Blackstone. 1992. An analysis and discussion of the optimized production technology software and its use. *Production and Operations Management* 1(2) 229–242.

Fuxman, L. 1998. Optimal buffer allocation in asynchronous cyclic mixed-model assembly lines. *Production and Operations Management* 7(3) 294–311.

Gaimon, C., R. H. Burgess. 2003. Analysis of the lead time and learning for capacity expansions. *Production and Operations Management* 12(1) 128–140.

Garza, O. F., A. J. Golub, J. F. Luper, A. W. Neebe. 1992. Load cubing at R. J. Reynolds. *Production and Operations Management* 1(2) 151–158.

Goldratt, E. M., J. Cox. 2004. The Goal: A Process of Ongoing

Improvement, 3rd edition, North River Press, Great Barrington, Massachusetts.

Hartl, R. F. 1995. Production smoothing under environmental constraints. *Production and Operations Management* 4(1) 46–56.

Heady, R. B., Z. Zhu. 1994. An improved implementation of the Wagner-Whitin Algorithm. *Production and Operations Management* 3(1) 55–63.

Herrmann, J. W., C.-Y. Lee, J. Hinchman. 1995. Global job shop scheduling with a genetic algorithm. *Production and Operations Management* 4(1) 30–45.

Hill, A. V., I. S. Khosla. 1992. Models for optimal lead time reduction. *Production and Operations Management* 1(2) 185–197.

Hsu, C., L. Rattner. 1992. Integration in manufacturing: An information theoretic perspective. *Production and Operations Management* 1(3) 286–294.

Inman, R. R., M. Leon. 1993. The validity of the independent increments assumption for production: An empirical study of the automotive assembly plant. *Production and Operations Management* 2(4) 276–288.

Ittner, C. D., J. P. MacDuffie. 1995. Explaining plant-level differences in manufacturing overhead: Structural and executional cost drivers in the world auto industry. *Production and Operations Management* 4(4).

Jack, E. P., A. S. Raturi 2003. Measuring and comparing volume flexibility in the capital goods industry. *Production and Operations Management* 12(4) 480–501.

Jin, Z. H., K. Ohno, T. Ito, S. E. Elmaghraby. 2002. Scheduling hybrid flowshops in printed circuit board assembly lines. *Production and Operations Management* 11(2) 216–230.

Johnson, D. J., U. Wemmerlöv. 1996. On the relative performance of functional and cellular layouts—an analysis of the model-based comparative studies literature. *Production and Operations Management* 5(4) 309–334.

Johnson, D. J., U. Wemmerlöv. 2004. Why does cell implementation stop? Factors influencing cell penetration in manufacturing plants. *Production and Operations Management* 13(3) 272–290.

Kanet, J. J., Z. Zhou. 1993. A decision theory approach to priority dispatching for job shop scheduling. *Production and Operations Management* 2(1) 2–14.

Ketzenberg, M. E., G. C. Souza, V. D. R. Guide. 2003. Mixed assembly and disassembly operations for remanufacturing. *Production and Operations Management* 12(3) 320–335.

Kim, S. L., J. C. Hayya, J.-D. Hong. 1995. Setup reduction and machine availability. *Production and Operations Management* 4(1) 76–90.

Kim, S.-C., P. M. Bobrowski. 1995. Evaluating order release mechanisms in a job shop with sequence-dependent setup times. *Production and Operations Management* 4(2) 163–180.

Krämer, F.-J., C.-Y. Lee. 1993. Common due-window scheduling. *Production and Operations Management* 2(4) 262–275.

Krämer, F.-J., M. Elhafsi, S. X. Bai. 1997. Production flow control for a manufacturing system with flexible routings. *Production and Operations Management* 6(1) 37–56.

Kulkarni, S. S., M. J. Magazine, A. S. Raturi. 2004. Risk pooling advantages of manufacturing network configuration. *Production and Operations Management* 13(2) 186–199.

Lawrence, S. R., M. J. Rosenblatt. 1992. Introducing international issues into operations management curricula. *Production and Operations Management* 1(1) 103–117.

