Concept and Possible Application of an Automated Framework to Influence Production Dispatch Based on Supply Chain Events

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Abstract— We present in this paper an automated framework for linking supply chain events to production management. While events in the supply chain are detected using statistical process control, the control loop to production is closed using ideas inspired from run-to-run control. The proposed framework is expected to offer a higher level of flexibility with respect to demand changes. This results in increased on-time delivery for customers. While the semiconductor industry faces the challenge of volatile markets, long cycle times and short product life cycles, systems for demand planning and production management are nowadays often decoupled. Therefore, the proposed framework will be applied to semiconductor manufacturing to link demand planning with production management.

Keywords—Statistical Process Control; Advanced Process Control; Automated Decision Making; Advanced Dispatch Control

I. Introduction

In a volatile market with short product lifecycles but long development and production times, an increase in flexibility to meet the customer demands is a significant competitive advantage. To avoid large inventories and possible write-offs, forecasts, production planning and production control need to be closely linked and well aligned. In Industry 4.0, this concept is called horizontal integration [1]. It ensures a high transparency, fast reaction times and a cross-system optimization.

The semiconductor industry faces the challenges of long cycle times up to several months, short product life cycles and a volatile market. As early as 2001, the consortium of the International Technology Roadmap for Semiconductors described their vision of Factory Integration [2]. Today, this vision is extended to a global virtual factory, which links the production network with the supply chain planning processes [3].

In this paper we describe an automated framework for linking supply chain events, e.g., changes in demand planning, to production management. Today these systems are often decoupled: after the demand is released to production, it enters into a freeze fence in the planning systems and it cannot be changed. The production commits to a delivery date with respect to the cycle time. During the freeze fence period, demand changes have no impact on production.

Our new integrated dispatching approach addresses this challenge to increase the flexibility of companies acting in volatile markets. Supply chain events are automatically detected via Statistical Process Control (SPC) adapted to supply chain processes. These events are then incorporated into the Manufacturing Execution System, specifically in the dispatching process in complex job shop environments.

In the next section we will review literature on SPC in Supply chain applications as well as the coupling between production control and the planning process. In Section III, our proposed approach is introduced. In Section IV, the usage of these events in factory scheduling is described. In Section V, the concept is applied to the planning and production system of a large semiconductor manufacturing company (Infineon), which faces the described challenges.

II. Process monitoring and control

A. State of research in SPC

We provide an overview about the current state of research in the field of process monitoring and SPC, i.e., we identify patterns, themes and issues in available academic literature [4]. This approach allows us to identify relevant research work based on pre-defined criteria [5]. The development of search strings and the determination of included criteria is an essential

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part of a literature review. The metadatabase Web of Science (Thomson Reuters) is scanned for scientific papers that fulfil the criteria for inclusion (cf. Fig. 1).

The results of the search string applied in the metadatabase Web of Science resulted in 107 academic papers which fulfill the pre-defined search criteria. Finally, the total number of 107 papers could be reduced by certain refinement criteria such as several Science Citation Index indicators, thematically fitting research areas and a timespan from 1990-2016, to a final sample of 28 papers.

In the manufacturing field, SPC is a well-known and established concept for monitoring the performance of the system and the quality of the products. Originally developed by Walter Shewart in the 1930s [6], the concept is defined as a continuous monitoring of a process to determine whether or not it is in control. It is assumed that a process has natural variations, which have a common source, and variations caused by special sources, which should not occur in the process. Common variations can be deemed to be in-control since they are process-specific and produce a stable distribution, whereas special variations cause out-of-control signals which occur sporadically and unpredictably. Special causes can either be single outliers or permanent deviations of the process as a whole.

