Report from Dagstuhl Seminar 20452

Decision-Making Modeling and Solutions for Smart Semiconductor Manufacturing

Edited by

Chen-Fu Chien[1], Hans Ehm[2], John W. Fowler[3], and Lars Mönch[4]

1 **Department of Industrial Engineering & Engineering Management, National Tsing Hua University, Hsinchu, Taiwan,** cfchien@mx.nthu.edu.tw
2 **Supply Chain Innovation, Infineon Infineon Technologies, München, Germany,** hans.ehm@infineon.com
3 **Department of Supply Chain Management, Arizona State University, Tempe, USA,** john.fowler@asu.edu
4 **Chair of Enterprise-wide Software Systems, University of Hagen, Germany,** lars.moench@fernuni-hagen.de

Abstract

In November 2020 the Dagstuhl Seminar 20452 explored the needs of the semiconductor industry for making smart semiconductor manufacturing decisions and the information systems to empower flexible decisions for smart production. The seminar participants also spent time identifying the core elements for a simulation testbed which allows for assessing smart planning and control decisions in the semiconductor industry. 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.

Seminar November 1–5, 2020 – http://www.dagstuhl.de/20452

2012 ACM Subject Classification Computing methodologies → Modeling and simulation, Information systems

Keywords and phrases Modeling, Simulation, Smart Manufacturing, Analytics, Semiconductor Manufacturing

Digital Object Identifier 10.4230/DagRep.10.5.1

Edited in cooperation with Mönch, Lars

1 Summary

Chen-Fu Chien
Hans Ehm
John W. Fowler
Lars Mönch

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Introduction

The Industry 4.0 vision is a frequently discussed topic in manufacturing enterprises in Europe, Asia, and North America. It is expected that advanced technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), cloud computing, artificial intelligence, machine learning, and big data technologies enable the emergence of smart manufacturing systems.

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A smart factory promises to bring transparency to manufacturing facilities by integrating technological advances in computer networks, data integration, and analytics [13]. At the same time, critical questions are asked related to the benefits of Industry 4.0 ([14], [17], [15]). It is mainly criticized that the requirements and consequences of Industry 4.0 regarding future production planning and control strategies are not fully understood or not even taken into account in the overall Industry 4.0 conception, i.e., many of key decision processes are not included [14].

The semiconductor industry is capital intensive with the cost of an entire wafer fab up to nearly $10 billion US. The high cost is primarily due to extremely expensive machines, some cost up to $100 million US each. The manufacturing process is very complex due to reentrant flows in combination with very long cycle times and multiple sources of uncertainty [16]. Capacity expansions are expensive and time-consuming. The semiconductor industry is an extreme field for production planning and control solutions from an algorithmic and also from a software and information systems point of view. At the same time, the degree of automation has always been and continues to be high compared to other industries [1]. On the one hand, one can argue that some elements of smart manufacturing are already realized in wafer fabs, namely:

- most manufacturing information is available in real-time
- the manufacturing process is paperless
- lots can be uniquely identified and located
- collaborative human-machine interactions exist.

On the other hand, there are significant differences from automation efforts in manual work-intensive industries such as automotive or aircraft manufacturing where assembly operations are performed in flow lines. In addition to shop-floor control concerns, supply chain management (SCM) problems have become more and more important in the last decade in the semiconductor industry which necessitate horizontal integration of the semiconductor supply chain.

The literature with respect to an adoption of Industry 4.0 principles for semiconductor manufacturing is small and mainly on a survey or conceptual level ([6], [4], [9], [3], [10, 11]). Concrete answers towards future production planning and control strategies that exploit the new possibilities of CPSs and big data approaches to address complicated decisions involved in semiconductor supply chains are only very initially given in the literature.

The major objective of the proposed seminar was related to developing a research agenda for making smart semiconductor manufacturing decisions and the information systems to empower flexible decisions for smart production. This includes innovative modeling approaches for supply chain planning and more detailed production planning and scheduling in semiconductor manufacturing and an analysis of requirements for next-generation information systems that support such decisions. One of the expected outcomes of the seminar consisted of developing a significant draft of a concept for a simulation testbed which allows for assessing smart planning and control decisions in the semiconductor industry.

