Report from Dagstuhl Seminar 16062

Modeling and Analysis of Semiconductor Supply Chains

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Abstract

In February 2016 the Dagstuhl Seminar 16062 explored the needs of the semiconductor industry for better planning and scheduling approaches at the supply chain level and the requirements for information systems to support the approaches. The seminar participants also spent time identifying the core elements of a conceptual reference model for planning and control of semiconductor manufacturing supply chains. This Executive Summary describes the process of the seminar and discusses key findings and areas for future research regarding these topics. Abstracts of presentations given during the seminar and the output of breakout sessions are collected in appendices.

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1 Summary

Chen-Fu Chien
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Complex manufacturing processes are the heart of semiconductor manufacturing. A semiconductor chip is a highly miniaturized, integrated circuit (IC) consisting of thousands of components. Semiconductor manufacturing starts with thin discs, called wafers, (typically) made of silicon. A large number of usually identical chips can be produced on each wafer by fabricating the ICs layer by layer in a wafer fabrication facility (wafer fab). The corresponding step is referred to as the Fab step. Next, electrical tests that identify the individual dies that are likely to fail when packaged are performed in the Probe facility. An electronic map of the condition of each die is made so that only the good ones will be used. The probed wafers are then sent to an Assembly facility where the good dies are put into an appropriate package. The assembled dies are sent to a test facility where they are tested to ensure that only good products are sent to customers. The tested devices are then sent to regional warehouses or directly to customers. Wafer fabrication and probe are often called the front-end and assembly and test are called the back-end.

Supply chain management (SCM) problems have become more and more important in the last decade. This has been caused by the fact that front-end operations are often performed in highly industrialized nations, while back-end operations are typically carried out in countries where labor rates are cheaper. Moreover, there are centers of competencies (e.g. bumping) that may consist of only a few process steps that may be done in a different company owned facility or remotely by a subcontractor. These centers of competencies speed up innovations and reduce costs, but increase the complexity of SCM.

The semiconductor industry is capital intensive with the cost of an entire wafer fab up to nearly $10 billion US caused primarily by extremely expensive machines, some up to $100 million US each. The manufacturing process is very complex due to the reentrant flows in combination with very long cycle times and the multiple sources of uncertainty involved. Capacity expansions are very expensive and time-consuming. This kind of decision is based on demand forecasts for the next years. Because of the rapidly changing environment, the demand is highly volatile. Consequently, the forecast is rarely accurate. The semiconductor industry is an extreme field for SCM solutions from an algorithmic as well as from a software and information systems point of view. The huge size of the supply chains involved, the pervasive presence of different kinds of uncertainties and the rapid pace of change leads to an environment that places approaches developed in other industries under major stress. Modeling and analysis approaches 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 (cf. [1]).

The purpose of this seminar was to bring together researchers from different disciplines including information systems, computer science, industrial engineering, operations research, and supply chain management whose central interest is in modeling, analyzing, and designing complex and large-scale supply chains as in the semiconductor industry. Moreover, practitioners from the semiconductor industry who have frequently articulated their perception that academic research does not always address the real problems faced by the industry brought in their domain knowledge to make sure that progress towards applicability and feasibility would be made during this seminar. The seminar had 26 attendees from ten different countries (see participant list at the end of the report). We had participants from leading semiconductor companies Infineon Technologies and Intel Corp. as well as researchers who work closely with ST Microelectronics, Globalfoundries, and Taiwan Semiconductor Manufacturing Company (TSMC).

A primary purpose of the workshop was to extend the scope of the academic research community from single wafer fabs to the entire semiconductor supply chain. We show the principle architecture of the planning and control system of a semiconductor supply chain in Figure 1.

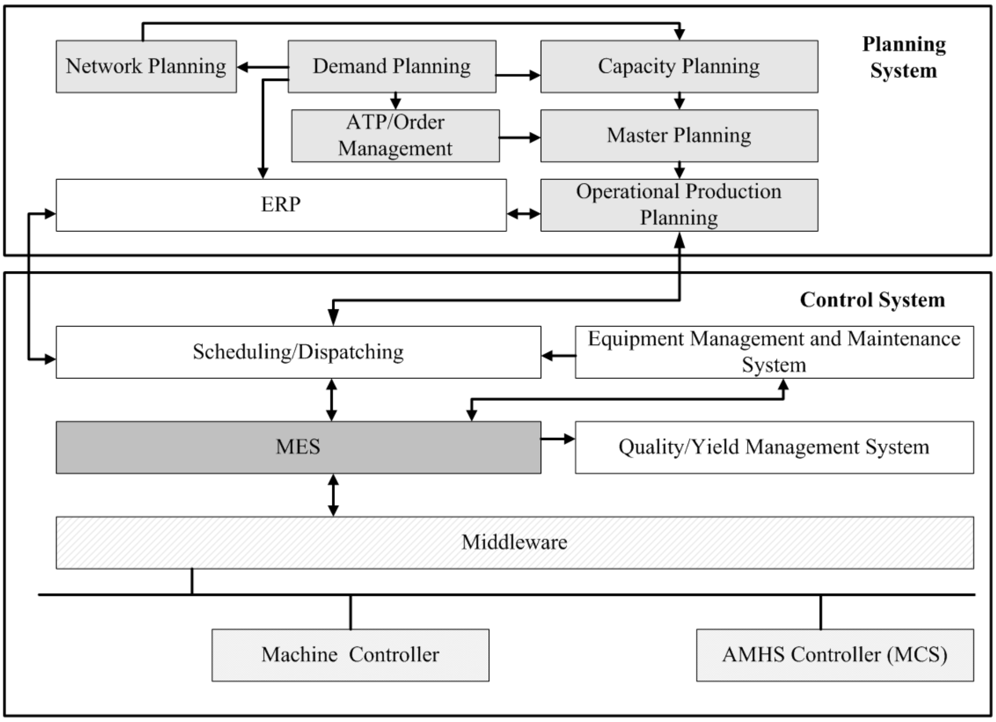

Figure 1 Planning and Control System of a Semiconductor Supply Chain (adapted from [2]).

Seminar Objectives

The first objective of the seminar consisted of developing a research agenda for semiconductor supply chain modeling and analysis topics. This includes innovative modeling approaches for supply chain network planning, demand planning, master planning, and detailed production planning and scheduling in semiconductor supply chains. But it also includes ideas on how to design the related future information systems.

The research agenda was developed around the following two main topics:

- **Topic 1: Novel planning and scheduling approaches that can deal with the complexity and stochasticity of the semiconductor supply chain:**
  - Many planning approaches on the SC-level are based on (distributed) hierarchical and generally deterministic approaches to deal with the sheer complexity of the semiconductor supply chain. The role of anticipation of lower level behavior in upper level decision-making is still not well understood and has to be studied in more detail. Because a semiconductor supply chain contains many different, often autonomous decision-making entities including humans, negotiation approaches are typical in such distributed hierarchical systems for planning and control. It should be researched how such negotiation approaches can be automated and which decisions should be made by humans.
  - The overall cycle times in a typical semiconductor supply chain are on the order of 10 to 15 weeks. Therefore lead times have to be modeled in planning formulations. Using lead times as exogenous parameters in planning formulations leads to a well-known circularity because the cycle time depends in a nonlinear manner on the resource utilization which is a result of the release decisions made by the planning approach.

  Different types of clearing functions have to be researched in the semiconductor supply chain context.
  - Approaches to demand planning that take the product life cycle into account have to be studied. The interaction of demand planning and supply chain planning has to be investigated.
  - Different ways to anticipate stochasticity including robust optimization, approximate dynamic programming, and stochastic programming have to be researched in the semiconductor supply chain context.
  - Different ways to appropriately deal with stochasticity including rolling planning techniques and inventory holding strategies have to be studied.
  - Generation of scenarios and other distribution parameters for planning problems in supply chains using data mining techniques have to be researched.
  - Because of the complexity of supply chains, long computing times still hinder the usage of analytic solution approaches especially for what-if analysis. The role of state-of-the-art computing techniques including parallel computing on Graphics Processing Units (GPU) machines or Cloud computing techniques in decision-making for semiconductor supply chains has to be investigated.
- **Topic 2: Future information systems and supply chain management in the semiconductor industry:**
  - Understanding the limitations of today's packaged software for supply chain management in the semiconductor industry.
  - Proposing alternative software solutions including software agents and service-oriented computing for planning and scheduling applications in the supply chain context.
  - Integration concepts for state-of-the-art computing techniques to get models that are computationally tractable and address the different uncertainties encountered in this industry.
  - Approaches to embed real time simulation techniques in current and future information systems to support decision-making in semiconductor supply chains.
  - Understanding the interaction of human agents with information systems.

The implementation of ERP, APS, and MES systems in semiconductor supply chains provides both an opportunity and the need for development of supply-chain wide integrated production planning and scheduling solutions. Therefore, we think that the second topic is important and should be also addressed in the research agenda. Research related only to the first main topic is not sufficient.

The second objective of the seminar consisted of identifying the core elements of a conceptual reference model for planning and control of a supply chain in the semiconductor industry that can be used for analysis and performance assessment purposes and to foster a common understanding in the research community both in academia and industry. This included specifying reference planning and control activities, the major information flows, and their interaction with a reference system of a physical supply chain. Due to the inherent complexity of semiconductor supply chains it requires simulation of the physical supply chain to understand the interactions between the planning and control components and the physical supply chain, to find solution approaches to problems and to verify them in the risk-free simulation environment before implementing them. There are widely accepted reference (simulation) models for single wafer fabs, mainly developed in the Measurement and Improvement of Manufacturing Capacity (MIMAC) project (led by one of the organizers of this Dagstuhl seminar) 20 years ago that are still used by many academic researchers working with the semiconductor industry.

Existing reference models on the planning and control level like the Supply Chain Operations (SCOR) reference model and the supply chain planning (SCP) matrix are too generic to be useful for detailed analysis and have to be refined considerably to cover the important domain-specific aspects of semiconductor supply chains.

The Process

In the opening session, the organizers welcomed the participants and acknowledged Infineon Technologies as a sponsor of the seminar. Next, the participants each introduced themselves. This was followed by an overview of the goals and objectives of the seminar and a detailed review of the seminar program including the ground rules for interactions.

