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MODELING AND ANALYSIS OF SEMICONDUCTOR MANUFACTURING IN A SHRINKING WORLD: CHALLENGES AND SUCCESSES

Chen-Fu Chien
Industrial Engineering Division
TSMC
Hsinchu, 30077, TAIWAN

Stéphane Dauzère-Pérès
Department of Manufacturing Sciences and Logistics, Ecole des Mines de Saint-Etienne
13541 Gardanne, FRANCE

Hans Ehm
Supply Chain Management Semiconductor Industry
Infineon Technologies AG
81726 Munich, GERMANY

John W. Fowler
Department of Industrial Engineering
Arizona State University
Tempe, AZ 85287, USA

Zhibin Jiang
Dept. of Industrial Engineering & Logistics
Shanghai Jiao Tong University
Shanghai, 200240 CHINA

Shekar Krishnaswamy
Industrial Engineering
Advanced Micro Devices
Austin, TX 78741, USA

Lars Mönch
Dept. of Mathematics and Computer Science
University of Hagen
58097 Hagen, GERMANY

Reha Uzsoy
Department of Industrial and Systems Engineering
North Carolina State University
Raleigh, NC 27695, USA

ABSTRACT

A panel session on the role of modeling and analysis in semiconductor manufacturing in a shrinking world is presented. Therefore, two participants are from Asia, two from Europe, and two from US and there are two panel organizers/moderators (Fowler and Mönch). One panelist from each continent is from industry and one from academia. Only initial position statements are included in the proceedings. However, these initial statements form the basis for the panel discussion. The statements of the panelists from industry relate to modeling and analysis problems found in their own companies. The position statements of the panelists from academia describe the role that modeling and analysis is expected to play in their current and ongoing research in semiconductor manufacturing. Furthermore, their views on the challenges and successes of modeling and analysis in a globalized world are also included.

1 MOTIVATION FOR THIS PANEL SESSION

A panel discussion related to operational modeling and simulation in semiconductor manufacturing was organized ten years ago at the Winter Simulation Conference 1998 in Washington, DC (cf. Fowler *et al.* 1998). At that time, nine of the panelists were from the US, and only one panelist from outside the US (Germany). The main theme of the 1998 panel discussion was the application of discrete event simulation in semiconductor manufacturing. In 1999, the first focused mini track related to semiconductor manufacturing was launched at the Winter Simulation Conference. Since this time, such a mini track has been organized every year. These mini tracks have become one of the major events where people from the semiconductor modeling and analysis community meet.

In 2000, the first International Conference on Modeling and Analysis of Semiconductor Manufacturing (MASM 2000) was held in Tempe, Arizona. The conference brought together almost 200 practitioners and leading academics and from around the world to share best practices and the latest research findings related to the application of Industrial Engineering, Operations Research, and Statistical tools and techniques to semiconductor manufacturing operations. The conference was held again in 2002 in Tempe, Arizona (MASM 2002) and in 2005 in Singapore (MASM 2005).

In 2008, the Modeling and Analysis of Semiconductor Manufacturing (MASM 2008) Conference is an integrated part of the Winter Simulation Conference for the first time. One track of this conference deals with modeling and simulation, a second with supply chain management and fab economics, and a third with enabling computing techniques and statistical methods. There were almost 50 total submissions from all over the world. The popularity of these tracks is partially a result of the success of modeling and analysis in semiconductor manufacturing in the last decade and partially an indication that more remains to be done.

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It is interesting to note that for the supply chain management track had almost as many papers submitted as the modeling and simulation track did with many of these submissions from Asia. That is a result of the increasing interest of the industry in supply chain management solutions.

The organizers of this panel discussion believe that the international modeling and analysis community in semiconductor manufacturing address important questions (cf. Gupta *et al.* (2006) for a more detailed description of current research activities in semiconductor manufacturing). For example:

- scheduling approaches for different types of tools and also for entire wafer fabs,
- integration of scheduling solutions with automated material handling efforts taking the increasing importance of automation into account,
- enterprise-wide planning, i.e., consideration of the entire supply network,
- modeling manufacturing strategies by linking with operational decision analysis problems (cf. Wu and Chien 2008),
- usage of modern software technologies like software agents or service-oriented architectures (cf. Mönch *et al.* 2006, Yoon and Shen 2008, Qui 2007),
- application of distributed simulation techniques,
- development of advanced forecasting techniques,
- Fab economics for modeling economical implications for semiconductor industry (cf. Leachman, Ding, and Ching 2007).