Thus, the purpose of this workshop was to bring together researchers from different disciplines including information systems, computer science, industrial engineering, supply chain management, and operations research whose central interest is in decision-making for smart semiconductor manufacturing. 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 the seminar. Due to the Covid 19 pandemic, the seminar had only nine attendees from Germany who physically attended at Dagstuhl (see Section Participants). Moreover, four online talks were

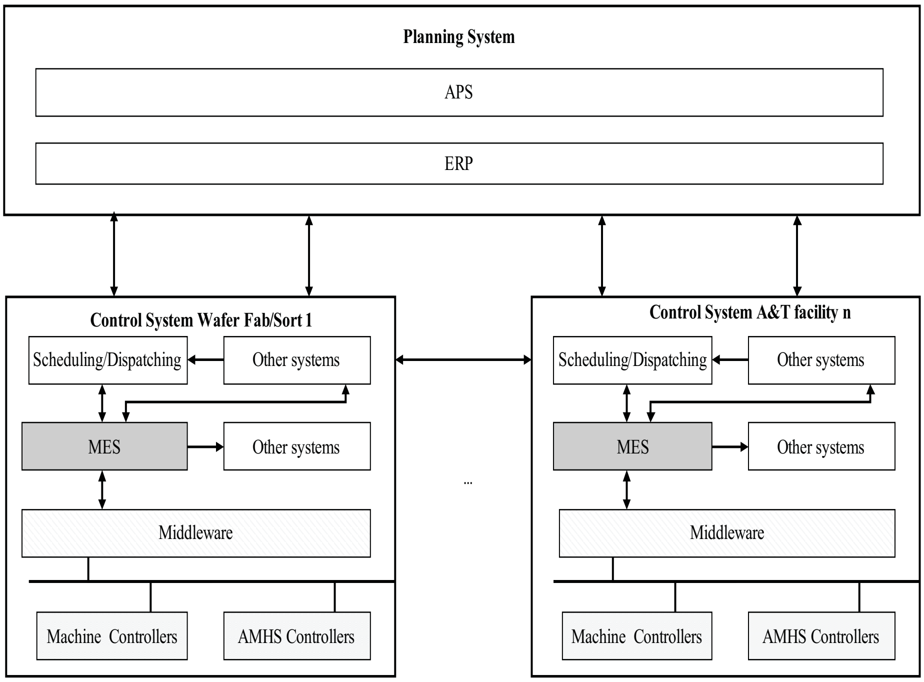

Figure 1 Planning and Control System of a Semiconductor Supply Chain (adapted from [16]).

given by participants from US, Taiwan, and Germany. We had participants from the leading semiconductor companies Infineon Technologies and Globalfoundries.

A primary purpose of the workshop was to extend the scope of the academic research community from conventional decision-making for single wafer fabs to making smart semiconductor manufacturing decisions for entire semiconductor supply chains. The principle architecture of the planning and control system of a conventional semiconductor supply chain is shown in Figure 1.

Seminar Objectives

The primary objective of the proposed seminar was to develop a research agenda for decision-making in smart semiconductor manufacturing. This included innovative modeling approaches for supply chain planning and detailed production planning and scheduling/dispatching in semiconductor supply chains. But it also included ideas on how to design the related future information systems.

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

- **Topic 1: Novel decision-making approaches that exploit the huge amount of available data and orchestrate the interrelated decisions:**
  - It is required to develop a better understanding of which parts of the Industry 4.0 vision are already implemented in semiconductor manufacturing and what is still missing.
  - The specific automation drivers in semiconductor manufacturing compared to other industries must be identified.

  - The usage of additional data which, for instance, is provided by sensors and cyber-physical systems has to be explored to make better decisions [2]. The improvement potential based on the advanced data availability must be quantified [10].
  - Research is necessary to determine which decisions can or even should be integrated. Possible examples for integrated short-term decisions are job scheduling on machines and automated transportation and job scheduling and preventative maintenance planning. Integrated scheduling and process control decisions are another example. On the mid-term planning level, the integrated management of production jobs and engineering jobs is challenging. Up to 30% of all jobs in a wafer fab are engineering jobs. They compete with the production jobs for the scarce capacity of the machines. It is also interesting to make integrated production planning and inventory planning decisions in semiconductor manufacturing.
  - We are interested in which changes are required (or even possible) for planning and control algorithms in smart manufacturing systems. It has to be discussed whether we expect fundamentally new algorithms or not.
  - We are also interested in exploring the need for new fab layouts in the context of smart manufacturing. Initial steps towards the possible redesign of the automated material handling system (AMHS) are discussed by Ham and Kim [7] and Hwang and Jang [8].
  - Dynamics and stochasticity have to be included into decision-making. Different modeling techniques that attempt to reduce the effects of stochasticity include robust optimization, approximate dynamic programming, and stochastic programming and these techniques need to be researched in the smart semiconductor manufacturing context. Different approaches to appropriately deal with stochasticity include rolling planning techniques and inventory holding strategies and these also need to be studied. Generation of scenarios and other distribution parameters for planning problems in supply chains using big data techniques have to be investigated.
  - Many planning and control approaches are based on (distributed) hierarchical approaches. 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 many different, often autonomous decision-making entities including humans occur in semiconductor manufacturing, negotiation approaches are typical in such distributed hierarchical planning and control systems. Research is needed to investigate how such negotiation approaches can be automated and which decisions should continue to be made by humans.
  - It has to be explored how to incorporate sustainability issues into decision making. For instance, taking advantage of real-time pricing in future energy markets is only reasonable when scheduling decisions can be made in real-time.
  - The relationship of real-time decisions based on real-time information on the status of the shop-floor (or even the supply chain) and planning nervousness has to be studied.
  - As the level of automation increases in the factory of the future, there is a need to adapt the decision-making entities to the current situation on the shop floor and at the entire supply chain level. Different machine learning paradigms have to be investigated for this purpose.
- **Topic 2: Future information systems for decision support and facilitating digital transformation:**
  - The required changes for next-generation decision support systems have to be investigated. It is expected that decentralized decision support systems are more important than in the past.