The remainder of the day on Monday consisted of four industry overview talks (by Hans Ehm, Kenneth Fordyce, Chen-Fu Chien, and Irfan Ovacik) and a review of the literature related to modeling an analysis of semiconductor supply chains (by Lars Mönch and Reha Uzsoy). Tuesday and half a day on Wednesday were devoted to presentations and discussions about the various elements of the semiconductor supply chain planning and control systems shown in Figure 1 above. See Table 1 for a list of topics and presenters and Section 3 for abstracts of the presentations.

Wednesday afternoon was the excursion that was enjoyed by the participants. Thursday was devoted to 3 breakout sessions with report outs on the topics in Table 2. Section 4 has the breakout report outs.

The first set of breakout sessions had four groups focus on the individual elements in Figure 1 and one group focus on a semiconductor supply chain reference model. The second set of breakouts had three groups consider the interaction between various elements in Figure 1, one group talked about the incorporation of humans in the supply chain, and one discussed how to go from the reference model to a specific semiconductor supply chain model instance.

The final Friday set of breakouts included three groups that discussed process models of multiple elements from Figure 1 and the flow of information needed between the elements to provide core elements of a reference model. Another group discussed the role of agents in a semiconductor company's supply chain. The final breakout group discussed the level of detail needed in a top down reference model. Friday consisted of a discussion on the required core elements of a reference model for semiconductor supply chains and a wrap-up session.

Key Take Aways

There were a number of key findings and areas for future research that were identified in the seminar. We will first summarize some of the key findings and will follow this with some areas for future research.

One of the first findings was that the participants generally agreed that the different elements in Figure 1 are reasonably well understood by both the industrial and academic communities, but the interactions between the elements are less well understood. Having said this, a number of the software solutions for the elements are not geared toward the complexities of the semiconductor industry (e.g. ATP/APS systems are generally focused on profit maximization and ignore many of the system complexities). Second, it appears that there are still limitations in solution approaches in practice such as: capacity generally is expressed without regard to mix; fixed lead times are generally still assumed despite research done on clearing functions for planning; and ignoring all but production lots when developing

Table 1 Individual Presentations

Topic	Presenter
Network Planning Demand Planning Capacity Planning	Scott Mason Chen-Fu Chien Adar Kalir
Master Planning Order Release Planning ATP	Thomas Ponsignon Hubert Missbauer José Framinán
Global and Local Decisions Complexity in SCM Inventory Management	Stéphane Dauzère-Pérès Can Sun Jei-Zheng Wu
Semiconductor Supply Chain Contracts Supply Chain Planning Coordination via Planning Sustainability in SCM	Cathal Heavey Ton de Kok Jesus Jimenez
Simulation Modeling for Supply Chains (Distributed) Simulation for Semiconductor Manufacturing (Supply Chain) Decision Making Agent-based Simulation	Leon McGinnis Peter Lendermann Iris Lorscheid

Table 2 Breakout Sessions

Session	Topic	Participants (lead in bold)
1	Demand and Inventory Planning	**Uzsoy**, de Kok, Chien, Missbauer, Lee
	Capacity Planning	**Kalir**, Knopp, Lörscheid, Mönch, Dauzère-Pérès
	Master Planning	Fordyce, Herding, Mason, Ovacik, **Ponsignon**
	Available To Promise (ATP)	**Framinán**, Heavey, Ehm, Tirkel, Jimenez
	Reference Model	**Rose**, Sun, Weigert, Lendermann, McGinnis
2	Demand and Inventory Planning– Capacity Planning– Master Planning	de Kok, Tirkel, Uzsoy, **Dauzère-Pérès**
	Master Planning– Available to Promise	Framinan, **Fordyce**, Herding, Ponsignon, Kalir
	Master Planning– Factory	**Missbauer**, Weigert, Jimenez, Mönch, Knopp
	Incorporation of Human Behavior in the Supply Chain	Ehm, Heavey, Mason, Rose, **Lörscheid**
	From Reference Model to Systems	Chien, Sun, Lendermann, McGinnis, **Ovacik**
3	Process Models Demand and Inventory Planning– Capacity Planning– Master Planning	Kok, Tirkel, Uzsoy, **Dauzère-Pérès**
	Process Models Demand and Inventory Planning– ATP – Master Planning	Fordyce, Herding, Kalir, **Ponsignon**
	Process Models Master Planning– Factory	Missbauer, Weigert, **Jimenez**, Mönch, p
	Agents in the Level 3 Supply Chain	Lörscheid, **Mason**, Ovacik, Sun
	Top Down Reference Model	Ehm, Heavey, **Lendermann**, McGinnis, Rose

plans. Third, as indicated above both the industrial and academic participants generally agree that the integration of the decisions made by the different elements is often fairly ad hoc and could/should be improved. Finally, the participants generally agreed that there does not currently exist an adequate reference model for the semiconductor supply chain. In fact, there is not even a reasonable set of data sets that describe instances of the semiconductor supply chain such as the MIMAC datasets at the factory level. There is some indication that a reference model and incorporating human behavior of the various decision makers on the supply chain level will help to better understand supply chains producing and containing semiconductors.

In addition to the findings mentioned above, several areas for future research were identified. An overarching idea was that the future research should focus more on formulation of appropriate models because this is fundamentally more important than the actual solution techniques chosen. Some of the future research areas are included below:

- Using event-driven process chains (EPCs) to model/visualize planning processes.
- Developing better integration of various decisions made in the elements of Figure 1.
- Combining rolling horizon strategies with demand forecast evolution models.
- Incorporating sustainability aspects into supply chain models.
- Developing stochastic model versions of current deterministic models.
- Incorporating the behavior of human decision makers (this will be useful, but challenging).
- Exploring the use of different simulation paradigms (systems dynamics, agent-based, hybrid models, reduced simulation models) to model and analyze semiconductor supply chains.

Next Steps

As a way to further the discussion of and collaboration on the topics of the seminar, Prof. Lars Mönch, Prof. Chen-Fu Chien, Prof. Stéphane Dauzère-Pérès, Hans Ehm, and Prof. John Fowler are guest editing a special issue of the *International Journal of Production Research* (IJPR) entitled *Modeling and Analysis of Semiconductor Supply Chains*. The deadline for submission is September 1, 2016. This date was selected to allow time for ideas created by the participants of the seminar to be incorporated into papers for the special issue. The Call for Papers can be found at the following address:

http://explore.tandfonline.com/cfp/est/semiconductor-supply-chains-call

Acknowledgements. The seminar organizers would like to thank Infineon Technologies AG for their support of the seminar. The seminar also would not have been nearly as productive without the active contribution of every attendee, and for that the organizers are extremely grateful.

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2 Table of Contents

3 Overview of Talks

3.1 Industry Overview – Modeling and Analysis of Semiconductor Supply Chains

Hans Ehm (Infineon Technologies – München, DE)

The semiconductor innovation race continues, comparing with 6 years ago, many new technologies emerge, which also bring us a lot of challenges. The semiconductor supply chain is characterized by steep ramps, short product life cycles and long cycle times. Especially for companies who are far away from the end customers, the bullwhip effect is more significant and has a huge impact on the supply chain complexity. This speech discusses from Infineon, a company point of view and shares its best practices as well as its challenges on production planning and supply chain management. On one hand, Globalization and Flexibility are effective tools to manage global supply chain; on the other hand, the complexity of manufacturing process and planning is thus increased. The Modeling and simulation techniques become an important lever to solve complex problems and support decision making. A four-level approach is proposed: from the tool and work center bottom level to the end-to-end supply chain top level. A semiconductor supply chain simulation library called SCSC-SIMLIB was thus designed together with academia and implemented, and key objects in each level are developed. Following this structure many concrete examples and various applications within Infineon are given and demonstrated. Finally, the hot topics, e.g., human behaviors analysis, disruption management and change management are highlighted; and the future trends towards the Industry 4.0, IoT, and big data are referred to.

3.2 Supply Chain Management Planning for the Production of Semiconductor Based Packaged Goods Tasks, Purpose, Challenges, and a bit of History A Perspective from Agents of Change in the Trenches

Harpal Singh, John Milne, Ken Fordyce, and Robert Tenga (Arkieva – Wilmington, US)

Joint work of Peter Lyon, Gary Sullivan, Alfred Degobotse, Brian Denton, Bob Orzell

The purpose of any demand supply network is to meet prioritized demand on time without violating constraints and as much as possible meet business policies (inventory, preferred suppliers, request and commit date, etc.). Typically, the demand supply network for the production of semiconductor based packaged goods (SBPG) is divided into FAB and POST-FAB. The dynamic interaction between the two is limited in nature for logical and historical reasons. One reason is the nature of complexity which makes life interesting for planners is different between FAB and POST-FAB. FAB has long routes, reentrant flow, deployment and the ever present shadow of the operating curve – to name a few – generating wafer start / cycle time focus. POST-FAB is faced with constant exit demand uncertainty, allocation of shared components and capacity to competing demands, alternative operations; transport decisions, and the all-important "plan repair" – name a few – generating an exit demand /

efficiency frontier focus. Their differences become clear when examining the nature of the models (from spreadsheets to optimization) supporting decisions and analysis. The purpose of this presentation was to provide overview of the current best practices for central planning and identify computational challenges to reduce the current slack and make these networks more responsive.