In general, the literature review shows that SPC has emerged from the manufacturing field and has been extended to different kinds of applications. From the health industry [7, 8] through commercial industries [9] and environmental applications [10] to supply chain processes [11–13]. Moreover, another essential part of these concepts is the utilization of control charts in inventory control, due to the awareness that inventory replenishment policies are considered one of the major causes of the bullwhip effect in supply chains [14–20]. Most of these approaches have the fundamental assumption that the observed variables are normally distributed. To obtain these assumptions, various proceedings can be found in the literature. The basic approach is the simple assumption of normality of the used data as found in [8, 9, 13]. Only very few industrial processes are actually perfectly normally distributed [21]. A more precise method to verify the assumption of normality was used by [7, 11] by considering the Central Limit Theorem. Reference [10] used an advanced approach and transformed the data with a logarithmic transformation if the observed variables lacked normality. An improved representation of the underlying distribution in reality was done by [12]. On the other hand, due to the reason of increasing quality standards and the fact that in reality only a few processes are normally distributed, non-parametric concepts have gained more attention in the recent years [22–25].

Database	Search string
Web of Science (Thomson Reuters)	*TS= (statistical process control OR spc) AND TS= (control chart AND chart*) AND TS= (perform* OR monitor* OR inventory*) AND TS= (forecast* OR demand* OR supply chain)*

Fig. 1: Metadatabase search string.

B. SPC vs APC

Traditionally, there have been two distinct approaches to process control. On the one hand, there is the already described SPC, originating from the parts industry where the process output is monitored to detect out-of-control processes. On the other hand, there is advanced process control (APC), sometimes also referred to as engineering process control (EPC), where important process variables are measured to incorporate a feedback loop to control the process. The feedback loop uses a mathematical model to adjust process inputs based on these measurements. Therefore, the mathematical model needs to link variability in the output variable to an input control variable. APC originated from the process industry [26–28]. While both SPC and APC aim at reducing the variability and therefore improving the process quality, they seek to achieve these goals in different ways. Partially, this is a result of from their origination of different industries [29, 30]. Table 1 compares SPC and APC.

Some industrial processes, such as those in semiconductor manufacturing, are characterized by certain aspects of the parts industry and others of the process industry. Within these processes, the sharply drawn lines dividing the parts industry and the process industry have begun to disappear [27]. Addressing these special needs, the concept of run-to-run (R2R) control emerged. The R2R approach combines techniques from both SPC and APC to minimize process drift, shift and variability. Achieving this, the product recipe with respect to a particular machine and process is modified at an ex-situ process-to-process-level [28, 31]. Therefore, SPC and APC complement each other very effectively [30]. However, there are also other approaches in R2R than relying solely on SPC. Research aimed in this direction includes works concerning neural networks, expert systems and fuzzy logic controllers [31].

TABLE 1: Comparison of SPC and APC [31], enhanced by [27, 29].

	SPC	**APC**
Goal	*Minimize variability*	
Concept	*Minimize variability by detecting and removing process upset*	*Minimize variability by adjusting the process to counteract process upset*
Function	*Monitor the process*	*Control the process*
Application	*Expect stationary process*	*Expect continuous process drift*
Automated Process Adjustment	*None*	*Semi-automated to automated*
Reaction to	*Statistically significant changes*	*Continuous changes*
Implementation	*Downward*	*Upward*
Results	*Process improvement*	*Process optimization*

III. Detection of supply chain events

The digitalization and globalization of supply chains lead to comparable levels of complexity and innovation speed in the incorporated processes and the manufacturing process alone [32]. In contrast to manufacturing processes, supply chain processes do not necessarily follow a certain, simply assessable, distribution. A major difference is the influence of human interactions in the processes and specific supply chain challenges like the bullwhip effect. Further differences of supply chain and simple manufacturing processes are compared in Table 2. Consequently, a simple transfer of SPC from the manufacturing level to supply chain processes is not possible since these specific characteristics have to be considered and integrated into the monitoring concept. Especially the semiconductor manufacturing, with its complex processes and the accompanying challenge of the long cycle times compared to the short life-cycle of the products containing semiconductors, necessitates an accurate monitoring system for all kinds of different supply chain processes.

