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Digitalization in Semiconductor Manufacturing- Simulation Forecaster Approach in Managing Manufacturing Line Performance

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Abstract

Digitalization symbolizes as a next level of technologization and industrialization and covers all functions and areas of life. In manufacturing stand point, digitalization brings influence to productivity and secures sustainable growth. The complexities in managing bottleneck and equipment efficiency in semiconductor manufacturer are increasing dynamically. This paper addresses the approach and case studies by a semiconductor manufacturing company managing its line performance in digitalization era. Manufacturing experts are from cross functional departments- from planning, operation to equipment maintenance divisions and they support various methods and strategies in handling complexity of product mix. The main Key Performance Indicator (KPI) is set in a way that ensures manufactured products are delivered on time with high quality. Prediction towards manufacturing line performance while supporting dynamic market demands are challenging. The production experts have the challenge to predict the future line performance just by self-experienced or human handling manual data study in analyzing historical performance. Foreseen the current and future needs, the company operation research and engineering team introduce work-in - progress (WIP) flow simulation solution in digital twin platform to provide solution for production. This paper discusses how the model's framework is supported with computer programming and mathematic logics. Simulation team is responsible to maintain the functionality of this model and proposed solutions for manufacturing stakeholders making a strategic decision. This simulation model functions as a forecaster to provide prediction key figures such as flow factor, work-in progress (WIP) status and equipment utilization which applicable within short term and long term views depending on different demand scenarios. Projection towards equipment maintenance status such as equipment uptime can be validated upfront through the inputs from this model. Besides assisting the stakeholders in making a strategic decision in managing bottleneck, the simulation model supports to forecast manufacturing line performance when equipment preventive maintenance activities are scheduled to be performed at specified period; in parallel, assists the managers to plan resources such as manpower and materials. The simulation forecaster model also helps the manufacturing planner to analyze the gap on the actual capacity requirement with the original capacity plan in supporting the market demand. Results from several case studies from the simulation model would convince this organization's stakeholders

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that the digitalization through simulation model approach would improve manufacturing line performance and benefits the organization in its internal supply chain management.

Keywords: Digitalization; Simulation Forecaster; Simulation Model; Bottleneck Management; Supply Chain Management

1. Introduction

Infineon Technologies is a provider of semiconductor and system solutions. The company offers products such as automotive system integrated circuits (ICs), microcontrollers (MCUs), and smart card ICs. It operates in highly competitive semiconductor industry in which this industry is characterized with short product life cycles and rapid technological changes. According to CEO Infineon Reinhard Ploss [4], in order to keep up with the speed and challenges, the organization has to be able to act quickly and agile. Adapted to this dynamic, this organization's approach to digitalization is also agile. It learns from successful concepts from many different use cases in defined fields such as Industry 4.0 or Deep Learning and gradually expands its digital competence over time. Infineon has great advantages on digitalization because the products connect the real world with the digital world.

Digital twin is a virtual model of a process, product or service. Infineon wafer fab manufacturing sites are using digital twin to virtualize complete equipment condition and performance. One of the digital twin use cases is short term simulation (STS) platform that constantly update live data. STS facilitates manufacturer in managing operational efficiency and optimized (remote) maintenance.

The paper describes digitalization framework by defining terms between digitization, digitalization and digital transformation and how digitalization influence supply chain. In supply chain's perspective, digitalization has made the chain becomes an integrated ecosystem and transparent to all players involved. In today's global competition, manufacturers face challenges in reducing costs, increase revenues, shorten product lifecycle and improve deliver reliability. This paper relates literature reviews of digitalization with a current digitalization approach in a wafer fab semiconductor manufacturer like Infineon Technologies. The case study describes how manufacturing stakeholder from cross functional teams managing work-in-progress (WIP) flow and bottleneck using STS to support semiconductor manufacturing (wafer fab) supply chain internally.