3.3 Value Chain & Ecosystem Perspective for Modeling and Analysis of Semiconductor Manufacturing & SCM

Chen-Fu Chien (National Tsing Hua University, TW)

On the basis of my extensive collaborative studies with high-tech industries and the trends I have observed, this talk aims to address emerging research issues, from value chain & ecosystem perspective, driven by the needs in modeling and decision analysis in manufacturing that is enabled by the advances of automation and information technology. Semiconductor manufacturing is one of the most complicated and capital-intensive industries that is driven by Moore's Law for continuous improvements for technology advance and cost reduction. Therefore, high-tech companies are confronting with various decision problems involved in strategy, manufacturing, and technology that are characterized by uncertain (incomplete or massive) information and a need for tradeoff among different objectives and justification for the decisions to align with the overall strategic objectives. In the fully automation production facility such as semiconductor fab, manufacturing intelligence approaches have been developed to model the right decision problems involved in the operations and manufacturing strategies and to extract useful information to estimate the parameters and derive decision rules via data mining to enhance decision quality and production effectiveness. Owing to the advancement of information technology, researchers have developed various data mining methodologies to extract potentially useful patterns through semi-automatic exploration of a huge database in various domains. This talk will also use a number of empirical studies to illustrate the observation and the needs. Finally, we conclude this talk with discussion of the ongoing changes of manufacturing in high-tech industries and the emerging research directions. In addition, since the uncertainty involved in demand forecast is increasingly amplified with the forecast lead-time, high-tech companies often suffer the risks of oversupply and shortage of capacity that will affect the profitability and growth. High-tech industries including semiconductor and TFT-LCD industries are capital intensive, in which the capacity plan and corresponding capital investment decisions are critical due to demand fluctuation. Once the capacity is planned, the company may suffer the risks of either low capital-effectiveness due to low capacity utilization and capacity oversupply, or poor customer satisfaction caused by the capacity shortage. Most of the existing studies focused on solving the long-term capacity shortage issue through optimizing the capacity investment plan, or medium-term capacity plan to allocate demands among the wafer fabrication facilities (fabs) to balance the loading and product mix. Focusing on a real setting, this talk aims to share a proposed systematic decision method to analyze short-term solutions of cross-company capacity backup between the companies in the semiconductor industry ecosystem. In particular, a game theory and decision tree analysis model was developed to support this decision. A case study was conducted with real data of semiconductor manufacturing companies in Taiwan for validation. The results have demonstrated practical viability of this approach. The approach suggested has been implemented in this company. This talks concludes with a case study on the paradigm shifts of Global Unichip to address the issues involved in value chain & ecosystem perspective.

3.4 Master Production Scheduling Journey at Intel

Irfan Ovacik (Intel Corporation – Chandler, US)

In this talk, we discuss the journey that Intel took to build a world-class Master Production Scheduling (MPS) solution. MPS involves decisions as to what each factory in the supply network needs to manufacture, when, and at what quantities so as to meet the demand while minimizing supply chain costs. Most semiconductor companies have elected to use a best-in-class strategy and partnered with solution providers to build their supply chain planning solutions. In contrast, Intel chose to develop its solution in-house. We discuss how Intel decomposed the problem into smaller problems to better align with its strategy and organization boundaries and share the lessons learned during this journey.

3.5 Modeling and Analysis of Semiconductor Supply Chains: Preliminary Results of a Literature Survey

Lars Mönch (FernUniversität in Hagen, DE), Reha Uzsoy (North Carolina State University, US), and John Fowler (Arizona State University, US)

We conduct and report on a literature review of academic and industrial research in the domain of supply chain management in the semiconductor sector. Areas examined include demand planning, inventory management, network design, master planning, production planning, contracts and coordination, supply chain simulation, and involved Information systems. We also briefly discussed research from other domains and future research directions.

3.6 Network Planning

Scott J. Mason (Clemson University, US)

Semiconductor network planning is a challenging problem of great importance. However, not all plans are created equal – a variety of factors that can influence a plan include perspective, level of granularity, objective function(s), and whether or not uncertainty is included. We discuss an industrial case study using both Excel and mathematical optimization to analyze network plans for wafer starts, assembly starts, and test starts to minimize total costs.

We examine target inventory levels, lead times, and capacity constraints to illustrate key trade-offs faced by semiconductor manufacturers.

3.7 Modeling and Analysis of Semiconductor Manufacturing & SCM: Demand Forecast/Planning for Capacity Planning

Chen-Fu Chien (National Tsing Hua University, TW)

Semiconductor industry is capital intensive in which capacity utilization significantly affect the capital effectiveness and profitability of semiconductor manufacturing companies. Thus, demand forecasting provides critical input to support the decisions of capacity planning and the associated capital investments for capacity expansion that require long lead-time. However, the involved uncertainty in demand and the fluctuation of semiconductor supply chains make the present problem increasingly difficult due to diversifying product lines and shortening product life cycle in the consumer electronics era. Semiconductor companies must forecast future demand to provide the basis for supply chain strategic decisions including new fab construction, technology migration, capacity transformation and expansion, tool procurement, and outsourcing. Focused on realistic needs for manufacturing intelligence, this talk aims to share a proposed multi-generation diffusion model for semiconductor product demand forecast, namely the SMPRT model, incorporating seasonal factor (S), market growth rate (M), price (P), repeat purchases (R), technology substitution (T), in which the nonlinear least square method is employed for parameter estimation. An empirical study was conducted in a leading semiconductor foundry in Hsinchu Science Park and the results validated the practical viability of the proposed model. Furthermore, the forecasted demands can be used for capacity planning. Due to constant technology advance driven by Moore's Law in semiconductor industry, multiple production technologies generally co-exist in a wafer fabrication facility with utilization of a pool of common tools for multiple technologies and critical tools dedicated for a specific technology. In semiconductor industry, demand forecasts are rolling and updated when the latest market and demand information is available. This demand forecast mechanism makes forecast errors in different time periods correlated. Because part of the equipment is common for products of different technologies, production managers have limited flexibility to dynamically allocate the capacity among the technologies via capacity migration. The possibility of capacity migration and interrelationship among different technologies make capacity planning difficult under demand and product-mix uncertainties. We developed a dynamic optimization method that captures the unique characteristics of rolling demand forecast mechanism to solve capacity expansion and migration planning problems in semiconductor industry. We also proposed a mini-max regret strategy for capacity planning under risk. We estimate the validity and robustness of the proposed dynamic optimization method in an empirical study in a semiconductor manufacturing company in Taiwan. The results showed practical viability of this approach and the findings can provide useful guidelines for capacity planning process under rolling forecast mechanism.

3.8 Capacity Planning in Semiconductor Manufacturing: A Practical Perspective

Adar Kalir (Intel Israel – Qiriat-Gat, IL)

Capacity planning problems have been researched extensively over the past two decades and still are, even with more intensity, in recent years. In this talk, an industry perspective is provided on the classification of the problems and the evolution in the various solution approaches to these problems. Insight to current and future challenges is also discussed with respect to both strategic and tactical capacity planning.

3.9 Master Planning in Semiconductor Supply Chains

Thomas Ponsignon (Infineon Technologies – München, DE)

Given the specifics of semiconductor manufacturing networks, the development of enterprise-wide planning approaches that are computationally tractable and address the uncertainties typically encountered in this industry remains particularly challenging. This talk focuses on Master Planning in semiconductor supply chains. Master Planning determines production quantities of end-products in a manufacturing network to meet external demands (e.g., customer orders and forecasts) and internal demands (e.g., requests for stock replenishment). A mid-term horizon (i.e., six months) expressed in weeks is considered. The outcome is capacitated production requests. Master Plan details the aggregated Sales & Operations Plan and it is the main input for Site Scheduling and Order Promising. In this presentation, Master Planning formulations and solving approaches as found in the scientific literature and the industry are discussed. Their performances with regard to solution quality, computational burden, and plan stability are outlined. Some insights from a semiconductor manufacturer into a real-world Master Planning approach are showed. Finally, trends and future challenges both for academia and practitioners are presented.

3.10 Optimization-based Order Release Planning

Hubert Missbauer (Universität Innsbruck, AT)

Order release is the interface between the centralized planning of the material flow through the entire logistic chain and detailed scheduling of the work orders within the production units. The presentation deals with multi-period models that optimize order release quantities per product and period based on a descriptive model of the material flow within the production unit that is represented as a network of work centers. We describe models with fixed target lead times as well as models with load-dependent lead times. Their shortcomings and the relevant research issues are outlined.

3.11 Available To Promise (ATP)

José M. Framinán (University of Sevilla, ES)

Available-To-Promise (ATP) systems deal with a number of managerial decisions related to Order Capture activities in a company, including order acceptance/rejection, due date setting, and resource scheduling. These different but interrelated decisions have been often studied in an isolated manner, and even the terminology and models employed differ largely. This communication intends to give an overview of the main contributions in the field and present some open issues for discussion.

3.12 Consistency between Global and Local Scheduling Decisions in Semiconductor Manufacturing

Stéphane Dauzère-Pérès (École des Mines de Saint-Etienne, FR)

Joint work of R. Sadeghi and S. Dauzère-Pérès

The operational level in semiconductor manufacturing can be divided into global (fab) and local (workshop) decision levels. The global level provides objectives or constraints for the local level. Based on previous research, our goal is to develop a framework to simultaneously optimize multiple performance measures and support the consistency between global and local scheduling decisions. A first approach is based on a global rule that aims at ensuring that lots satisfy their time constraints. Numerical experiments on industrial data show the interest of the approach. A first optimization model has also been proposed to take into account multiple constraints and objectives.

3.13 Complexity Management in Semiconductor Supply Chain

Can Sun (Infineon Technologies – München, DE)

Semiconductor supply chain is a complex system characterized by increasing number of interactive and interdependent components with dynamic behaviors working together as an entirety. Many innovative activities occur in the daily supply chain and manufacturing, and these changes inevitably bring in the complexities to the organization. But not all of them are valuable to the business goals. Decision makers want to keep value-added complexity and reduce non-value-added complexity. However, the quantitative analysis of the complexity generated by these components and their behaviors and its impact on the system still lacks practical methodology. Therefore we design a framework to measure the complexity of Semiconductor supply chain. The first step is to understand and represent the complexity using an conceptual model called PROS (process, role, object, state) idea, which provides an understandable and structural way to describe the complexity.., we can thus develop the formulas to measure system complexity based on the metrics of process complexity as well as the properties of complex system. A simplified small real example from semiconductor supply chain is used to demonstrate this approach. It is also noticed that the human plays an important role in the complexity due to its uncertainty behaviors. This is demonstrated and investigated through a classical supply chain phenomenon – the bullwhip effect, which can be demonstrated using a serious game called beer distribution game.