- Alternative software solutions including software agents and service-oriented computing for planning and scheduling applications in smart semiconductor manufacturing have to be proposed.
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- We have to study role of different simulation paradigms in the factory of the future/supply chain of the future.
- The benefit of digital twins in semiconductor manufacturing has to be explored. For instance, it has to be decided at what levels (e.g. factory, supply chain) they should be considered.
- 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 have to be investigated for their usage in smart semiconductor manufacturing.
- Getting a better understanding the interaction of human agents with information systems in the factory of the future is required.
- Because of the complexity of semiconductor 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 smart semiconductor manufacturing needs to be investigated.

Since the expected potential of smart manufacturing is based on advanced information and communication technologies, 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.

Due to the inherent complexity of semiconductor supply chains, simulation of the physical supply chain is required to: a) understand the interactions between the planning and control components and the physical supply chain, b) find solution approaches to problems, and c) verify the solution approaches in the risk-free simulation environment before implementing them. Existing models do not reflect the complexity and the level of detail of current and future semiconductor supply chains. Therefore, the secondary objective of the seminar consisted in identifying the core elements of a simulation testbed which allows for assessing smart planning and control decisions in the semiconductor industry.

The Process

In the opening session, the organizers welcomed the participants. 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 a keynote talk by Chen-Fu Chien and two industry overview talks (by Hans Ehm and by Steffen Kalisch). Another keynote talk was given by Leon McGinnis on Monday afternoon. The rest of Monday afternoon, Tuesday, and half a day on Wednesday were devoted to presentations and discussions about the various elements of smart decision-making in semiconductor supply chain planning and control systems as shown in Figure 1 above. There was another keynote talk delived by John

Table 1 Individual Presentations.

Topic	Presenter
Smart manufacturing	Chen-Fu Chien (virtual)
Industry overview	Hans Ehm
Challenges for smart manufacturing in wafer fabs	Steffen Kalisch (virtual)
Reference modeling and smart manufacturing	Leon McGinnis (virtual)
Semantic data integration for supply chain management	Nour Ramzy
Visualization and interpretation of customer order behaviors in semiconductor supply chains with machine learning approaches	Marco Ratusny
Ontology-based information modeling in the industrial data space	Niklas Petersen
Modeling and simulation for the pandemic, the bullwhip effect and sustainability	Abddelgafar Ismail
How simulation modeling can help reduce the impact of COVID-19	John Fowler (virtual)
S2CMAS: an agent-based system for planning in semiconductor supply chains	Raphael Herding
Sustainability in smart manufacturing	Lars Mönch
Data-driven production planning	Tobias Völker
Digital twin and simulation	Sven Spieckermann

Table 2 Breakout Sessions.

Session	Topic	Participants (lead in bold)
1	Smart Planning in Semiconductor Supply Chain Management	Hans Ehm, **Niklas Petersen**, Marco Ratusny, Tobias Völker
	Smart Manufacturing Control Decisions	**Raphael Herding**, Lars Mönch, Sven Spickermann
2	Smart Planning in Semiconductor Supply Chain Management	Hans Ehm, **Niklas Petersen**, Marco Ratusny, Tobias Völker
	Requirements for Performance Assessment of Smart Manufacturing Control Decisions	**Raphael Herding**, Lars Mönch, Sven Spickermann

Fowler on simulation modeling to reduce the impact of COVID-19. See Table 1 below for a list of topics and presenters and Section 3 for abstracts of the presentations.