At the same time it is more and more difficult for researchers in the semiconductor manufacturing domain from academia to get funded from either the government or from industry, at least in US and in Europe. On the government side, this is partly due to the success of previous research (some in government think the problems are solved) and partly because of reduced government budgets. On the industry side, the fact that the industry has smaller margins today means that there is less money to spend on R&D. Therefore, just as it was a decade ago, a lot of us spend much of our energy and time to “justify our existence”. Some members of the research community have reached the conclusion that challenging research problems with better funding chances exist in domains like health care or logistics.

In this panel discussion, the panelists will reflect on the previous successes of this community as well as discuss the current challenges we face. We start with collecting industry position statements from Asia, Europe, and US. Then we continue with academia position statements.

2 INDUSTRY POSITION STATEMENTS

Disclaimers: The views expressed in these position statements are those of the individual panelists, and do not represent the views of the employee’s company or other individuals employed by the company.

Chen-Fu Chien, TSMC

The knowledge economy and globalization provides a great opportunity for innovative business models and managerial practices. As global competition intensifies, modern business no longer competes as individual companies but rather as supply chains. Supply chain is driven by strategically focusing on core competences to pursue higher value proposition and radically improving capital effectiveness. In particular, high-tech industries have been steadily penetrating and revolutionizing our lives worldwide, in which semiconductors are both the enabling solutions and substitution for comparable interests as raw materials increasingly high. Nevertheless, the rapid technology advances and business/service/product innovations make the managerial research fall far behind and fail to respond the needs in a shrinking world (Chien 2007).

To deal with increasing capital investments in a shrinking world, semiconductor companies are transforming into virtual collaborations of horizontal modular partners as major IDMs are taking asset-lite strategy. To maintain growth and profitability, one significant paradigm shift of modeling and analysis for semiconductor manufacturing in Taiwan is to vertically integrate from capacity planning and capital expenditure management down to resource allocation among fabs and operational excellence at each fab to enable manufacturing strategic decisions. The challenges and opportunities can be traced at least in part to the lack of a decision analysis framework in which the interrelation between manufacturing strategies and operational activities can be structured and then be integrated for solving the present problem as a whole (Wu and Chien 2008).

However, little research nor solutions have been developed to address these issues and support critical corporate planning and manufacturing strategic decisions under the risks of uncertain demands, technology migration challenges, and business dynamics of global supply chains etc.

Hans Ehm, Infineon Technologies AG

The global supply chain is our new Fab!

Diminishing trade barriers made global resource sharing attractive. Boosting information technologies made it possible (manage and controllable). Today “best fitting needs” global supply chains are a must for those surviving in the IT, electronics and semiconductor business.

Take an highly integrated chip from a platform chipset for mobile communication. It may initially be manufactured (manufactured not prototyped!) at the only technical capable supply chain, e.g.

- Wafer fabrication in Germany,
- Bumping in Taiwan (maybe the only option),
- Testing back in Germany (close link to Wafer fab),
- Assembly in Korea,
- Final Test back in Germany.

As the product matures, penetrates the market and requires more capacities other options emerge and are needed as manufacturing cost will now dominate further growth. It is not unusual that within a year a booming product is produced in ten or more new supply chains. Each new chain is either increasing output or - equally important – decreases costs. Costs would of course decrease by using one low cost manufacturing site for the entire value chain. However, this is often technically not achievable during the short economically life cycles (Moore's Law) of many products in our industry. Besides typical "economy of scale" and "make or buy" optimizations supply chain options for single processes or groups of processes are defined by a combination of technical possible low cost manufacturing on the one hand and technical capable manufacturing at "the best of bread" location in the world on the other hand. In harvesting the opportunities of these supply chain management options (within and outside the own enterprise) cost reductions of 40% or more within a year are demonstrated.

The question to simulation and modeling is: "What chain(s) are when economically at minimum risk most feasible?", at the condition that neither steep ramps nor sudden failures in launching the product can be predicted well (decreasing Forecast Accuracy in a faster moving world!). Supply chain can't be modeled? This is a too simple answer and as false as it was 15 years ago for a single semiconductor Fab. Academy has proven that modeling cluster tools, inter- and intra bay transportation systems and many more is possible. It is used by the industry and highly beneficial. X-factor and characteristic curve philosophy showing the relationship of speed and capacity utilization (thus costs) became the bible of many Fab managers. For academia the time has come to do research on above for the global supply chain network. Set up object oriented models and architectures, develop smart algorithm and simulations with the best fit goal functions in your solver engines. Distributed simulation techniques and software agents continuously optimizing the supply chain network. Turn on the light in the industry darkness of handling the overwhelming opportunities of supply chain management.