Lawrence, S. R., A. H. Buss. 1994. Shifting production bottlenecks: causes, cures, and conundrums. *Production and Operations Management* **3(1)** 21–37.

Lee, W. J., D. Kim. 1998. Effects of integrating order/backorder quantity and pricing decisions. *Production and Operations Management* 7(3) 312–324.

Leschke, J. P. 1998. A new paradigm for teaching introductory production/operations management. *Production and Operations Management* 7(2) 146–159.

Leschke, J. P., E. N. Weiss. 1997. A comparison of rules for allocating setup-reduction investments in a capacitated environment. *Production and Operations Management* 6(4) 329–340.

Li, C.-L., S. J. Erlebacher, D. H. Kropp. 1997. Investment in setup cost, lead time, and demand predictability improvement in the EOQ model. *Production and Operations Management* 6(4) 341–352.

Li, C.-L., T. C. E. Cheng. 1994. An economic production quantity model with learning and forgetting considerations. *Production and Operations Management* 3(2) 118–132.

Liang, M., S. P. Dutta. 1993. Solving a combined part-selection, machine-loading, and tool-configuration problem in flexible manufacturing systems. *Production and Operations Management* 2(2) 97–113.

Lieberman, M. B., S. Helper, L. Demeester. 1999. The empirical determinants of inventory levels in high-volume manufacturing. *Production and Operations Management* 8(1) 44–55.

Litchfield, J., R. Narasimhan. 2000. Improving job shop performance through process queue management under transfer batching. *Production and Operations Management* 9(4) 336–348.

Liu, J. J. 1992. Dynamic feeding in a stochastic parallel processing system. *Production and Operations Management* 1(3) 308–319.

Machuca, J. A. D. 1998. Improving POM learning: Systems thinking and transparent-box business simulators. *Production and Operations Management* 7(2) 210–227.

Matta, R., T. Miller. 1996. Evaluating the Trade-Offs between idling and shutting down production lines in process industries. *Production and Operations Management* 5(4) 371–390.

McAfee, A. 2002. The impact of enterprise information technology adoption on Operational performance: An empirical investigation. *Production and Operations Management* **11**(1) 33–53.

McKone, K. E., E. N. Weiss. 1998. TPM: Planned and autonomous maintenance: bridging the gap between practice and research. *Production and Operations Management* 7(4) 335–351.

Melnyk, S. A., D. R. Denzler, G. L. Magnan, L. Fredendall. 1994. An experimental model for investigating the sensitivity of job shop performance to job release time distribution parameters. *Production and Operations Management* 3(1) 64–74.

Metters, R., V. Vargas. 1999. A comparison of production scheduling policies on costs, service level, and schedule changes. *Production and Operations Management* 8(1) 76–91.

Morton, T., V. Narayan, P. Ramnath. 1995. A tutorial on bottleneck dynamics: A heuristic scheduling methodology. *Production and Operations Management* 4(2) 94–107.

Mosier, C. T., G. E. Martin. 1995. Cellular production systems: A concurrent cluster analytic framework. *Production and Operations Management* 4(4) 414–420.

Munson, C. L., M. J. Rosenblatt. 1998. Theories and realities of quantity discounts: An exploratory study. *Production and Operations Management* 7(4) 352–369.

Petersen, C. G. 2000. An evaluation of order picking policies for mail order companies. *Production and Operations Management* 9(4) 319–335.

Pinedo, M. 1997. Commentary on "An exposition of multiple constraint scheduling as implemented in the goal system." *Production and Operations Management* 6(1) 25–27.

Rao, P. C., R. Suri. 2000. Performance analysis of an assembly station with input from multiple fabrication lines. *Production and Operations Management* 9(3) 283–302.

Rohleder, T. R., G. Scudder. 1993. A comparison of order-release and dispatch rules for the dynamic early/tardy problem. *Production and Operations Management* 2(3) 221–238.

Sahin, I., H. Polatoglu. 1996. Manufacturing quality, reliability and preventive maintenance. *Production and Operations Management* 5(2) 132–147.

Sakakibara, S., B. B. Flynn, R. G. Schroeder. 1993. A framework and measurement instrument for just-in-time manufacturing. *Production and Operations Management* 2(3) 177–194.