Wednesday afternoon was the hiking excursion that was enjoyed by the participants.

Tuesday afternoon was devoted to one breakout session with report outs on the topics in Table 2. Section 4 has the breakout report outs. The first set of breakout sessions had two groups focus on smart planning and control decisions. The second set of breakouts on Wednesday morning again had two groups that discuss requirements for performance assessment of smart planning and control decisions in semiconductor supply chains.

Thursday consisted of a discussion on the required core elements of a simulation testbed for assessing smart semiconductor and supply chain planning and control decisions 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 term smart manufacturing is somehow fuzzy. While the different elements in Figure 1 are reasonably well understood by both the industrial and academic communities with respect to smart decision-making, the interactions between the elements are less well understood. Second, the 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 are new requirements for an adequate reference model for smart manufacturing in semiconductor supply chains. Although there are reasonable data sets available on the factory (i.e., the SMT2020 dataset, cf. [12]) and supply chain level (cf. [5]) no data sets exist yet that take the specifics of smart manufacturing into account.

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 using artificial intelligence tools in smart manufacturing for semiconductor supply chains. Some of the future research areas are included below:

- Using ontologies, for instance the digital reference, for planning and control purposes.
- Developing better integration of various smart decisions made in the elements of Figure 1.
- Incorporating sustainability aspects into wafer fab and supply chain models.
- Extend existing performance assessment schemes for smart manufacturing, for instance by considering renewable energy sources such as the sun and wind.
- Extend existing simulation-based performance assessment schemes in the sense that machine learning-based planning and control schemes can be benchmarked. This requires adaptive behavior of the planning and control schemes.

Next Steps

The organizers plan to repeat the seminar after the end of the Covid 19 pandemic since several objectives of the seminar were not reached due to the limited number of participating attendees. This is especially true for the development of the research agenda for smart decisions in semiconductor manufacturing and for the simulation testbed which allows for assessing smart planning and control decisions in the semiconductor industry.

Acknowledgements

The seminar organizers would like to thank the Dagstuhl team for the provided support and the flexibility which was required due to the Covid 19 situation. The seminar also would not have been nearly as productive without the active contribution of every physical or virtual attendee, and for that the organizers are extremely grateful.

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2 Table of Contents

3 Overview of Talks

3.1 Modeling & Simulation for the Pandemic, the Bullwhip Effect and Sustainability

Ismail Abdelgafar (Infineon Technologies – München, DE)

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Modelling & simulation could help governments, companies and organizations in making decisions on the best strategies to pursue in different situations. Some of the examples of these situations are a global pandemic, the bullwhip effect phenomenon and the sustainability. In the part related to the simulation of the impact of Covid19, I presented first an Agent-Based approach that allow optimizing the return of employees to the work areas without compromising their safety and spreading the virus. Different scenarios were tested to have a better idea about the parameters to achieve a safe return to work. In the second model, I presented a system dynamics approach to find the correlation between the governmental restrictions and the number of new cases of Covid19. A linkage between the governmental restrictions and the impact on the supply chain is also presented in order to find better ways to optimize and mitigate the risks of this disruption. In the part related to the bullwhip effect, I presented a system dynamic model to show how the end-to-end supply chain of the automotive industry react to end-market demand variations resulting from the different demand recovery scenarios U, L, V, W, . . . etc. The results of this analysis show that demand drops impact the most upstream members of the supply chain the most. The supply chain need to collaborate to mitigate the risks of the disruptions. In the part related to the sustainability topic, I presented a discrete event simulation model that shows how the flexibility in supply chain could save CO2 emissions by optimizing the usage of electricity in fabs. The next steps in this research is to include modelling techniques such as hybrid modelling and include AI algorithms to achieve better results.