2. Literature Review

2.1. Digitization & Digitalization In Manufacturing Supply Chain

Suppliers, partners, companies and dealers in supply chains do use, generate and share information with others. These associations lead to multitude of challenges and opportunities within the supply chains. A Digital Supply Chain (DSC) is a smart, value driven, efficient process to generate new forms of revenue and business values of organizations and to leverage new approaches with novel technological and analytical methods [3]. The supply chain today is a series of largely discrete, siloed steps through marketing, product development, manufacturing and distribution and finally into hands of the customer. This network will depend on a number of key technologies: integrated planning and execution systems, logistic visibility, autonomous logistics, smart procurement and warehousing, spare parts management and advanced analytics [12]. Digitization will change that, bringing down walls and creating a completely integrated ecosystem that is fully transparent to all the players involved [11]. Digitalization was introduced by Gottfried Wilhelm Leibniz, who developed the transformation from Arabic numbers to binary strings. For example, the Arabic number 26 could be decoded to the digital string 'I I 0 I 0' [15]. Digitization originally describes the conversion of analog to digital information and processes in a technical sense [6]. Digitally enabled organizations are supported by new ICT, referred to as digital technologies, which increasingly promise enormous opportunities for growth [7]. Tech- driven manufacturing leads to smarter supply chains with on-demand, cost –efficient production of parts. Digital capabilities and digital manufacturing produces high quality, complex goods in less time, without the traditional handoffs and delays between disciplines [2]. At the next level of operating transformation, companies leverage information and relationships across channels, business units and supply chain partners. This makes it possible to integrate digital and physical components that provide the most value- to improve speed to market, for example, or to equip employees with information, enabling them to surpass customer expectations [1].

SCM World's recent 2016 Future of Supply Chain report [8] highlights the increasing importance of digitalization within supply chain function. Over 1,400 supply chain practitioners named Big Data analytics, cloud computing, advanced robotics, IoT and machine learning as "disruptive and important" technologies. The author claims that businesses are working with unprecedented flow of data. Billions of devices – both upstream in manufacturing as well as downstream at the point of sale – are generating enormous amounts of data, every moment of the data. This leading to what can only be described as "digital obesity" as shown in Fig. 1.

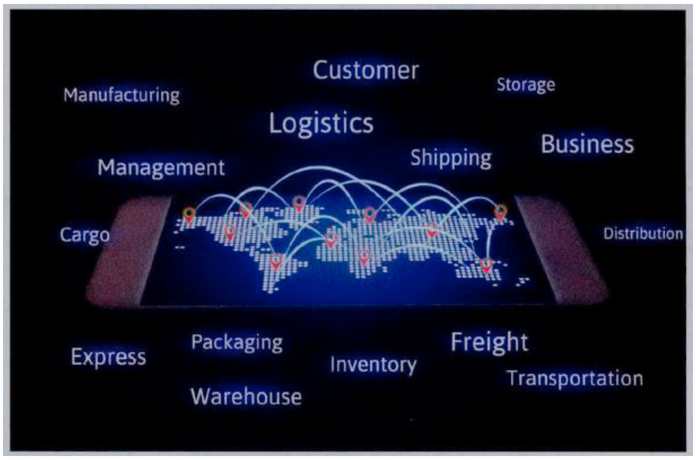


Fig. 1. "Digital Obesity" within Supply [8]

The summary of digitalization framework for a better understanding of digitalization [10] as proposed by Unruh and Kiron [14] is shown in Fig. 2.

Fig. 2. Digitalization framework [10]

2.2. Digital Twin Toward Smart Manufacturing And Industry 4.0

Smart manufacturing (SM) is a term generally applied to a movement in manufacturing practices towards integration up and down the supply chain, integration of physical and cyber capabilities and taking advantage of advanced information for increased flexibility and adaptability. It is often equated with "Industry 4.0", a term originated from a project in the German government that promotes a 4th generation of manufacturing [9]. NIST (National Institute of Standard and Technology) which is an agency of the U.S Department of Commerce defines Smart Manufacturing as "fully-integrated and collaborative manufacturing systems that respond in real time to meet the changing demands and conditions in the factory, supply networks and customer needs. In other words, it means that the active manufacture-based technologies and systems that can respond to complicated and diversified situation of manufacturing field in real time [5]. The authors also claim that Germany, the U.S and Korea are running various programs and projects related to Smart Manufacturing. They selected key technology area, and they are the leaders in technology development. The common technologies of the three countries were classified and selected as shown in Fig. 3.