If modeling and simulation is so important for us why is industry not funding Academia in a broad perspective? The overall success of industry and of the semiconductor one in particular is based on fierce competition selecting the always fittest fast. Yielding to a dominated industry thinking in quarterly results for the own company – but economical benefits gained from research initiated in academia has longer horizons and serves once being successful the whole industry sector. The power of those in industry knowing from experience that long-term relationship with Academia is of high mutual benefit is limited by the nature described above especially in times of low margins and falling stock prices.

Thus what we both (industry and academia) need are un-bureaucratic programs & funding from national and supra-national governmental institutions. It would serve as lubricants to get the win-win machinery from academia and industry for modeling and analyzing in the Semiconductor industry up to speed - giving back an irresistible speed of innovations semiconductors and thus in the IT industry. That a booming IT industry improves communication, resolves conflicts, helps to understand and solving ecological problems - to close the cycle for the motivation of governments to invest into the MASM direction.

For you in academia - with or without above mentioned lubricants - supply chain management questions of today are the Klondike river gold nuggets of the past – go for it. Those coming back with gold are welcome everywhere.

Global supply chains are your new Fabs – model, analyze and simulate it!

Shekar Krishnaswamy, Advanced Micro Devices

In order to stay competitive, many IC manufacturers have migrated their fab manufacturing processes to 300mm wafers. The promise of lower die costs due to larger wafer area, equipment improvements present with newer technology and factory automation inherent in 300mm manufacturing among other reasons, are major driving forces for this migration. However, there are still significant challenges to achieving the expected results. The increased capital costs of 300mm dictate higher volumes of manufacturing with a richer product mix. This significantly affects product cycle time, equipment productivity and AMHS effectiveness, not to mention other peripheral impacts such as test wafer and reticle logistics, volume and usage.

300mm manufacturing also brings certain unique tool characteristics such as lot cascading during processing, equipment automation aspects like loadports, tool-to-tool FOUP delivery, multiple lots in FOUP, multiple storage methods (stocker, UTS and loadport), etc.. Due to the random and process driven event sequence that occurs as a result of these capabilities, it is extremely difficult to analyze their combined impact without a modeling tool like simulation.

Another important interaction happens between the processing tool and the AMHS. While the significant evolution of the process tool has already been covered, equally important are the changes happening in the AMHS arena. Advances in vehicle technology such as side transfer buffers, under track storages (UTS), tool station buffers, advanced MCS logic such as vehicle staging, or empty vehicle balancing have a major impact on the flow of material in the fab. Again, with a backdrop of such combined effects, the upfront planning of resources and the tuning of activities at a tactical level demand advanced modeling techniques.

Though modeling and simulation methods have addressed most of these changes, they have done so with a piece-meal approach. An integrated approach that encompasses these advances on the fab floor as well as the AMHS and produces interpretable output in an acceptable timeframe is lacking. As more advances are in the making with efforts in small lot sizes, continuously moving AMHS, virtual metrology, etc. it remains absolutely necessary to provide the required decision support for 300mm manufacturing through modeling and simulation.

Lastly, the fab cannot be viewed as an independent island of manufacturing. Though it forms a major component of the supply chain, it impacts as well as is affected by upstream and downstream components such as design, development, assembly, test, etc.. All of these are driven by customer demand and the product roadmaps. Current modeling and simulation tools and techniques do not address these components in a comprehensible way. Model definitions and integration from a supply chain perspective is woefully lacking. With the rapid migration towards higher product mixes in the fabs while enhancing customer delivery, the modeling of the supply chain that comprehends both internal and external manufacturing becomes an even higher priority.

3 ACADEMIA POSITION STATEMENTS

Stéphane Dauzère-Pérès, Ecole des Mines de Saint-Etienne

Although semiconductor manufacturing has been the subject of numerous publications, most of them tackle problems at one decision level, e.g. overall capacity planning or scheduling in various production areas (photolithography, diffusion, etc.). However, many challenges still arise when considering the integration of two or more decision levels; from supply chain management to real-time control. Here are some examples of relevant research problems of interest for the industry.