3.2 Industry Overview

Hans Ehm (Infineon Technologies – München, DE)

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The semiconductor industry is global, fast growing and has a complex manufacturing and supply chain process. 1000 Process steps taking up several months in a wafer fab is the standard despite a 365/24 production environment. The speed of innovation and the flexibility requirement of the markets and of the customers require a supply chain flexibility with alternate routings of the high volume products around the globe. As there are thousands of products this needs to planned and controlled in manufacturing and in the supply chain. In many companies a best-of-breed IT Tools System emerged which is able to manage this network with daily update of ATP (Available To Promise) and daily (re)confirmation of 500k+ Orders. DES (Discrete Event Simulation) and partially also Agent based simulation e.g. for the understanding and thus enabling mitigation of the bullwhip effect has provided great value add so far in the supply chain and manufacturing network. So for us now Risks and Opportunities like the COVID-19 pandemic on the risk side and Artificial Intelligence and Deep Learning with XAI (explainable AI) on the Opportunity side. The Digital Reference transferred from the successful BtC environment to our BtB environment with the H2020/ECSEL projects like productive4.0 bears further huge potential. A further opportunity is given by both Quantum Annealing and Quantum Computing to solve NP hard supply chain problems holistically and it also open new options on how to efficiently handle scenarios. This Dagstuhl gave us the opportunity to explore our field of smart semiconductor supply chain and manufacturing.

3.3 How Simulation Modeling Can Help Reduce the Impact of COVID-19

John W. Fowler (Arizona State University – Tempe, USA)

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Modelling and simulation have been used extensively by all national governments and the World Health Organization in deciding on the best strategies to pursue in mitigating the effects of COVID-19. Principally these have been epidemiological models aimed at understanding the spread of the disease and the impacts of different interventions. But a global pandemic generates a large number of problems and questions, not just those related to disease transmission, and each requires a different model to find the best solution. In this presentation, we identify challenges resulting from the COVID-19 pandemic and discuss how simulation modelling could help to support decision-makers in making the most informed decisions. Modellers should see the article as a call to arms and decision-makers as a guide to what support is available from the simulation community.

3.4 S2CMAS: an Agent-based System for Planning in Semiconductor Supply Chains

Raphael Herding (Westfälische Hochschule – Bocholt, DE)

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Due to the complexity of the different planning and control approaches in semiconductor supply chain manufacturing it is important to get detailed insights about the interplay between various planning approaches. To handle SSC planning complexity, a distributed hierarchical decision-making process is reasonable [16]. Packaged software has limitations in case of demand uncertainty, long cycle times, and reentrant process flows. Preventing monolithic software design, supporting a certain level of autonomy and enable decision-making capabilities, an agent-based solution can provide advantages. In addition, a suitable testbed is required in order to investigate problems which are close to the reality. Usually, planning and control approaches in semiconductor manufacturing require long processing times since a lot of details and data are incorporated into the algorithms to ensure a high solution quality. In order to prevent long computation time and therefore enable important what-if-analyses for human decision-makers cloud computing seems promising. Cloud computing offers financial benefits in terms of pay as you use concepts and on the other hand it offers a high degree of scalability. To combine that into a reference system, we have developed the S²CMAS prototype which bases on FABMAS, a MAS for scheduling for a single wafer fab. We extended FABMAS for using it in a supply chain scenario and for that we integrated supply chain-wide planning decision and staff agents on the one hand and various planning algorithms on the other hand. We also introduced web services for modularity and for interoperability reasons which allows to integrate MES, ERP and other existing systems. To support scalability, AWS as cloud-based system was used. Finally, the S²CMAS supports typical semiconductor supply chain-wide planning and control activities and is able to use the AWS cloud for scaling purposes. This enables to investigate the detailed interplay between various planning and control algorithms and analyze side-effects. It also allows to show up the detailed relationship and associations between the selected planning algorithms.

3.5 Reference Modeling and Smart Manufacturing

Leon F. McGinnis (Georgia Institute of Technology – Atlanta, USA)

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A fundamental promise of "smart manufacturing" is that advancing and emerging technologies will make manufacturing systems much more efficient and effective. For that to happen the smart manufacturing system must be designed and implemented. Analysis agnostic system models have proven to be an essential element of the systems engineering of other large-scale complex systems, like passenger aircraft, automobiles and integrated circuits, and certainly will be required for the cost effective design of smart manufacturing systems. This presentation describes requirements for a reference model and an illustration of a prototype reference model applicable to smart manufacturing.

3.6 Sustainability in Smart Manufacturing

Lars Mönch (FernUniversität in Hagen, DE)