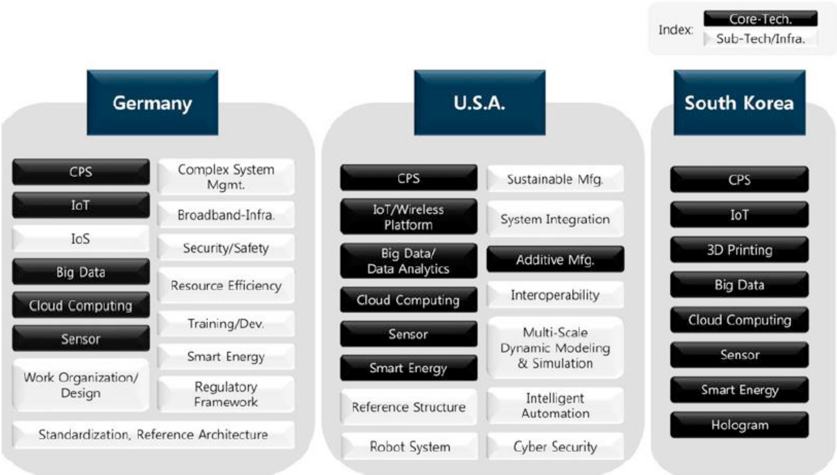


Fig. 3. Classification and selection of core technology for smart manufacturing [5]

The concept of digital twin was firstly presented by Grieves in 2014 [13]. In general, virtual models of physical objects are created in a digital way to simulate their behaviors in real-world environments. As shown in Fig. 4, digital twin integrates all manufacturing processes, which can achieve the closed loop and optimization of the product design, manufacturing and smart maintenance, repair and overhaul (MRO). From the input of raw material to the output of finished products, the whole manufacturing process is managed and optimized through digital twin. The virtual workshop or factory include the geometrical and physical models of operators, material, equipment, tools, environment as well as the behaviors, rules , dynamic models and others. The virtual workshop or factory simulate and evaluate the different manufacturing strategies and planning until a satisfactory planning is confirm. In the accrual manufacturing execution stage, the real-time monitoring and adjustment of manufacturing process are realized through virtual-physical interaction and iteration. The virtual models update themselves based on the data from the physical world, to keep abreast of the changes.

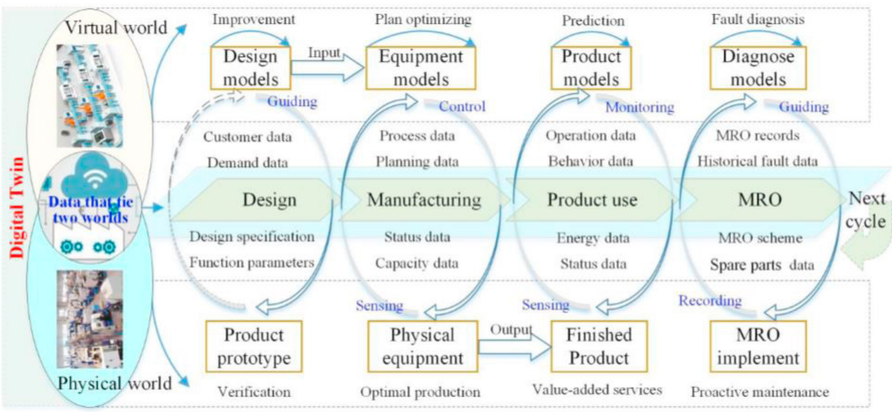


Fig. 4. Digital twin in manufacturing [13]

3. Digitalization in Infineon Technologies and Case Study

3.1. Current Approach

In Infineon, digitalization is seen as tremendous opportunities for new and revolutionary business models and individualized product – pathway for higher productivity and efficiency using more intelligent manufacturing methods. The concept of Industry 4.0 has mainly focused on automation and digitalization of manufacturing. The company's top management emphasizes the potentials of digitalization methods, specifically for the challenges of data analysis and decision making in its wafer fab manufacturing. The approach on digital transformation is through "try and learn" concept and organize the learning steps iteratively and incremental development to increase knowledge within the whole organization. Digital Twin (DT) and Artificial Intelligent (AI) are few tops technology topics that are actively being implemented in this organization with number of events.

3.2. Case Study: Managing Line Performance Using Short Term Simulation Forecaster

This case study relates digitalization concepts from literature review and focuses wafer fab manufacturing like Infineon, on how the manufacturing team making a daily production wafer moves based on the availability of the equipment from a specific workcentre in the production. In Infineon, Short Term Simulation (STS) is part of digital twin platform. It is a forecaster in wafer fab manufacturing that functions to perform predictive result from a simulation and provide virtual operational support based on manufacturing real data. The result from simulation forecaster becomes part of decision making by manufacturing stakeholders such as equipment, operation, planning and process engineering teams in strategizing and optimizing wafer fab performance. This case study focuses on Workcentre A and B representing two processes in wafer fabrication. In capacity planning, Workcentre A has 13 equipment, running the front end (FE) process and is set for Plan productive time (Plan PR) at 79%; whereas Workcentre B , running the back end (BE) process has six equipment with Plan productive time (Plan PR) of 83%.