A control chart design has been formulated that is able to incorporate the specifics of supply chain processes. The proposed control chart fulfils the following requirements: (i) The basis variable for the control limits and the basis variable for the centerline are differentiated; (ii) The control limits are not placed based on a predefined distribution of the observed variable, but based on a percentage of the cumulative distribution function assessed from a second variable that reflects the individual human behavior in the observed process; (iii) The upper and lower control limits do not have to be placed at the same distance to the centerline to take asymmetric planning behaviors into account; and (iv) the control chart incorporates a flexible centerline whose position may vary over time – since supply chain processes often do not have an overall average value, which could be represented by the centerline, the centerline is adaptable to the underlying planning situation of the observed process. An example of the proposed control chart design is depicted in Fig. 2.

Supply chain processes can be set up according to the Supply Chain Operations Reference (SCOR) model [33]. This reference model is an inter-industrial approach, which enables organizations to describe, analyze and improve their processes within a standardized framework and provides a common base for benchmarking between companies [34]. The six main processes are Plan, Make, Source, Deliver, Return and Enable. The standardized definitions of these processes enable the description of complex as well as simple supply chains on a common basis and can and should be applied to all links of a given supply chain [33]. Particularly with regard to the complexity of the semiconductor industry, the application of this reference model is useful to obtain standardized processes and a reasonable set up of the global supply chain. Breaking down the Plan process according to the SCOR model, five sub-processes, which we will exemplify using Infineon Technologies AG in the following section, can be determined as depicted in Fig. 3.

TABLE 2: Comparison of the data structures.

Manufacturing	Supply Chain Processes
Constant Behavior	Trends, Seasonal Effects
Taking samples possible at every time	Relies on database setup and data granularity
Same process step is repeated very often	Comparability: e.g. cycle time of given products
Univariate data	Multivariate data

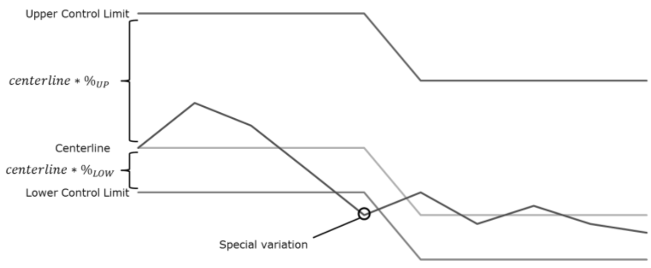

Fig. 2. Example of a control chart.

The proposed concept monitors the processes within these areas and triggers corrective actions via events in another planning field. This accelerates the reaction to occurring events and supports early warnings for the responsible planners. In a further step, the information is used to trigger automated intervention in the manufacturing execution system. This supports the planners and reduces the workload with better performance at the same time.

IV. Automated production dispatch influence

Due to criteria such as re-entrant production flows or sequence-dependent setup times semiconductor manufacturing can be modeled as a complex job shop. Within complex job shops, scheduling and dispatching highly impacts the performance of the manufacturing process. Scheduling describes the planning process of allocating resources to tasks over given time periods with the goal of optimizing one or more objectives. In the context of job shop scheduling, jobs will be assigned to machines for a specific time period in the future, where the definition of future depends on the planning horizon. This procedure aims at an effective and efficient use of the available resources [35, 36]. Dispatching, on the other hand, is a just-in-time decision. When a machine becomes available, the dispatching algorithm assigns the job with the highest priority from a queue of waiting jobs to the machine. The order of jobs may be determined by schedules or by dispatching rules [36]. Nowadays, rule-driven dispatching is still the dominant shop floor control method for semiconductor manufacturing [35, 36]. Advantages of dispatching rules are the real-time capability due to a small calculating effort and the fact, that results are easily comprehensible for operators [36]. In theory as well as practical application there are a lot of dispatching rules. Among them are popular ones such as First In First Out (FIFO), Shortest Processing Time (SPT) or