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The talk starts by defining the smart manufacturing notion. Sustainability is one of the pillars of smart manufacturing. We then briefly discuss possibilities for including sustainability issues on the different levels of the semiconductor planning and control hierarchy. In the second part of the talk, a bi-criteria scheduling problem for parallel identical batch processing machines in semiconductor wafer fabrication facilities is studied in detail. Only jobs belonging to the same family can be batched together. The performance measures are the total weighted tardiness and the electricity cost where a time-of-use (TOU) tariff is assumed. Unequal ready times of the jobs and non-identical job sizes are considered. A Mixed Integer Linear Program (MILP) is formulated. We analyze the special case where all jobs have the same size, all due dates are zero, and the jobs are available at time zero. Properties of Pareto-optimal schedules for this special case are stated. They lead to a more tractable MILP. Three heuristics based on grouping genetic algorithms (GGAs) that are embedded into a non-dominated sorting genetic algorithm II framework are designed. Solution representations are studied that allow for choosing start times of the batches to take into account the energy consumption. Computational experiments are conducted based on randomly generated problem instances. The ϵ-constraint method is used for both MILP formulations to determine the true Pareto front. For large-sized problem instances, we apply the GAs. Some of the GAs provide high-quality solutions. The need for modeling wind, sun, and time-dependent electricity costs as external sources of uncertainty is identified as an important future research direction.

3.7 Ontology-based Information Modeling in the Industrial Data Space

Niklas Petersen (eccenca GmbH – Leipzig, DE)

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Main reference Niklas Petersen: "Towards Semantic Integration of Supply Chain and Production Data", 2019.
URL https://www.researchgate.net/publication/344287067_Towards_Semantic_Integration_of_Supply_Chain_and_Production_Data

Modeling Supply Chains and exchanging data among companies gains more and more traction in academia and industry. It is a challenge for organizations to agree on which models and technologies to use to drive their automation goals and thus, gain a competitive advantage. The presentation describes the work on the model SCORVoc, a vocabulary based on the Supply Chain Operation Reference (SCOR) to support semantic, graph-based Supply Chain Knowledge management and to lay the foundation for inter-organizational Supply Chain management. Besides the model, the SCOR KPI queries were discussed to evaluate the performance of an (inter-organizational) Supply Chain. The second part of the presentation focused on the International Data Spaces (IDS) initiative and similar global so-called "dataspace" activities. The IDS works on providing a secure, vendor-agnostic, decentralized, infrastructure, which enables organizations to exchange their data with the option to build business models on top of it. The general idea, the status, similar activities, and the future were discussed with the audience. Finally, the presentation concluded with identified open problems by the presenter. These included the difficulty to build stable models for Supply Chains, to align different models, to collaboratively work on them, to build them in a way that they can be understood by the model user, etc.

3.8 Semantic Data Integration for Supply Chain Management

Nour Ramzy (Infineon Technologies – München, DE)

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Industry 4.0 has established interoperability, real-time, service orientation, and decentralization as design principles allowing companies to engage in digitalization. Therefore, companies are driven to rethink ways to handle their industry, among them, their supply chain. Consequently, due to the digitalization of the supply chain, data has increased in size, complexity, sparsity, and diversity. This has led to harder knowledge extraction, interoperability issues and cumbersome handling and storage of data. Semantic Web is a lingua franca to handle data heterogeneity namely, variety in systems, structured, quality, and security. Semantic data integration is used to combine the content of various data sources and present a unified view. This means defining a common understanding of concepts across different data sources. The creation of an Enterprise Knowledge Graph (EKG) allows linking between the same concepts spread and used in different data silos. Additionally, the supply chain is a paradigm where expert knowledge is the key to success. Semantic Web is a way to capture, formalize, and represent this knowledge. This allows to make informed business decisions and to create a common understanding of how different systems in an organization function and how various people and agents can work together to reach a common goal of creating and maintaining a competitive advantage. Additionally, standardized vocabulary enables leveraged knowledge from external sources. This facilitates impact analysis on how external real-world dependencies e.g. natural disasters, pandemics, and politics affect the Supply chain. It also allows cross-correlations studies for better recommendations e.g. examination of far-reaching consequences of a product change. Especially the semiconductor industry is affected by digital development as semiconductors build the basis for all technologies enabling digitization. In fact, the semiconductor industry is characterized by complex supply chain structures due to its wide range of customers with fluctuating demands for products as well as globally distributed production sites with highly complex processes manufactured on the other hand, the environment comprises uncertain demand due to volatility of the electronics market. The product life cycles in the semiconductor industry itself but also in supply chains containing semiconductors become shorter and more volatile. As a result, companies in the semiconductor industry need to adapt their operations to such an evolving environment, and in turn require their supply chains to be highly resilient and agile. EKG within and across semiconductor supply chains enables mutual understanding and sharing of knowledge.