3.3. Short Term Simulation Forecaster Framework and Algorithm

Fig. 5 shows the architecture of STS. Key figures such as daily incoming Work-In-Progress (WIP), WIP level, basic planning data for equipment, and equipment utilization for Workcentre A are being fed into the model. The simulation runs daily automatically at night to provide a one week output forecast on the next day for both workcentre.

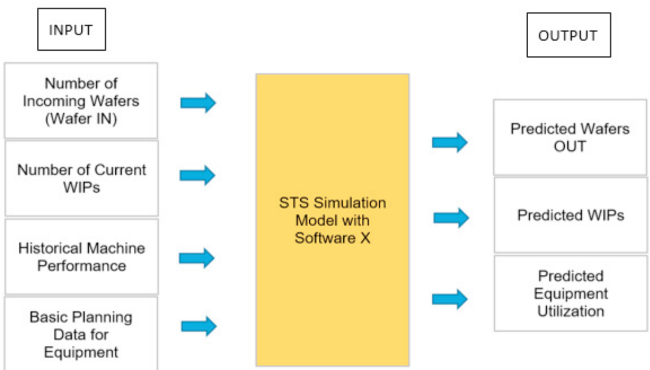


Fig. 5. STS framework

4. Data Analysis & Results of Case Study

4.1. Analysis on Incoming wafers to Workcentre A and B

Fig. 6 shows an STS reporting platform of both workcentre that provides a predictive result of total incoming wafers to this workcentre for the next seven days. Besides that, the report also displays the actual (real) incoming wafers as compared to the simulation result from previous days. The gap between simulation and actual is because of the influence in WIP linearity and equipment performance from upstream processes before these workcentre. These results show that the level of incoming wafers to Workcentre A and B are within the baseline limits.

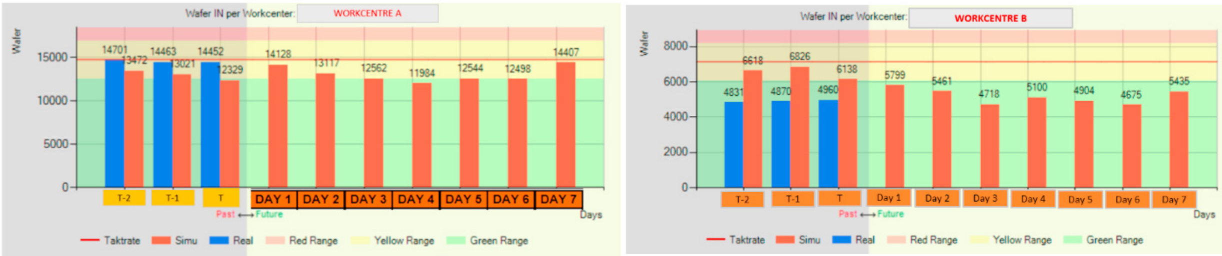


Fig. 6. STS report of incoming wafers to Workcentre A (left) and B (right)

4.2. Analysis on WIP status in Workcentre A and B

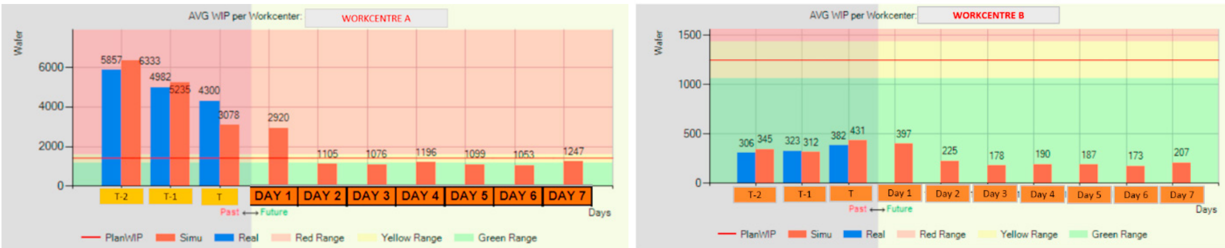


Fig. 7. STS report of WIP status in Workcentre A (left) and B (right)

In Fig. 7, STS report shows that for the past three days, Workcentre A had a huge WIP in the manufacturing line. STS forecast that the WIP performance is going to be lower than the Plan WIP limit, starting on day 2 from the simulation period. In contrast, Workcentre B had lower WIP in the manufacturing line. Indeed, as this workcentre is running at the BE process with shorter process time, the WIP level is considered manageable in its baseline.