- Tactical planning decisions, in particular capacity planning, should be taken in connection with scheduling decisions (see Dauzère-Pérès and Lasserre 2002).
- Given the complexity and the size of semiconductor fabs, it is common to differentiate between fab-wide scheduling and detailed area scheduling. It is important to study how to ensure consistency between these two levels (see Bureau *et al.* 2007).
- Already mentioned but still not really tackled, the integration of scheduling decisions with Automated Material Handling System is tricky.
- New problems are induced by considering Advanced Process Control constraints when scheduling lots.

To conclude, the full automation of semiconductor fabs requires to propose effective and consistent management policies at all decision levels. This leads to very complex but motivating research problems.

Zhibin Jiang, Shanghai Jiao Tong University

In recent years, China has become the world's largest semiconductor market, and it is expected to reach 30% of the global market by 2010. Given the incessant influx of funds, increased technologic capabilities, and relatively low labor cost, semiconductor manufacturing will continue to inflate and become one of the most important industries in china. Driven by increased global competition, shorter product-life cycles and downward price pressures, Chinese semiconductor manufacturers, like their competitors worldwide, are turning their attention to reduce costs by improving operation efficiency. Technologies of semiconductor performance evaluation, system planning and scheduling are struggling to enhance the system efficiency and maintain profitability.

Measuring the performance of a manufacturing system is essential to understand the baseline of system output capability, forecast the future, and identify continuous improvement opportunities. While system planning and scheduling are required to adapt and react efficiently and effectively to gain optimal system performance. However, semiconductor is among the most complicated operation system encountered today. The complicated characteristics in semiconductor manufacturing processes include: hundreds of complex operations, re-entrant flows, uncertain yield, unreliable machines, sensitive to environment and multi-objective optimization. All these intricate characteristics along with the drastic competition on larger throughput and shorter cycle time make technology innovation on system performance evaluation, semiconductor planning and scheduling encounter great opportunity and challenge (Liu and Jiang 2007).

Reha Uzsoy, North Carolina State University

The expansion of modeling and simulation applications in the semiconductor industry over the last two decades has been very satisfying to those of us who remember the slow adoption of these techniques into the industry in the mid-1980s. At that time, the number of academics working on modeling and simulation problems in semiconductor manufacturing was probably less than ten, led by researchers at Stanford and Berkeley. Since then a growing number of academics have contributed to the literature related to this industry in a variety of areas: simulation modeling, shop-floor scheduling and dispatching, queuing models and production planning models, as well as a wide range of other engineering models to support yield and quality improvement. The number of publications in this area has also increased to the point that a relatively complete and concise review, such as that we attempted in the early 1990s (Uzsoy, Lee, and Martin-Vega 1992, 1994) would probably be hard to perform within the confines of a single paper.

Clearly, much excellent research has emerged from academics working with leading companies in the industry who have developed internal groups and collaborated with academics to design and implement state of the art planning and control systems. I believe that this work was motivated by the realization that the large, complex production systems and global supply chains encountered in this industry were unlikely to perform well with simple, manual techniques sufficed earlier. It is notable that this industry went global quite early on, with many firms establishing assembly and test facilities in Asia beginning in the 1970s. The heavy, successful competition from Japanese firms in the mid-1980s probably supported this trend.

It is interesting to speculate on what it is that has made the semiconductor industry so attractive to academics working in this area. One factor is the recognition that the semiconductor manufacturing environment has led to the formulation of a number of different problems that had not been widely studied in other industries. Among these we can cite the scheduling problems arising from batch processing machines, such as diffusion furnaces and burn-in ovens; the integrated scheduling of multistage robotic workstations such as wet etch stations; planning production in the presence of random yield, and uncertain binning-out at final test.

Another factor contributing to academic interest in this industry is the recognition that as one of the most complex and challenging industrial environments in widespread use today, it provides an extreme environment for production planning and control, scheduling and simulation models. The sheer size of the facilities and supply chains involved, the pervasive presence of different kinds of uncertainties and the rapid pace of change combine to yield an environment that places approaches developed in other industries under major stress. The capital intensive nature of the industry requires plants to run consistently at high utilization levels; reentrant flows create complex competition for capacity at resources; and the increasing level of automation reduces the ability to use people, the most flexible resource, to buffer the equipment. Thus models that are successful in this industry are likely to find applications in other areas, and to significantly advance the state of the art in their fields. To cite two examples, the work on artificial intelligence techniques for scheduling and planning problems at Siemens, Intel, IBM and Texas Instruments (Zweben and Fox 1994) led to substantial advances in that area; and the work of Leachman and his coworkers at Harris (Leachman *et al.* 1996) and Samsung (Leachman, Kang, and Lin 2002) is a clear example of an industry-academic collaboration that has significantly advanced the state of the art in production planning.