3.9 Visualization and Interpretation of Customer Order Behaviors in Semiconductor Supply Chains with Machine Learning Approaches

Marco Ratusny (Infineon Technologies – München, DE)

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Advancements in the semiconductor industry have resulted in the need for extracting vital information from vast amounts of data. In the operational processes of demand planning and order management, it is important to understand customer demand data due to its potential to provide insights for managing supply chains. Heat maps are used as a means to visualize the Customer Order Behavior patterns of Infineon's customers over a time horizon of 26 weeks before the actual delivery week. This information exchange helps to lessen the demand variability across the supply chain and to prevent excess stocks or idle capacities in manufacturing pipelines. Exploratory analysis of these heat maps, having led to the identification of certain order patterns, was furthered by training a Convolutional Neural Network with one-delivery-week heat maps as image inputs. This approach extends with input heat maps covering several delivery weeks and providing a broader context of transitions in Customer Order Behavior, for the Convolutional Neural Networks to learn and infer from. Analyzing order behaviors over several weeks not only determines how stable is the demand on a weekly basis but also hints at the market evolution over a broader time horizon, eventually further allowing to scale the model to be predictive. Thus, analyzing a short-term as well as a long-term demand picture helps in the interpretation of changing economic conditions (e.g. recession/down-turn/up-turn). Early detection using Deep Learning also provides important information for the supply chain in being reactive to changing demand. By comparing the Convolutional Neural Networks with Benchmark Models (e.g. Random Forest, Gradient Boosting, etc.) we have seen that the Convolutional Neural Network outperforms all Benchmark Models with respect to the accuracy however, the training time is between 3-20 times higher. The results have shown that the order behaviors of Infineon's customers can to an extent, be meaningfully identified and classified into postulated categories, which with expert knowledge and further research can also be improved to find more unidentified behaviors in the data.

3.10 Digital Twin and Simulation

Sven Spieckermann (SimPlan AG – Hanau, DE)

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The talk on digital twinning and simulation is based on my experience as head of a simulation software and service provider with more than 70 simulationists working on more than 350 simulation projects for production and logistic systems per year and using simulation software packages from various different software vendors such as Siemens, Rockwell, or Anylogic. The talk started on arguing that in the field of discrete-event simulation, we still have no widely accepted common meta-modelling language and that, e.g., SysML was not able to fill that gap over the past decade. The talk continued focusing on the core topic of digital twinning and presented an idea of a digital twin as being a combination of a simulation model (used to mimic structure and behaviour of a real system) and a data shadow ore data lake providing all relevant data. A stand-alone simulation model in itself is not sufficient to fulfil this definition. It was also discussed that data collected by means of Industry 4.0 assets (e.g. sensors, tracking and tracing devices etc.) could help digital twinning. However, in real-world context, successful deployment of digital production and logistic twins are still rather rare due to challenges such as keeping structural and behavioural features in the digital model up-to-date for the whole life-cycle of the real system. The talk concluded with a glance at research opportunities arising in the context of coupling machine learning and simulation as well as process mining and simulation.

3.11 Data-driven Production Planning

Tobias Völker (FernUniversität in Hagen, DE)

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Joint work of Tobias Völker, Lars Mönch

This talk focuses on the data-driven production planning formulation based on system states. System states model the non-linear relationship between work-in-process and expected throughput for discrete states of the entire base-system. This aggregated view on the system does not consider single machine groups or process steps, but is able to capture the interactions between work-in-process and throughput levels for the different products. The mixed integer linear programming formulation and previously used grid-based sampling methods do not scale well to large-sized problem instances including a large number of products. A stochastic sampling approach and two heuristics are introduced and applied to solve problem instances for a large-scale semiconductor wafer fabrication facility with up to 32 products. The results of the simulation-based performance evaluation show that the data-driven formulation is able to solve these instances with lower cost and lower computation time than the allocated clearing function formulation.

4 Breakout Reports

4.1 Breakout Session: Smart Manufacturing Control Decisions and Requirements for Performance Assessment

Raphael Herding (Westfälische Hochschule – Bocholt, DE), Lars Mönch (FernUniversität in Hagen, DE), and Sven Spieckermann (SimPlan AG – Hanau, DE)