3.14 Inventory Management in Semiconductor Supply Chains

Jei-Zheng Wu (Soochow University, TW)

Joint work of C.-F. Chien, J.-Z. Wu, and H.-C. Yu

The rapid technology development and shortening product life cycle lead to high risk of product obsolescence. Manufacturers still need to hold a reasonable level of inventory to satisfy customers under demand uncertainty and long lead-time. This study introduces the inventory days into the multi-stage inventory model that incorporates with complex BOM, product substitution, wafer release schedules (wafer start), turnaround times (TAT, lead times), production plans, safety stock strategies, and end product-demand forecasts with four banks, i.e., VIA Bank, Wafer Bank, Die Bank, Finished-Good Bank for delayed differentiation and postponement strategy. Survival analysis is used to estimate inventory days and to group products. Inventory ages and accrued provision rates are also added into the model for the compliance with international financial reporting standards, No. 2.

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3.15 Semiconductor Supply Chain – Contracts

Cathal Heavey (University of Limerick, IE)

This presentation presented an introduction to contracts used in Semiconductor Supply Chain. It first presented the purpose of contracts, which are to coordinate a supply chain, the flow of product, information and funds. The presentation then stated that contracts need to be included into supply chain planning as they are a core element of planning in a similar way that inventory control is. The presentation also presented information on optimizing a RHF contract for a semiconductor SC with forecast error. It then presented an introduction to comparing option contracts with RHF contracts. The presentation finally stated that this is an important aspect of semiconductor SC.

3.16 Coordinating the Semiconductor Supply Chain by Planning

Ton de Kok (TU Eindhoven, NL)

Starting from the Eindhoven Framework for Production and Inventory Control (EFPIC) we discuss decision hierarchies and mathematical models used at different levels. The key feature of the hierarchy proposed is the (planned) lead time that enables decomposition between supply chain planning and production unit planning and scheduling. Though stochastic multi-item multi-echelon inventory models produce empirically valid results, they cannot cope with the planning complexities of the semiconductor supply chain. This leads to alternative mathematical programming formulations. We briefly discuss the interplay between APS and human planner and scheduler.

3.17 Sustainability in Supply Chain Management

Jesus Jimenez (Texas State University – San Marcos, US)

Joint work of Tongdan Jin
Main reference V. Santana-Viera, J.A. Jimenez, T. Jin, and J. Espiritu, "Implementing Factory Demand Response with On-site Renewable Energy: A Design-of-experiment Approach", in International Journal of Production Research – Special Issue on Energy-aware Manufacturing Operations, Vol. 53(23), pp. 7034–7048, 2014.
URL http://dx.doi.org/10.1080/00207543.2014.957877
Main reference S. Villarreal, J.A. Jimenez, T. Jin, and M. Cabrera-Rios, "Designing a Sustainable and Distributed Generation System for Semiconductor Wafer Fabs", in IEEE Transactions on Automation Science and Engineering, Vol. 10 (1), pp. 16–26, 2012.
URL http://dx.doi.org/10.1109/TASE.2012.2214438
Main reference L. Sanders, S. Lopez, G. Guzman, J.A. Jimenez, and T. Jin, "Simulation of a green wafer fab featuring solar photovoltaic technology and storage system", in Proc. of the 2012 Winter Simulation Conference (WSC), pp. 1–12, 2012.
URL http://dx.doi.org/10.1109/WSC.2012.6465269

The high-tech facilities used for the fabrication of semiconductor wafers consume a significant amount of electricity. The impact of energy consumption on climate change and the rising cost of energy have become a challenging issue facing the semiconductor manufacturing industry today. ITRS urges chip manufacturers to reduce carbon footprints by designing and deploying green and sustainable manufacturing facilities. The focus of this presentation is to present opportunities for the supply chain in semiconductor manufacturing. We studied the penetration of renewable technology in wafer fabs and identified the costs of these systems. We measure carbon emissions and probability of black outs. Future research is the development of models that measure carbon dioxide savings across the supply chain.

3.18 What Is a Reference Model and What Is It Good For?

Leon F. McGinnis (Georgia Institute of Technology, US)

Semiconductor supply chains are very complex, distributed, and dynamic systems, and it is simply not possible to make important decisions about designing, planning, or controlling them without computational decision support. Today, a grand challenge is to make that computational support as ubiquitous as using Google Maps on your mobile phone to find the short route from Frankfurt to Schloss Dagstuhl. In the status quo, however, these computational decision support tools require a great deal of customization for every different decision maker. So how do we change that?

An approach that holds great promise involves adapting two key concepts from computer science. The first is meta-modeling, or the creation of reference models of the domain of interest. These reference models can be articulated using languages like UML, its variant, SysML, or related Ecore, and define the semantics and to some extent the syntax for describing instances of problems in the semiconductor supply chain. The second is model-to-model transformation, which allows us to capture the "algorithm" for translating one model – say a formal model of a problem instance in the semiconductor supply chain domain – into another model – say a large scale optimization for planning the production and logistics for device manufacture over the next six months. Once these models are generated, there are many solvers that can be used effectively to compute solutions.

This presentation argues for the importance of meta-modeling and model-to-model transformation as keys for bringing academic research results into semiconductor supply chain practice faster, and more reliably.

3.19 (Distributed) Simulation for Semiconductor Manufacturing (Supply Chain) Decision-Making

Peter Lendermann (D-SIMLAB – Singapore, SG)

The presentation describes a number of challenges associated with the use of distributed simulation for decision-making in semiconductor supply chain management such as the heterogeneity of external drivers of such supply chains, the need of representing planning decisions and human decision-making as well as the constraints arising from time synchronization between the different federates of such a simulation system.

Additional challenges are arising from the fact that in a real fab environment product mix changes continuously and operations are never in steady state. To address this the author is advocating a simulation-based WIP Management approach, allowing a great reduction of variability in fab operations. One of the current research questions is whether this kind of variability reduction can also be reached on the Semiconductor Supply Chain level. This would obviously depend on which specific use cases are relevant on the Supply Chain level and which regular SCM decisions are to be enabled. As of now the within-echelon Semiconductor SCM challenge, i.e. the Borderless Fab, appears to be the most promising next application.

A number of key learnings have evolved from the author's experience with real-world semiconductor manufacturing systems and supply chains: In particular, there is no need to find an optimum because a real optimum can only be found with a perfect model. In reality it is sufficient to find a "considerably better" solution as fast (i.e. with as few iterations) as possible. This can be achieved through "smart" heuristics and enabled by a parallel computing infrastructure. It is essential though that constraints are portrayed as much as possible because otherwise "solutions" will be generated that are infeasible in practice and managers will lose trust in the enabling software tool. For this reason the Discrete Event Simulation approach can be quite powerful, however, automation is key not only for "analysis" but also for "modelling" including model verification and model maintenance as well as data calibration. Otherwise it would not be possible neither to keep up with the fast-changing real world operations nor to carry out "routine" analysis instantly and at zero (variable) cost.

3.20 Agent-based Simulation

Iris Lorscheid (TU Hamburg-Harburg, DE)

Agent-based simulation may provide new perspectives on supply chains from three angles: analyzing the supply chain as an emergent system resulting from individual interactions, incorporating the uncertainties caused by human behavior, and using artificial agents to find new designs or strategies. The first perspective models individual (inter-)actions in complex systems and analyzes the resulting system behavior. This provides an understanding on self-organizing processes and emergent phenomena that are not explicitly modeled or even understood by the modeler. By analyzing the human factor in supply chain planning processes, the second perspective, good or bad individual strategies may be observed, their effect analyzed, and the decision maker environment designed in a way that those are promoted or prevented. Artificial agents, finally, may help to optimize complex system by optimizing individual strategies by means of machine learning algorithms.

4 Breakout Reports

4.1 Demand and Inventory Planning

***Reha Uzsoy**, Ton de Kok, Chen-Fu Chien, Hubert Missbauer, and Peng-Chie Lee*

The purpose of demand and inventory planning is to create reliable forecasts of demand for the portfolio of products offered by a semiconductor manufacturer and to determine the amount of inventory needed to buffer against the inevitable demand uncertainty. Effective demand planning can guide companies to improve the accuracy of revenue forecasts, align inventory levels with peaks and troughs in demand, and enhance profitability. In today's environment, utilization is the "name of the game" since fab investment is the main cost component, but is mostly a sunk cost and has a long lead time to add capacity. Backend utilization is also important, but is generally not quite as important because the equipment is not as expensive and has shorter lead times to purchase. In addition, many companies subcontract backend operations. Overall, there are low marginal costs to meet demand and therefore profit margins are often relatively high for satisfying additional demand.

As seen in Figure 1, the output of demand planning provides inputs to both network planning (strategic needs) and capacity planning (tactical needs) in regards to likely future demand. It also provides inputs to the available to promise (ATP) system in terms demand expected in the near term. In some companies (such as TSMC), the demand planner uses data and models along with tacit knowledge to act as a middle man in consolidating regional sales plans, correcting for correlations between products, and in communicating with capacity planning.

There are a number of things that need to be done to improve the overall effectiveness of demand and inventory planning. First, it would be helpful to develop swim lane schemes of the relation between sales planning, demand planning and capacity planning. Second, even though utilization determines long-term planning, the short-term match of supply and demand requires new ATP functionality, in particular the need for better allocation schemes during tight demand is very important. Third, there is a need to better integrate production planning and inventory planning. As researchers investigate these issues, the focus should be on problem formulation, not on algorithm development and should keep in mind that determining the correct cost structure is key to arrive at the right solution. Finally, there is a need to distinguish between fabless companies, foundries and fab owners.

4.2 Capacity Planning

***Adar Kalir**, Sebastian Knopp, Iris Lörscheid, Lars Mönch, and Stéphane Dauzère-Pérès*

Capacity planning incorporates planning for future capacity to ensure that capacity is available for production planning (tactical) and adjusted for forecasted demand (strategic). Capacity planning is fed from the aggregate planning and feeds into the master planning. The following decisions are addressed by capacity planning:

- equipment changes (buy, convert, qualify)
- feasibility check for the production plan (capacity-wise, not schedule)
- wafer start quantities per period by product (aggregate, not fab level)
- performance expected (production cycle time)

Figure 2 shows where capacity planning is located in the production planning and scheduling hierarchy.