As the industry continues to develop, new and challenging problems will continue to emerge. In the area of simulation modeling, our ability to simulate large systems has steadily advanced, but our ability to interpret the massive amounts of data produced by these models in a manner that supports analysis and managerial intuition is becoming a significant bottleneck. The implementation of ERP systems across the industry provides both an opportunity and a challenge for the development of enterprise wide integrated production planning and scheduling applications; the development of production planning models that are computationally tractable and address the different uncertainties encountered in this industry in an integrated manner remains a particular challenge. It is more than likely that the next two decades will continue to challenge and surprise the research community with new problems and, as ever, innovative solutions.

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AUTHOR BIOGRAPHIES

CHEN-FU CHIEN has been the Deputy Director of Industrial Engineering Division at Taiwan Semiconductor Manufacturing Company since 2005 and is also a Professor of Industrial Engineering and Engineering Management being on-leave from National Tsing Hua University, Taiwan. He received B.S. of double majors in Industrial Engineering and Electrical Engineering with the Phi Tao Phi Honor from National Tsing Hua University in 1990 and then received M.S. in Industrial Engineering and Ph.D. in Decision Sciences and Operations Research from the University of Wisconsin-Madison in 1994 and 1996, respectively. He was a Fulbright Scholar in UC Berkeley from 2002 to 2003 and received the Executive Training in Harvard Business School in 2007. He has served in the Steering Committee of Industrial Engineering and Management Division in National Science Council (NSC), Taiwan, since 2002. He is on the Board of Directors of CIIE and CIDS. He is an Associate Editor of *IEEE Transactions on Automation Science and Engineering* and also on the advisory and/or editorial board of several journals including *OR Spectrum*. His research and development efforts center on decision analysis, modeling and analysis for semiconductor manufacturing, data mining, and manufacturing strategy. He received the Outstanding Research Award and Tier 1 Principal Investigator from NSC, Distinguished University-Industry Collaborative Research Award from the Ministry of Education, Best Engineering Paper Award by Chinese Institute of Engineers, Distinguished Young Industrial Engineer and Best Paper Award from Chinese Institute of Industrial Engineers, Taiwan. His email address is <cfchien@mx.nthu.edu.tw> and <cfchiena@tsmc.com>.

STEPHANE DAUZERE-PERES is a Professor at the Provence Microelectronics Center of the Ecole des Mines de Saint-Etienne, where he is heading the Manufacturing Sciences and Logistics Department . He received the Ph.D. degree from the Paul Sabatier University in Toulouse, France, and the H.D.R. from the Pierre and Marie Curie University, Paris, France. He was a Postdoctoral Fellow at the Massachusetts Institute of Technology, U.S.A., and Research Scientist at Erasmus University Rotterdam, The Netherlands. He has been Associate Professor and Professor at the Ecole des Mines de Nantes in France, and was also invited Professor at the Norwegian School of Economics and Business Administration, Bergen, Norway. His research interests broadly include modeling and optimization of operations at various decision levels (from real-time to strategic) in manufacturing and logistics. Stéphane Dauzère-Pérès has coordinated multiple academic and industrial research projects, In particular, he is coordinator for the EMSE of the MEDEA+ European project HYMNE (with companies such as STMicroelectronics, NXP and ATMEL), and of the regional project Rousset 2003-2008 (with STMicroelectronics). His e-mail address is <Dauzere-Peres@emse.fr>.

HANS EHM is Principal of Logistics Systems of Infineon Technologies AG. He holds degrees in Physics from Germany and a M.S./OSU. In over 20 years in the Semiconductor industry he was granted managing and consulting Positions at Wafer Fabrication, at Assembly & Test and nowadays for the global Supply Chains - on production site, on business unit and on corporate level. He is Board member of camLine Holding AG an IT company for supply- and quality chains. He leaded Governmental supported projects on national and international level in the context of IT, Semiconductor Manufacturing and Supply Chains - within this he initiated the EU/US MIMAC co-operation on capacity modelling. He teaches Supply Chain Management at Universities and guides Master and PhD students - studying in Munich, Paris and Kuala Lumpur. He is INFORMS member and on the International Advisory Committee of the 2008 MASM. His email address is <hans.ehm@infineon.com>.