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We see that typical Manufacturing Execution System (MES) and Material Control System (MCS) decisions are not well connected today. That means MES is calculating schedules while the sync of the calculated schedule with the corresponding material handling systems of the facility leaks. This situation results in poor control decision since mostly only the local situation for a single machine or machine group is considered. To incorporate more data into that decision-making enables to consider comprehensive control steps and can finally help to gain more accurate schedules. Since sustainability becomes more important, corresponding measures have also to be taken into account. Especially reducing energy consumption or the reduction of CO2 in general are important goals. This leads to more complex control approaches since sustainability measures often are in conflict with the due dates of the lots, i.e. on-time delivery concerns. In addition, weather conditions are typically highly uncertain which increases the complexity of future control approaches. Today short scheduling horizons on work center level in wafer fabs are used in order to overcome uncertainty through machine breakdowns. This leads together with short rescheduling intervals to inefficient scheduling decisions because only a myopic scope in time and space is used. To mitigate this behavior a prediction of different arriving patterns of the lots seems promising. Especially under high uncertainty an accurate arriving pattern could be beneficial for scheduling stability. One approach to solve this problem is to calculate several feasible and robust schedules. From the calculated pool of schedules, one is chosen that fits best with the observed arrival realizations. An open question is how to detect when a schedule becomes infeasible. One remaining question leads to the issue of how to detect if a plan is no longer realizable? If a schedule is infeasible rescheduling has to be considered. On the one hand, rescheduling can be periodically executed. On the other hand, it could also be executed in an event-based manner. The design of corresponding triggers which initiates a rescheduling activity is crucial. It has to be evaluated if machine learning can help to identify conditions for raising a rescheduling event. It is also worth the effort to investigate how genetic algorithm-based learning, so-called genetic programming can be used to determine dispatching rules for wafer fabs. The overall goal is to obtain adaptive control systems for wafer fabs. Finally, in order to be successful in practice several acceptance criteria of the new approaches have to be evaluated.

Requirements for Performance Assessment of Smart Control Decisions

First, we believe that simulation models for smart control decisions have to include more details compared to the ones for conventional control decisions. We agree that today's conventional key performance metrics are not enough. Measures like robustness and stability become more important in the future to address the adaptive behavior of the smart control system. Additional measures regarding sustainability are fundamental for future control decision. Finally, we are unsure that a digital twin can help well. The main reason for that is the challenge to keep the twin a twin during the lifecycle while at the same time being capable to determine decisions for future time periods. This becomes even harder if the twin incorporates the data and the logic of the production process. Especially, when local logical changes are made on the shop floor by maintenance staff that are not reflected back to the control system.

4.2 Breakout Session: Smart Planning in Semiconductor Supply Chain Management

Niklas Petersen (eccenca GmbH – Leipzig, DE), Hans Ehm (Infineon Technologies – München, DE), Marco Ratusny (Infineon Technologies – München, DE), and Tobias Völker (FernUniversität in Hagen, DE)

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The idea of Smart Planning gains traction in the industry and in academia. The growth of data, of systems, of models, and the new KPIs make planning more and more complex. We exchanged in our working group the existing issues we observed in planning on the innovation we see in the field. In particular, we discussed in the working issues such as "local vs global optimization", the need for openess of organizations to enable deeper optimization, the need to understand the underlying models and systems better, in order to build a new generation of data-driven Smart Planning systems. We identified that different metrics may block a deeper, long-term and more global optimization in planning. As an example, business metrics (quarterly reports) for organization to think is short time spans which can be communicated back to the shareholders. Being more open to supplier and customers is hard, as they openess may be used against the open organization in future price negotiations. Further it was discussed how gaps between contexts (ex: Procurement, Transport, Sales, ...) could be bridged. We believe that only better models can help to capture these different contexts (or views). Maybe the ideas by the Semantic Web community can be used, to build ontologies which represent these different contexts. Furthermore, maybe the openess topic can be addressed by using some kind of anonymous exchange networks, where either some kindy of legal entity, or an AI, could to a Smarter Planning for inter-organizational Supply Chains. Research on this topics already exists. Multi-Part-Computing was proposed as well as a technology to be evaluated.

Participants

- Chen-Fu Chien
National Tsing Hua University – Hsinchu, TW (partially virtual)
- Hans Ehm
Infineon Technologies – München, DE
- John Fowler
Arizona State University – Tempe, USA (partially virtual)
- Raphael Herding
Westfälische Hochschule – Bocholt, DE
- Abddelgafar Ismail
Infineon Technologies – München, DE
- Steffen Kalisch
(Globalfoundries – Dresden, DE (partially virtual)
- Leon McGinnis
Georgia Institute of Technology – Atlanta, USA (partially virtual)
- Lars Mönch
FernUniversität in Hagen, DE
- Niklas Petersen
eccenca GmbH – Leipzig, DE
- Sven Spieckermann
SimPlan AG – Hanau, DE
- Nour Ramzy
Infineon Technologies – München, DE
- Marco Ratusny
Infineon Technologies – München, DE
- Tobias Völker
FernUniversität in Hagen, DE