4.3. Analysis on Equipment Utilization in WorkCentre A and B

Fig. 8 shows a forecast number of wafer moves OUT from 13 equipment in Workcentre A. With the strong relation to the WIP status as shown previously, Workcentre A are observed to have high forecast wafers to be produced. In order to generate the high moves, the overall equipment utilization in Workcentre A is forecasted high as shown in Fig 9. STS report shows that the equipment need to be stable throughout the operating period. It is recommended that these equipment are able to avoid unnecessary or unplanned downtime throughout this period. For Workcentre B, as the WIP level is low for the next incoming days, the forecasted moves reflect low as it is.

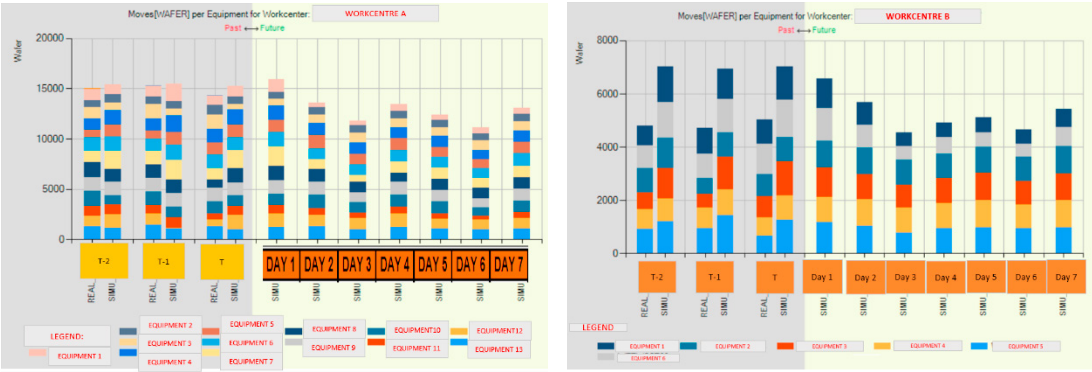
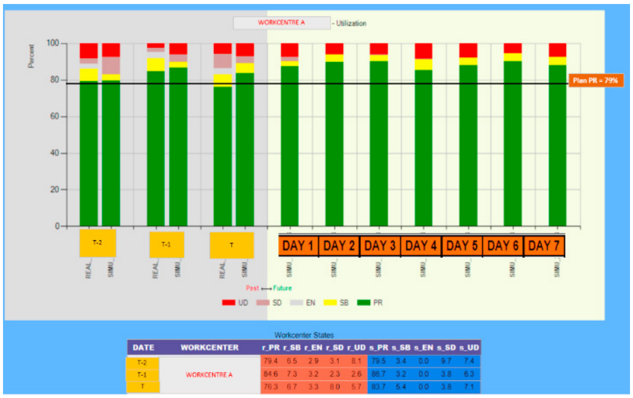


Fig. 8. STS report of WIP status in Workcentre A (left) and B (right)



DATE	WORKCENTER	r_PR	r_SB	r_EN	r_SD	r_UD	s_PR	s_SB	s_EN	s_SD	s_UD
T-2	WORKCENTRE A	79.4	6.5	2.9	3.1	8.1	79.5	3.4	0.0	9.7	7.4
T-1		84.6	7.3	3.2	2.3	2.6	86.7	3.2	0.0	3.8	6.3
T		76.3	6.7	3.3	8.0	5.7	83.7	5.4	0.0	3.8	7.1

Fig. 9. STS report of equipment utilization in Workcentre A

5. Conclusion and Recommendations

Combining all STS reports for Workcentre A and B, we can conclude that short term simulation forecaster facilitates manufacturing stakeholders like operation team to plan sufficient manpower in managing the WIP and wafer moves with desired equipment utilization as its plan productive time. The simulation forecaster also provides information to the equipment team in managing appropriate time window for preventive maintenance activity when it is required with proper resource planning. This is to ensure when the equipment undergoes preventive maintenance activity, wafer fab performance is maintained and bottleneck can be managed.

The paper concludes that Infineon Technologies as a semiconductor and systems organization has connected itself between the reality and digital world through digital twin (DT) activities such as short term simulation (STS). Besides short term simulation approach to support manufacturing, the organization would expand its digital data and technologies capabilities to develop long term simulation as next level of digital transformation approach to support future tactical strategy such as “what-if scenario”. This would leverage bottleneck management and high equipment utilization.

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