JOHN FOWLER is a Professor of Industrial Engineering at Arizona State University (ASU) and was the Center Director for the Factory Operations Research Center that was jointly funded by International SEMATECH and the Semiconductor Research Corporation. His research interests include modeling, analysis, and control of semiconductor manufacturing systems. Dr. Fowler is a member of IIE, INFORMS, and SCS. He is an Area Editor for *SIMULATION: Transactions of the Society for Modeling and Simulation International* and an Associate Editor of *IEEE Transactions on Semiconductor Manufacturing*. He is an IIE Fellow and is on the Winter Simulation Conference Board of Directors. His email address is <John.Fowler@asu.edu>.

ZHIBIN JIANG is a Professor and the Chairman of Industrial Engineering & Logistics Management at Shanghai Jiao Tong University (SJTU), China. He is also the Director of Academic Affairs Office of SJTU. He received his B.S. in mechanical engineering from Hefei University of Technology in 1982, M. S. in automotive engineering from Jiangsu University of Technology in1985, and Ph.D degree in manufacturing engineering & engineering management from City University of Hong Kong in 1999, respectively. He is a senior member of IEEE and IIE, and 2006-2007 President of Beijing (China) Chapter of IIE, He is also vice president of Chinese Institute of Industrial Engineering. He is member of editorial board of IJPE and IJOE. He has authored 2 books and more than 130 papers in international journals and conferences. His research interests include Petri nets and its application, modeling, simulation and scheduling of semiconductor manufacturing systems, logistics system optimization, and healthcare system. He has been collected in 2006-2007 Who is who in Science and Engineering. His email address is <zbjiang@sjtu.edu.cn>.

SHEKAR KRISHNASWAMY currently manages the Center for Operations Research (CORe) at Advanced Micro Devices (AMD) focused on the application of Operations Research across different functions within the company. Prior to this role, he was involved in scheduling, dispatching and simulation modeling applications in semiconductor manufacturing, assembly and test. He led the team at AMD that implemented the first production-worthy Real Time Dispatch system in 1997. Prior to AMD, Shekar had also worked at IBM Microelectronics in E. Fishkill, NY and at Motorola Semiconductor Products Sector (SPS) with a combined experience of more than 20 years in the Industrial Engineering applications for fab manufacturing. He has a Bachelors degree in Mechanical Engineering and a Masters degree in Industrial Engineering and Operations Research. His email address is <shekar.krishnaswamy@amd.com>.

LARS MÖNCH is a Professor in the Department of Mathematics and Computer Science at the University in Hagen, Germany and heads the chair of enterprise-wide software systems. He received a master's degree in applied mathematics and a Ph.D. in the same subject from the University of Göttingen, Germany. His current research interests are in simulation-based production control of semiconductor wafer fabrication facilities, applied optimization and artificial intelligence applications in manufacturing and logistics. He is a member of GI (German Chapter of the ACM), GOR (German Operations Research Society), SCS, INFORMS, IIE, serves as an Associate Editor of *IEEE Transactions on Automation Science and Engineering* and is on the Editorial Board of *European Journal of Industrial Engineering*. His email address is <Lars.Moench@fernuni-hagen.de>.

REHA USZOY is Clifton A. Anderson Distinguished Professor in the Edward P. Fitts Department of Industrial and Systems Engineering at North Carolina State University. He holds BS degrees in Industrial Engineering and Mathematics and an MS in Industrial Engineering from Bogazici University, Istanbul, Turkey. He received his Ph.D in Industrial and Systems Engineering in 1990 from the University of Florida. His teaching and research interests are in production planning, scheduling, and supply chain management. He is the author of one book, an edited book, and over eighty refereed journal publications. He has also worked as a visiting researcher at Intel Corporation and IC Delco. His research has been supported by the National Science Foundation, Intel Corporation, Hitachi Semiconductor, Harris Corporation, Kimberly Clark, Union Pacific, Ascension Health and General Motors. He was named a Fellow of the Institute of Industrial Engineers in 2005, Outstanding Young Industrial Engineer in Education in 1997 and a University Faculty Fellow by Purdue University in 2001, and has received awards for both undergraduate and graduate teaching. He is currently serving on the Editorial Boards of *IIE Transactions on Scheduling and Logistics* and *International Journal of Computer-Integrated Manufacturing*. His email address is <ruzsoy@ncsu.edu>.