The following objective function is maximized:

- profit (revenue – cost)
- cost (wafer cost, unit cost, backlog and inventory cost)

Risk minimization is also considered. The different types of capacity planning problems are summarized in Figure 3.

The following input data is used for capacity planning:

- planning horizon and time bucket
- demand plan (after smoothing) per product over planning horizon
- current equipment, and capacity by fab

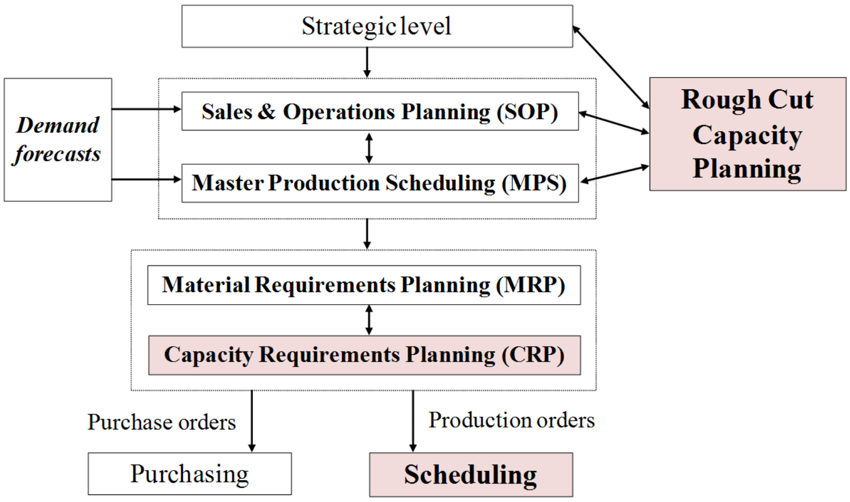

Figure 2 Capacity planning in the planning and scheduling hierarchy.

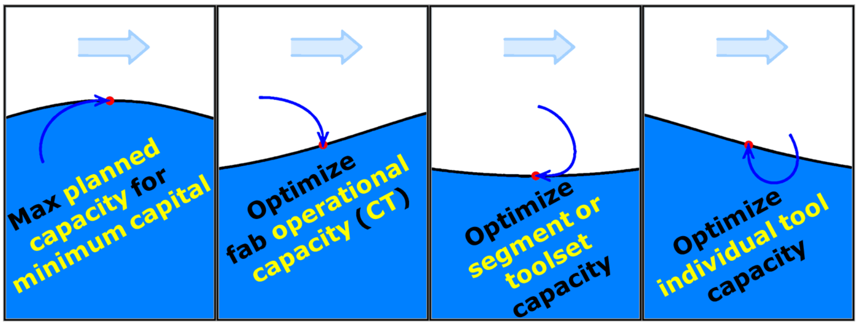

Figure 3 Mapping of Capacity Planning Problems.

- equipment data (RR, operations, ... – per product)
- capacity factors (dedications; setups; batching; ...)
- financial data (equipment value, wafer cost per fab)
- budget for expansion

The interface with network/demand planning is demand forecasting by product over time. The impact of multi-fab capacity is not considered. Typical modeling types are Excel for static considerations, MILP for deterministic settings, and simulation and stochastic programming for a stochastic setting.

Next, limitations of the current state and future needs are discussed. The hierarchy enforces 'independent' problems. However, capacity planning must be considered in the network/demand planning phase. Another imitation is the limited model accuracy because of time bucketing, the estimation of operational decisions such as setup, batching, QT, storage and transportation (especially for older manual fabs), reticles, etc., the deterministic nature of the forecast (point forecasts vs. the real dynamic nature of actual demand) and sensitivity to the impact of product mix. Current approaches are limited to production lots, often ignoring all other type of non productive wafer (NPW), engineering activities, new product introduction (NPI). The quality of the input data (typically aggregated) is crucial, this is especially true for scenarios for stochastic planning. APC/AEC and dedication schemes are not captured at all yet. Capacity planning is not adapted to the evolving SC in semiconductor industry. The dynamics of changing production across fab locations, cross-processing between fab locations, etc is not considered. A consideration of the impact of multi-fab capacity is important. In future modeling, agent-based simulation, game theory, and nonlinear programming are important ingredients for addressing new complexities. Moreover, rolling horizon approach are expected to be desirable to model decision-making changing over time.

The following issues have to be addressed in future research. From an industry point of view, considering NPW, engineering activities, and NPI in capacity planning is important. Moreover, getting refined model accuracy is desirable. The impact of multi-fab capacity has to be considered. From an academic point of view, getting more accurate models is one goal. Rolling horizon approach, capacity planning for the evolving SC, and considering the impact of multi-fab capacity are important future directions for academic research.

4.3 Master Planning

Kenneth Fordyce, Raphael Herding, Scott Mason, Irfan Ovacik, and ***Thomas Ponsignon***

Definition and Scope

Master Planning determines production quantities of end-products in a manufacturing network to meet external demands (e.g., orders and forecasts) and internal demands (e.g., requests for stock replenishment). A mid-term horizon (i.e., six months) expressed in weeks is considered. The outcome is capacitated production requests. The master plan details the sales & operations plan and it is the main input for site scheduling and order promising.

Current state-of-the-art

Most semiconductor manufacturing companies blend commercial solutions (e.g., JDA) and home-grown solutions (e.g., Intel). Regardless of the approach, most firms have operations research experts for development and analysis. The solution approaches typically involve solvers, which may be based on optimization techniques and/or rules-based heuristic approaches (e.g., forward-and-backward demand-supply assignment). A combination of optimization techniques and heuristic methods is frequently used in the industry. Software developers are key for the implementation and the deployment within a company (e.g., UI, data integration).

Inputs to Master Planning

Master planning requires the following inputs: the structure of the supply chain, demand signal, information on capacity, current inventory and work-in-progress levels, safety stock targets and policies, and the existing or previously generated master plan. The structure of the supply chain includes details on which products can be produced where, bill-of-material information, geographical information, details on available equipment as well as planning parameters such as lead times and planned yields. The demand signal is expressed as point estimates and capacity is often stated in gross terms (e.g., total starts per technology per week, hours of loading on a tool group).

Outputs from Master Planning

Master planning provides expectations or targets of what is required from each factory over time. It also states what each factory is expected to receive over time and from where. These outputs can be summarized as the current projected supply, which is provided to Available-to-Promise (ATP) usage and production planning processes. In some firms, the master plan may be a starting point for manual adjustments.

Limitations

Capacity statements are often given without consideration of mix. Furthermore, no common standard is available for describing capacity. The assumption of fixed lead times are here to stay as they are often politically influenced. This leads to input factors being conservatively stated. Deterministic point estimates do not capture the uncertainty of the base system. Hence, safety stock buffers for yield and demand variations may be overstated. As a result, potential opportunities may be lost. The interpretability remains a major limitation especially when optimization techniques are used to solve the master planning problem. Besides, little is known about the recommended plan granularity and model accuracy (e.g., time bucket specification).

Future steps

Directions for further research include: investigating which solution procedure works best in which situation, examining the usage of blended optimization and heuristic solution methods, Incorporating risk assessment into master planning models, and tightening model integration with data sources and other models.

4.4 ATP

José Framinán, *Cathal Heavey, Hans Ehm, Israel Tirkel, and Jesus Jimenez*

ATP it is all about confirming customer orders. The product the customer/channel is ordering determines the granularity. A "contract" with customer, the Operations, one initial negotiated price, and the heuristic of the implemented APS are prerequisites.

Continuously updated capacity, inventory, committed forecast/order, requests for confirmation are important input data. Here, capacity means supply in a two step process where supply is generated from capacity.

The following activities are required:

- check Inventory
- check Supply
- use Alternatives
- continuous assessment of confirmation process.

Response to forecast/order and rigger for capacity increase are outputs. Next, the current situation in companies is discussed. ATP usage systems (most of the time called APS and developed outside the semiconductor industry) are in place. Online data for the ATP usage system is already available at some semiconductor companies. ATP usage systems used in

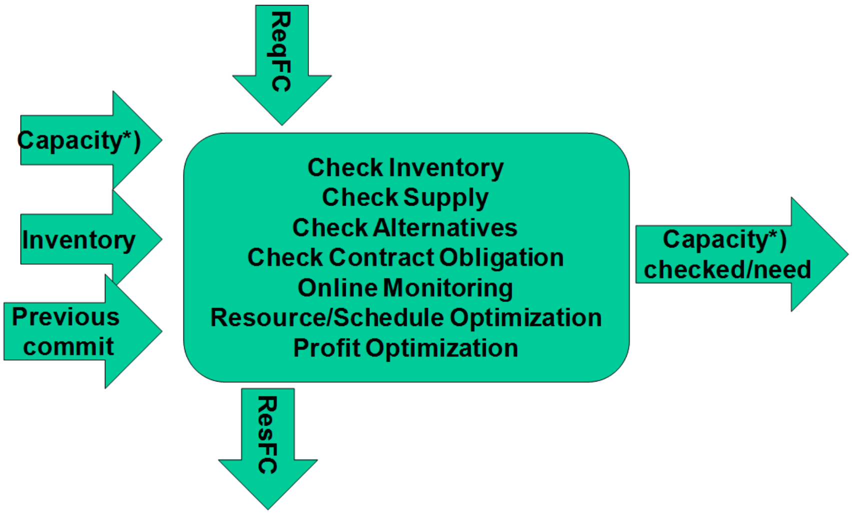

Figure 4 ATP Usage System.

the semiconductor industry are far from optimum. APS systems are optimized towards profit optimization and lack capacity/supply complexity need of the semiconductor industry. The full usage of resources is key for semiconductor companies. The main functionality of an ATP usage system is summarized in Figure 4.

The following future needs are identified:

- Make all data needed online available for an ATP usage system (at some companies available).
- Optimize the resources, and optimize the schedule (the heuristics in the ATP usage system).
- Make use out of the profit optimization in available ATP usage systems, i.e. short term benefit, mid term benefit, long term benefit.
- Measure the benefit.
- Measure the stability of the system.