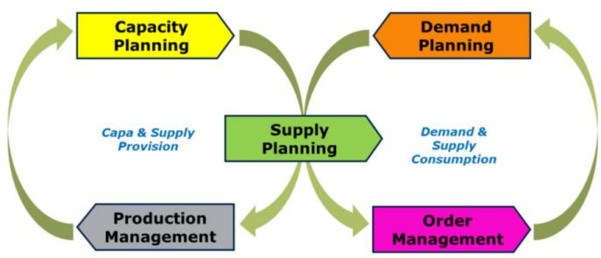

Fig. 3. Supply chain planning sub-processes according to the SCOR model.

Operation Due Date (ODD) which are described very well in the literature [36, 37].

Supply chain and logistics processes have reached a comparable level of complexity and innovation speed to the manufacturing processes themselves (cf. Section II). Therefore, they need to be closely monitored as well, which has been achieved by the concept proposed in Section III. In addition, ideas described by Industry 4.0 aim at decentralized and automated decision making [38]. This motivates the approach of advanced dispatch control (ADC) in transferring R2R control from manufacturing to dispatching as the interface between supply chain and manufacturing. Thereby, planning on the supply chain level and corrective actions on the manufacturing level are linked. The basis of this concept is an event-driven approach and a respective architecture (cf. Fig. 4). Events from supply chain SPC serve as triggers for corrective actions. These events will be further analyzed and enriched with additional data. Based on this data, corrective actions will be made automatically to influence job order by dispatching.

Key components of the ADC architecture, which are integrated by a manufacturing service bus (MSB) [39], are:

- Analyzer: The analyzer receives events from SPC and enriches them with additional data from manufacturing IT systems such as ERP or MES. While events already need to contain some information such as data on the violation of a limit or an estimated date of action, manufacturing IT systems could provide additional data. Among them are data on priority corridors or current work-in-process of the respective product.
- Rules Engine: Using the data supplied by the analyzer the rules engine decides on corrective actions. Corrective actions mean prioritization or de-prioritization of product groups via dispatching. Therefore, the rules engine correlates with the controller in the R2R concept. While R2R in manufacturing aims at minimizing variability in processes, ADC aims at grading output which is to some extent similar.

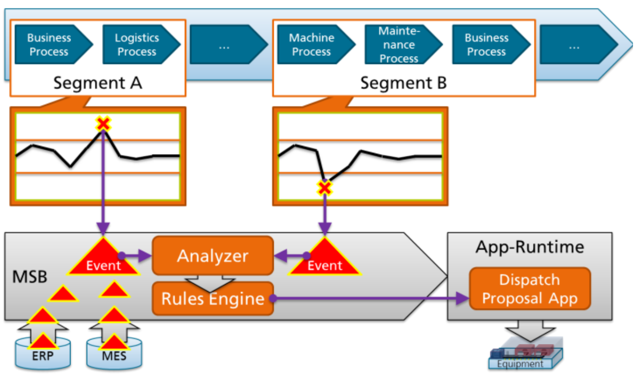

Fig. 4. Concept of ADC.

V. Demand Monitoring & Benefits

The planning landscape at Infineon Technologies AG is built according the SCOR model and specified for each sub-process as depicted in Fig. 5. Further explanations can be found in [40].

The developed concept is applied inside this planning landscape. The monitoring approach is used in Demand Planning where critical events are identified by means of the introduced control charts. For the monitored variable, the forecasts regarding the expected order quantities are used, which are extracted right before entering the planning of Operational Demand. This external information, sent by the customers, is one of the main inputs for the planning processes and therefore a major influencing factor in the system. Critical events in this context could for example be changes in the demand quantity or changes in the desired delivery date by the customer. Another critical event would be the appearance of a totally new order, which would make an adaption of the planned scenario necessary. The detection of a relevant deviation triggers a process in the system for Production Management which automatically adjusts the production to the new situation by changing parameters via the ADC. This will mainly be performed by applying short term decisions such as changing the priority of specific lots or changing the current flow factor of the production of a specific product.