Schwarz, L. B. 1998. A new teaching paradigm: The information/control/buffer portfolio. *Production and Operations Management* 7(2) 125–131.

Sethi, S. P., M. I. Taksar, Q. Zhang. 1992. Capacity and production decisions in stochastic manufacturing systems: An asymptotic optimal hierarchical approach. *Production and Operations Management* 1(4) 367–392.

Shore, H. 1996. Optimum schedule for preventive maintenance: a general solution for a partially specified time-to-failure distribution. *Production and Operations Management* 5(2) 148–162.

Shore, H. 1998. Solution procedures with limited sample data for the optimal replacement problem. *Production and Operations Management* 7(4) 417–422.

Simons, J. V., W. P. Simpson. 1997. An exposition of multiple constraint scheduling as implemented in the goal system (formerly disaster TM). *Production and Operations Management* 6(1) 3–20.

Sloan, T. W., J. G. Shanthikumar. 2000. Combined production and maintenance scheduling for a multiple-product, single-machine production system. *Production and Operations Management* 9(4) 379–399.

Smunt, T. L., J. Meredith. 2000. A comparison of direct cost savings between flexible automation and labor with learning. *Production and Operations Management* 9(2) 158–170.

Spearman, M. L. 1997. On the theory of constraints and the goal system. *Production and Operations Management* 6(1) 28–33.

Stadtler, H. 1996. An operational planning concept for deep lane storage systems. *Production and Operations Management* 5(3) 266–282.

Starr, M. K. 1997. Pedagogical challenge: teaching international production and operations management courses. *Production and Operations Management* 6(2) 114–121.

Talluri, K. T. and G. J. Van Ryzin. 2004. *The Theory and Practice of Revenue Management.* Kluwer, Boston, Massachusetts.

Tang, K., J. Tang. 2002. Time-based pricing and lead time policies for a build-to-order manufacturer. *Production and Operations Management* 11(3) 374–392.

Tempelmeier, H. 2002. A simple heuristic for dynamic order sizing and supplier selection with time-varying data. *Production and Operations Management* 11(4) 499–515.

Uzsoy, R., Y. Yang. 1997. Minimizing total weighted completion time on a single batch processing machine. *Production and Operations Management* 6(1) 57–73.

Veeramani, D., J. J. Bernardo, C. H. Chung, Y. P. Gupta. 1995. Computer-integrated manufacturing: a taxonomy of integration and research issues. *Production and Operations Management* 4(4) 360–380.

Venkataraman, R. 1996. Frequency of replanning in a rolling horizon master production schedule for a process industry environment: A case study. *Production and Operations Management* 5(3) 255–265.

Wang, H. 1995. A branch-and-bound approach for sequencing expansion projects. *Production and Operations Management* 4(1) 57–75.

Webster, S., F. R. Jacobs. 1993. Scheduling a flexible machining system with dynamic tool movement. *Production and Operations Management* 2(1) 38–54.

Weng, M. X., J. A. Ventura. 1996. A note on "Common due window scheduling". *Production and Operations Management* 5(2) 194–200.

Whybark, D. C. 1997. Does international operations management need a separate perspective? *Production and Operations Management* 6(2) 122–130.

Williams, E. F., S. Tüfekçi, M. Akansel. 1997. O (m2) algorithms for the two and three sublot lot streaming problem. *Production and Operations Management* 6(1) 74–96.

Woodruff, D. L., M. L. Spearman. 1992. Sequencing and batching for two classes of jobs with deadlines and setup times. *Production and Operations Management* 1(1) 87–102.

Yan, H., S. Lou, S. P. Sethi. 2000. Robustness of various production control policies in semiconductor manufacturing. *Production and Operations Management* 9(2) 171–183.

Yang, K. K. 2000. Managing a flow line with single-kanban, dual-kanban, or conwip. *Production and Operations Management* 9(4) 349–366.

Zhao, X., J. Xie, Q. Jiang. 2001. Lot-sizing rule and freezing the master production schedule under capacity constraint and deterministic demand. *Production and Operations Management* 10(1) 45–67.