4.5 Reference Model

Oliver Rose, Can Sun, Gerald Weigert, Peter Lendermann, and Leon McGinnis

The question what is a reference model is discussed first. The MIMAC data sets are instances that conform to some (unstated) reference model. A domain specific language (DSL) conforms to a reference model. A DSL is specified by symbols and rules and has a well-defined semantics. SCOR is "part of" a reference model, however, there are possible issues with precision of semantics definitions.

Next, the state of the art for supply chains is discussed. SCOR is more like an agreement how to present KPIs, it has a very simple process model. SAP (ARIS), Oracle are used for company-specific SC software design, but is not public. There exist various custom models.

Very general approaches are offered by OMG that are mainly from/for computer science. There are tools such as MOF, UML, SysML, BPML.

The following limitations exist. The motivation for developing a reference model is with respect to ROI not clear. Appropriate tools and tool chains do not exist or have some limitations. Some inertia with respect to reference modeling can be observed in organizations. The awareness of reference modeling issues by possible stakeholders is limited.

A SCSC DSL and tools (mock-ups) are identified as possible output of future research activities. This includes appropriate demos. The focus is on the internal supply chain (third level). Applying for Horizon 2020 projects (maybe only as a hidden agenda of a project) might be a future step. A core working group/task force (driven by industry needs) is highly desirable. A conference track or a journal special issue can be organized.

4.6 Demand & Inventory Planning – Capacity Planning – Master Planning

Ton de Kok, Israel Tirkel, Reha Uzsoy, and ***Stéphane Dauzère-Pérès***

Figure 5 shows the connections between the three planning modules, where capacity planning is actually divided into medium-term and long-term capacity planning.

Table 3 specifies various elements that characterize the planning modules.

Some comments are given below that are important in understanding how these planning decisions are performed:

- The role definition (in particular incentives), behavior and expertise of planners strongly impact the decision process,
- Delays (to get information and take decisions) are often non negligible (hours or days) and prevent the decision process to be conducted in real time,
- The informal communication among planners, sales, production and customers is critical to take informative and acceptable decisions.

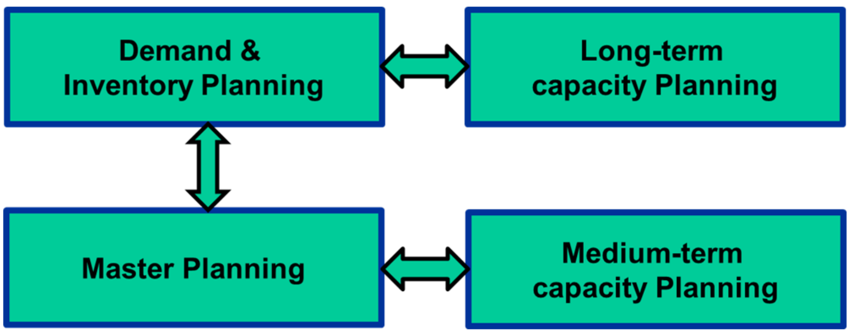

Figure 5 Relationships between planning modules.

Table 3

	D&I Planning	Capacity Planning		Master Planning
Input	Forecasts and orders	**Long term**: S&OP, aggregate capacity parameters	**Medium term**: MPS, detailed capacity parameters	Aggregate plan (S&OP) and orders
Output	Aggregate plan (S&OP), safety stocks	Projected capacity plan	Projected capacity plan	Master Production Schedule
Feedback loops	With Sales, with Capacity planning and with Master Planning	With D&I Planning and medium-term capacity planning	With Master Planning and Production (PP&S)	With everybody...
Granularity	One year or more with monthly / weekly buckets	One year or more with monthly / weekly buckets	6 months with weekly / daily buckets	6 months with weekly / daily buckets
Frequency	Monthly	Monthly	Weekly	Weekly
Tools	Multi-echelon inventory models, Statistical and qualitative forecasting	Stochastic models, LP models, MILP models	Stochastic models, LP models, MILP models, heuristics	LP models, MILP models, heuristics
Simulation	Appropriate at all levels in different ways			

4.7 MP & ATP

*José Framinán, **Ken Fordyce**, Raphael Herding, Thomas Ponsignon, and Adar Kalir*

The Central Planning Process (CPP) to manage the end to end demand supply network (DSN) for the production of semiconductor based packaged goods (SBPG) is focused on understanding and capturing exit demand, intelligently matching assets (WIP, inventory, and capacity across the network) to create a projected supply line linked to demand and synchronizing (but not scheduling) activities across the DSN.

Figure 6 has a high level summary of the core components in CPP and their relationship. The "order handling activity" (where ATP occurs) captures the requests of products (orders) from customers. An incoming order is either accepted and given a commit date or identified as pending further review. Orders (accepted and pending) are sent to the "demand and inventory planning activity" where a comprehensive statement of exit demand is established. This demand statement is sent to the "master planning activity" which matches assets with demand to create a projected supply line linked to demand. This is the basis for the commit decision – that is what product, in what quantity, can be committed to the customer or made available for the 'automatic' ATP process – that is when a commitment is made without going through the master planning process.

Although there are differences between firms, this is the basic process. Potential areas of

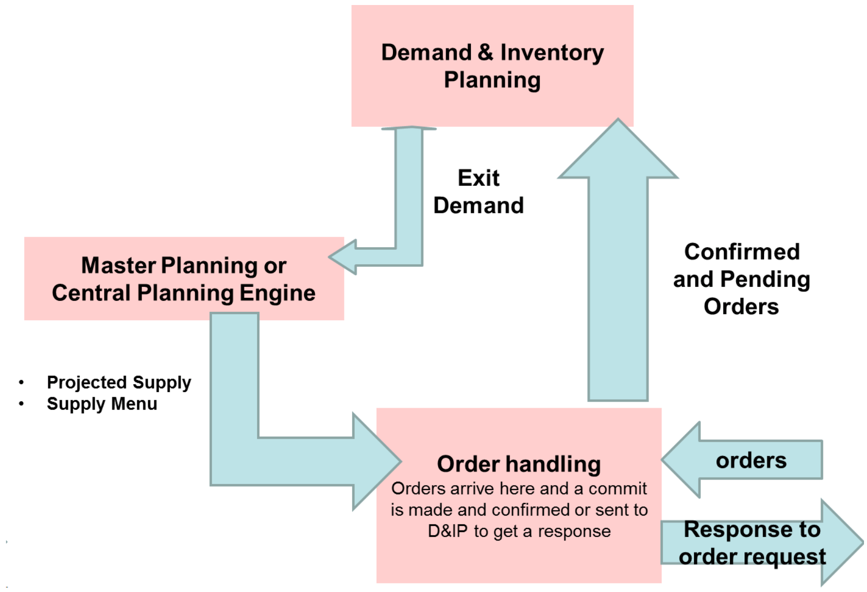

Figure 6 Summary of Master Planning and ATP flow.

improvement that will positively impact a firms' responsiveness are:

1. Improved flexibility in the projected supply used by the ATP, especially with regards to level of personalization. For example, assume I make T shirts in three colors: red, blue, and white – where red and blue shirts are made from white shirts going through an end step of dying and heating. I might project 100 reds, 100 blues, and 200 white as supply, but until the dye is done, this can be modified. Going a step back to material, until the shirt is cut, I have options to convert large to small, small to medium, etc. Often this flexibility is only captured if the in the master planning or central planning engine activity
2. On the order receiving side – being able to capture the "confidence"that the customer order is firm and using that within planning process would be most beneficial – that is how to incorporate uncertainty without creating confusion.
3. Faster and more intelligence central planning engines would be very beneficial – creating tighter coupling.

Figure 7 provides a more detailed view of the key components in master planning and ATP to create a projected supply linked to demand and synchronize the activities of the demand supply network (DSN), and planners workbench. From an operations research perspective, the most significant technical achievements occurred in the CPE (Denton et al., 2006 and Degbotse et al., 2013). Fordyce et al. (2011) has the best overall description of Order Planning System (OPS). The business contribution of OPS is covered in Lyon et al. (2000), Denton et al., (2006); and Fordyce (1998 and 2001). The work done by IBM in collaboration with Arkieva on demand management captured a critical paradigm shift that successful demand management was about a single integrated and flexible view of the key data sources (orders, forecast history, shipping, etc.), capturing sales estimates, collaboration, and developing insight – where statistical forecasting methods was just one component (Fordyce and Sullivan, 2016); this approach has carried forward to become best practice. Today the features and functions in OPS are standard best practice.

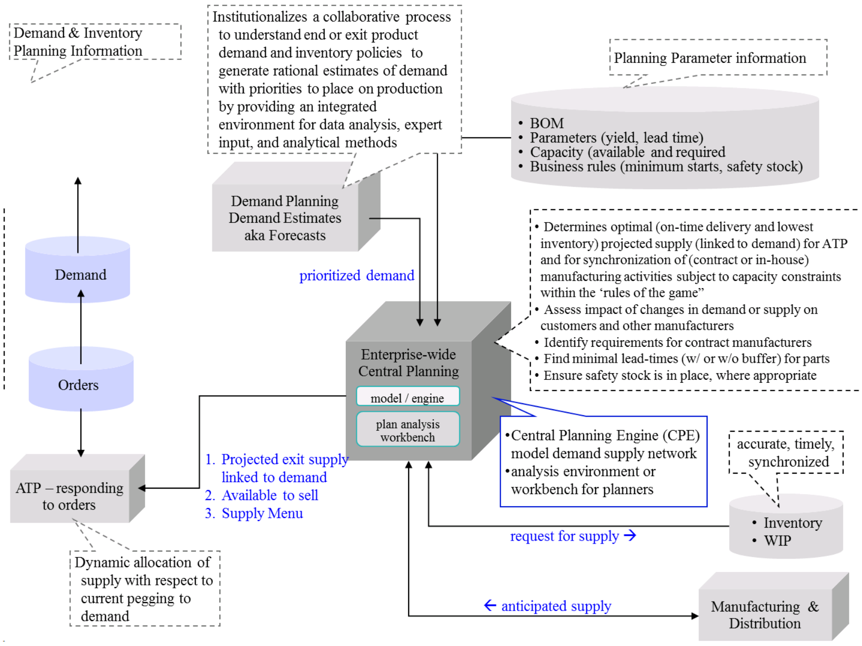

Figure 7 Detailed Components and Flow for Master Planning and ATP.