Fig. 6 depicts the data exchange between the monitoring concept, which detects events like described above, and the ADC system. The triggered exchange should contain all relevant information necessary for the application of automated rules in the short-term production planning. Especially the knowledge about the product and the customer is relevant for the importance of the adaptability of the production.

The applied concept enables a reduction of the impact of unpredictable events on the supply chain‘s performance. Deviations to the as-is planning situation are recognized as soon as they occur, while the false alarm rate is reduced due to the consideration of the human behavior in the control charts. This leads to a more flexible and automated planning and production process and an adequate reaction to demand changes and customer requests. As a further consequence, the inventory levels can be reduced, since the safety stocks can be lowered due to the more accurate planning in advance.

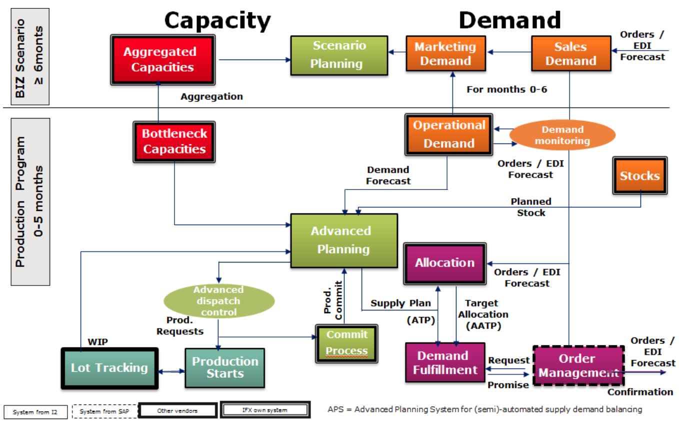

Fig. 5. Planning Landscape at Infineon Technologies AG.

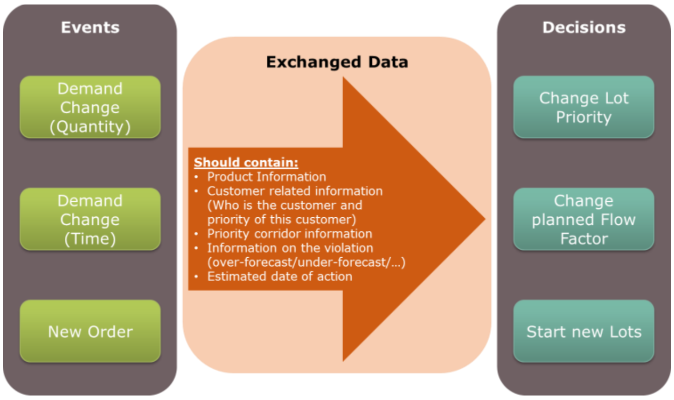

Fig. 6. Data exchange between monitoring and ADC systems.

VI. Conclusion and Outlook

In this paper we present a framework for automatically detecting supply chain events and acting on them by influencing the production schedules. The first step builds on SPC techniques which were transferred and applied to supply chain processes. The second step – the adjustment of production dispatching – implements a complete APC system. This results in a closed control loop as current work-in-process levels of the factories are considered in supply chain planning. With this approach, the IT systems used for supply chain planning and MES are closely integrated. We expect the system to offer a higher level of flexibility with respect to demand changes. This results in an increased on-time delivery rate for customers. The practicality and benefits have been shown in a feasibility analysis at Infineon Technologies AG. SPC for supply chain will be tested as notifications for the supply chain planners. With their feedback, the parameters of the SPC can be fine-tuned. In the next step, we want to implement the complete framework in a simulation model containing supply chain planning and production elements and quantify the benefits.

In conclusion, the framework supports the vision of a fully integrated factory as developed in Industry 4.0 by connecting supply chain planning and production with a closed feedback loop.

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