4.8 MP & Factory

***Hubert Missbauer**, Gerald Weigert, Jesus Jimenez, Lars Mönch, and Sebastian Knopp*

Interface to Master Planning (MP)

"Master Planning provides expectations or targets of what is required from each factory over time." (Master Planning – Breakout I). That is, quantities to be finished per product, period (usually weeks) and production unit (e.g., Fab, A/T, DC). Also the allocation to demand classes (e.g., customer order driven vs. forecast driven) which might affect the priorities.

The subproblems in order to finally arrive at a satisfactory schedule are the following:

- Split up the MP quantities into production lots, defined in terms of product, lot size and required due date in days. Both backward scheduling and forward scheduling should be possible.
- Order release (planning), where an order is a production lot. The extent to which releases are planned for several periods depends on the applied method (short-term release mechanisms vs. multi-period release planning). At this point the relationship between required output, target WIP and flow time norms must be considered. The underlying model of the material flow through, e.g., the fab is crucial. Target flow times can be fixed or load-dependent (see presentation Hubert Missbauer). Flow time anticipation using flow factors assumes strong correlation between processing time and flow time of an operation which is not always given. Order release usually is performed periodically. This can be complemented by event-driven releases (e.g., if otherwise machine idleness would occur), depending on the release mechanism.
- Due to the complexity of the material flow within a fab a global scheduling level ("Lot Planning") is required – setting intermediate due dates for production phases (work

centers or groups of work centers). This requires an overview of the whole fab which the local dispatchers do not have. (See presentation Stéphane Dauzère-Pérès.) End-of-horizon effects can occur, this requires look-ahead-feature.

- Based on the intermediate due dates for the released lots, detailed scheduling – dispatching is performed locally per production phase. This is often rule-based and requires extensive knowledge about the production process at this stage.
- Feedback (MES): The state of lots and work centers must be known at each time. This feedback information is transferred to the respective decision levels. In any case this must be the release level since load-based release requires accurate state information. Which decision level should react to unplanned events (e.g., machine downtimes) is a difficult question; as a general rule it should be the lowest possible level. Minor disturbances will just affect the dispatching level whereas major machine downtimes might even affect capacity and master planning.

Additional remarks

There are groups of wafers that share the first n operations; sometimes these base wafers are stored in order to benefit from variability pooling. This is an adaptation to individualization of customer needs. We discussed if it makes sense to formalize this and to declare the base wafers as SKUs (which implies a second release decision at this point).

Lot-to-order matching is an important task. How to assign this task to planning levels requires further discussion.

4.9 Incorporation of Human Behavior in the Supply Chain

Hans Ehm, Cathal Heavey, Scott J. Mason, Oliver Rose, and ***Iris Lorscheid***

The aim of this seminar is to provide a reference model that describes the structure, processes, and basic skeleton of a supply chain in semiconductor industries. However, this reference model not includes a relevant complication, which follows from the uncertainty of human behavior within supply chains. Thus, complementing to the reference model, we aim for incorporating human behavior by exploring ways to identify relevant individual behavior and understand their effect on supply chain performance.

First, the identification of individual strategies clarifies the existing individual deviations. Also, we aim to reveal (informal) interactions that proofed to support the quality of decisions and were therefore implemented by individuals. A simulation model may analyze circumstances that extend rational behavior, and aspects that may hinder rational behavior. Simulation experiments may quantify the risks for supply chain performance caused by less rational behavior.

Overall, we aim for improving the circumstances to support good decisions of planners. Knowing about favorable individual behavior, we may relate this to the right level of education that is required for the decision makers. Results can define criteria for recruiting with regard to technical and soft skills, and identify training requirements. By learning about the effect of varying strategies, the awareness and sensitivity to acknowledge (un-)favorable aspects of individual behavior can improve. In the end, we aim to avoid negative human subjectivity.

The first important step is to understand what humans actually do in our supply chains to understand the relevance: Where is the "Ron" in the model? As we know, Ron may have individual interests, for which he under- and over-estimates, and thus potentially behaves rational in his own interest but not rational for the company. In particular within demand, capacity, or master planning we observe persons who may "pre-process" data by adjusting regulation screws that improves individual planning result, such as by adapting demand, capacity, yield, or – as common example – lead time. We see events where undesirable behavior happens, and cases with undesired consequences. Also extreme cases such as hyper-optimistic or hyper-conservative planners are observable. Next to the planning scenario, other perspectives on the supply chain incorporate human behavior, such as negotiations between sales persons and customers and their effect on (un-)successful pricing, and order behavior by customers resulting in varying demand patterns.

We see some challenges for incorporating human behavior. First, the design of incentives can be relevant, so that individuals behave in the interest of the company rather than choosing fast and easy moves when fulfilling their tasks. Nevertheless, the design and successful implementation of incentives is challenging. Next to unfavorable behavior, we know about individual strategies that really stabilizes the supply chain. In compliance, for example, individual adaptations are necessary to fulfill the compliance challenge on the one hand, but be right for the internal processes such as product planning on the other hand. Thus, we know that individual behavior may work in certain circumstances but may lead to damage in others. The question is: How many Rons (or "Hans") do we need to keep the system running?

A further challenge with regard to collecting data for the identification of human behavior can be the identification of the "real" human factor that leads to the respective individual strategy of interest. Dominant factors such as experience, age, or seniority may prevail other aspects.

As concrete next step we propose to create a list of individuals that have an impact on the supply chain, with a description of why and how they have an impact. The definition of cases with positive and negative effects of human interactions on supply chain performance may clarify the relevance of incorporating human behavior. We expect that positive cases of individual strategies will include situations comprising complications such as innovations or complex tasks. Also, a literature review about similar studies about the effect of human factors on performance may support the research process.

4.10 From Reference Model to Systems (the SC System in 20201)

Chen-Fu Chien, Can Sun, Peter Lendermann, Leon F. McGinnis, and ***Irfan Ovacik***

The Reference Model for the Semiconductor Supply Chain contains a set of objects and the relationships between those objects, along with behaviors and controls that describe how the Semiconductor Supply Chain changes/evolves over time. These objects, behaviors and controls are described using a Domain Specific Language.

The Reference Model can then be used to instantiate/describe the physical supply chain of any semiconductor company. We refer to this as the Model Instance.

In academic settings and in practice, we usually talk about Math Programming, Queuing, or Simulation Models. In practical settings, we also find these models embedded in planning applications, wrapped with system and user interfaces. We will refer to these as Analysis Models. Each Analysis Model consists of inputs, algorithms, and outputs and targets a specific business decision.

Today, each Analysis Model potentially assumes a different Reference Model. For example, a JDA application may assume a different Reference Model than an SAP module even though each serves the same business function. Therefore, there is no guarantee that an Analysis Model that works in one setting will work in a different setting without considerable effort. Similarly, there may be considerable different effort to implement a JDA application than an SAP module in the same company.

In the long term, once a Reference Model for the Semiconductor Supply Chain is in place, then each Analysis Model in the environment is expected to conform to the Reference Model. Each Analysis Model can use a subset of information available in the Reference Model or an abstraction of it. For example, a Production Planning and Scheduling model would only use the relevant information for the Back End Supply Chain or a Master Planning model would treat each factory as an abstract black box, ignoring the details of each factory. In both cases, the Analysis Model would be consistent with the Reference Model. To the extent that the Analysis Model conforms to the Reference Model, then the model would be reusable whether it is interfacing with a Model Instance associated with company A or the Model Instance associated with Company B.

4.11 Process Models Demand and Inventory Planning, Capacity Planning, Master Planning

__Ton de Kok__, Israel Tirkel, Reha Uzsoy, and Stéphane Dauzère-Pérès

The relations between demand planning, inventory planning, capacity planning and master planning

We considered the recurrent communication between Demand and Inventory Planning (DIP), Capacity Planning (CP) and Master Planning (MP) at monthly and weekly frequency. Starting with monthly regional sales forecasts, which are consolidated into product forecasts by a demand planner, DIP communicates monthly with CP to agree on a long-term capacity and sales plan. This process is iterative as capacity may not be able to accommodate the initial sales plan. This results into updated regional sales plans which are input for MP. We realized that our process is closely related to the TSMC process, which focuses on wafer production. Companies with an integrated front-end and back-end start from customer sales plans at SKU level, which is consolidated with respect to resource requirements and possibly to SKU requirements in case multiple customers need the same IC. But similarly the long-term consolidated sales plans must be translated into long-term capacity requirements by capacity planning. A similar iterative process leads to updated customer (or regional) sales plans, which are input for MP.

MP processes the sales plans and derives time-phased key component requirements and key resource requirements. The latter are discussed with CP to check if mid-term the required resources are available. Again, an iterative process yields an updated MP, which is

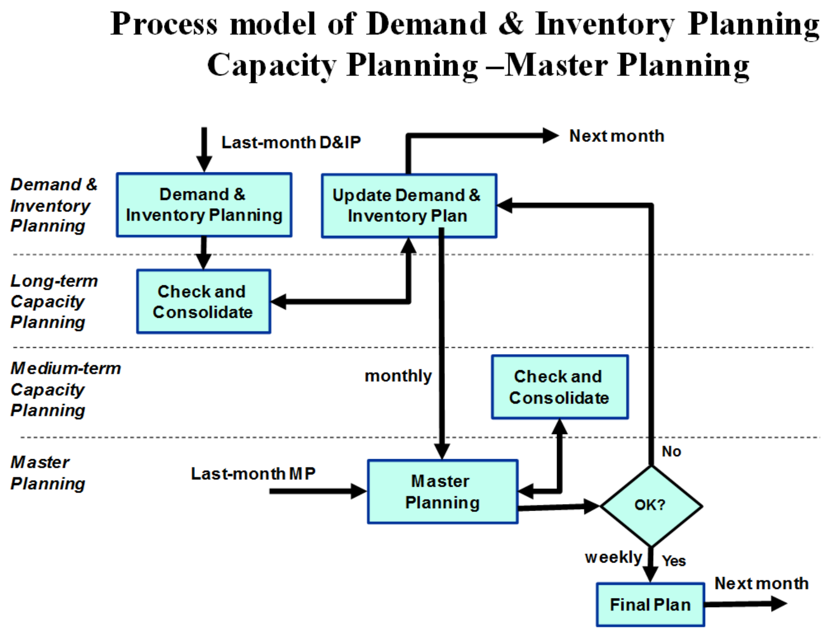

Figure 8 Process Modell Demand & Inventory Planning, Capacity Planning, Master Planning.

communicated with sales. This may lead to mid-term adjustments to the sales plans. This process repeats itself weekly.

We closed the loop by using the sales plans and masterplans of the current month as benchmarks for the sales planning and capacity planning for the next month.

4.12 Process Models Demand and Inventory Planning, ATP, Master Planning

Kenneth Fordyce, Raphael Herding, Adar Kalir, and ***Thomas Ponsignon***

Event-driven process chains Demand Planning – Master Planning – ATP Usage

New orders enter via the Order Handling System. A new order entry triggers the provision of confirmed and pending orders to Demand Planning. Demand Planning involves collaborative process/human activities. It is typically run according to time-scheduled events. The output from Demand Planning is a Demand Outlook, which is provided to Master Planning. Master Planning accepts further inputs from Capacity Planning and Production Management that are not represented on this chart. Master Planning involves a solver. The output is a projected supply or a supply menu (i.e., available supply with a set of conditions such as pricing and given lead times) depending on the business model of the company. The supply picture is provided to the ATP Usage, which involves an Order Promising System. The ATP Usage activity is usually run according to an order fulfilment event. It results an order response that is sent to the customer. Further information may be added to the process flow

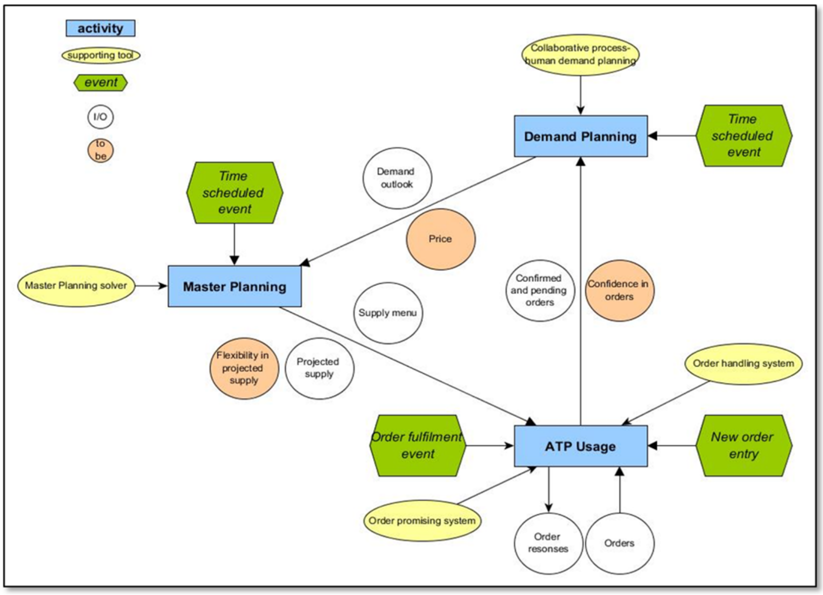

Figure 9 Process Model Demand Planning – Master Planning – ATP Usage.

to facilitate the decision-making: confidence in orders may help to capture the uncertainty of demand; price may support the prioritization of demand items in Master Planning; and Flexibility of projected supply may support the ATP Usage-related decisions. The process model is shown in Figure 9.

4.13 Process Models Master Planning and Factory

*Hubert Missbauer, Gerald Weigert, **Jesus Jimenez**, Lars Mönch, and Sebastian Knopp*

Event-driven process chains Master Planning – Factory

The master plan delivers quantities for the different facilities. Lots are generated based on the master plan. The lots are equipped with due dates. Release dates for the lots are either computed based on simple heuristics like backward and forward termination or based on optimization approaches. Intermediate due dates are derived. The proposed process model is shown in Figure 10.

4.14 Agents in the Level 3 Supply Chain

*Iris Lorscheid, **Scott Mason**, Irfan Ovacik, and Can Sun*

The “level 3” supply chain is defined by Infineon Semiconductor as a semiconductor company’s supply chain. Within this level 3 supply chain exists a number of potential types of agents

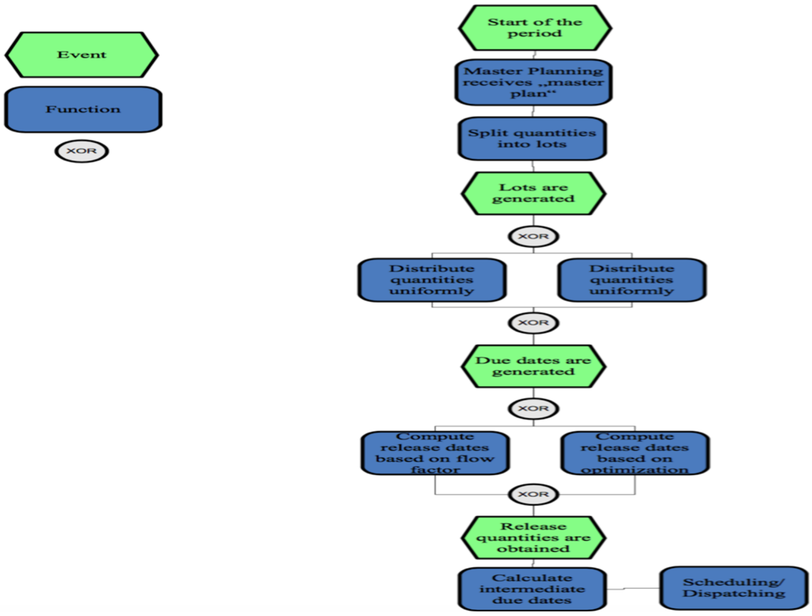

Figure 10 Process Model Master Planning – Factory.

(e.g., capacity planners, inventory planners, master planners, demand planners, supply chain planners, customer logistics managers, etc.). Regardless of its type, each agent has a set of attributes that include (but are not limited to) memory (i.e., the agent's knowledge base, rule set, and facts), the agent's role, and the coworkers with which the agent interacts. Further, each agent has abilities relating to individual strategies, input maintenance/analysis, and output analysis.

In terms of individual strategies, an agent can have specific strategy for dealing with inventory-related issues and ramp up/ramp down transitions, and another strategy for accommodating customer prioritization contingencies. As an example, consider a master planning agent (Figure 11; other agents could be inserted into this figure without loss of generality). During the input maintenance and analysis task, the agent may a) query databases and other data sources, b) ask the sales and marketing department for a demand input, and c) ask the factory planning department for a statement of available capacity. Once the master plan is complete, the output is analyzed for suitability. If the agent is satisfied, the results can be published to the production planning process (e.g., factory starts information) and/or the ATP process (e.g., a statement of supply). Otherwise, if the plan is not deemed to be suitable, the agent returns to the input maintenance and analysis task.

4.15 Top Down Reference Model

*Hans Ehm, Cathal Heavey, **Peter Lendermann**, Leon McGinnis, and Oliver Rose*

A High Level Semiconductor Supply Chain Model exists at a semiconductor company which can be considered a common denominator among all the stakeholders in Semiconductor

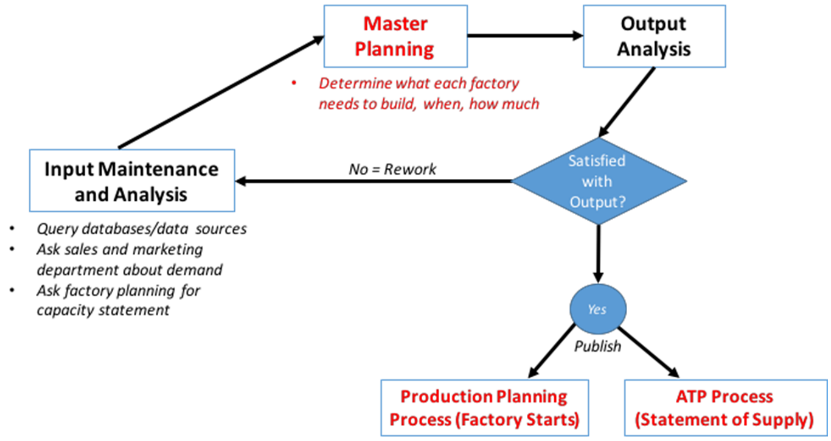

Figure 11 Process Model Master Planning – Factory.

Supply Chain Management and an appropriate starting point for the development of a Reference Model. However, business issues are typically identified on the lowest level process description level. A specific example would be an incident where it turned out that a change in shipment lot size for a particular product required different customs clearance procedure which was not taken into consideration during the Development and Master Planning stage for that product.

To avoid such incidents, the team agreed that a Reference Model could help if it also goes to the lowest level of process detail. However, for a process alignment on this level a common DSL (Domain Specific language) based on SYSML and containing PROS (Process, Role, Object, and State) would be needed. In a second stage this would also require an agreement between semiconductor manufacturers, software supplies, academia and other stakeholders to take full benefit of such a DSL in semiconductor supply chain. This could turn into an uphill task for the following reasons which need to be carefully taken care of:

- Low level process descriptions might contain some participants' IP which owners would want to protect. Once participants understand how a Top-Down Reference Model can be developed without disclosing company-sensitive information this restriction can be overcome as nobody wants to be left behind.
- Development of a Reference Model would require considerable resources which are only realistic if all participants can realise an ROI. After an initial publication and/or a panel discussion at WSC 2016, a European, US or Asia funded project could be the next step. The collaboration of International SEMATECH and JESSI, which ended up with the MIMAC models, could serve as a role model.

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