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## Enhanced Classification of Events for Manufacturing Companies in Supply Networks

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**Abstract**

Uncertainties in the supply network are often challenging for manufacturing companies. They arise from dynamic effects due to events linked to external supply networks as well as internal manufacturing. To deal with this issue, the present work offers an approach that classifies these events aiming to break down the complexity associated with the latter. By assigning appropriate countermeasures in production planning and control, manufacturing companies will be able to react more systematically to external volatile events. The novel classification approach has been successfully evaluated with a leading semiconductor manufacturer.

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**1. Introduction**

Driven by recent trends such as globalization, aspiration of developing and emerging countries as well as the shift from a seller's market to a buyer's market manufacturing companies are facing the challenge of an increasing volatility and uncertainty in the markets [1, 2]. Additionally, branches such as semiconductor manufacturing are characterized by fickle and complex manufacturing systems [3]. This results in an increasing number of events manufacturing companies need to react to ensuring the stability of value creation. However, existing production management approaches are vulnerable to abrupt changes and unforeseen events [4]. Especially for operators and managers in manufacturing, a great deal of time is required to ensure that production runs smoothly despite these events [5].

Due to the establishment of global supply networks, cross-location logistical processes are increasing, leading to coordination requirements in planning and control at various levels [6, 7]. These processes and their corresponding

decisions in planning and control can be categorized by the affected stage of the supply network, covering procurement, manufacturing, distribution and sales, as well as the temporal decision horizon, ranging from long-term to short-term [7]. The link between planning and control in the supply network and production is thereby established by a multi-level hierarchical planning process [3]. It can range from long-term planning for years or quarters down to a weekly planning as input for detailed scheduling and control. Simultaneously, the discussion about the achievement of logistical goals such as delivery reliability in supply networks is currently dominated by planning only. However, a plan can only be successful if control is fully able to implement the latter. As forecasts for the future are prone to errors, the importance of a control that reacts quickly and appropriately to fickle events is increasing [5, 8]. If control fails to act accordingly or does not respond at all, serious consequences will arise such as an increased effort for planning and control, orders not completed to customers satisfaction or ultimately financial losses [9, 10]. This paper proposes a systematic reaction to volatile events by presenting

a holistic approach that classifies events for manufacturing companies organized in supply networks. Based on these classifications, countermeasures can be derived and implemented. While countermeasures in general can be applied to any stage in the supply network as well as any hierarchical level, this paper focusses on countermeasures applied in production control at manufacturing sites. More precisely, countermeasures are used to achieve production planning's goal of ensuring an efficient production despite all unavoidable events by reducing the deviation between current and target values [5]. Therefore, countermeasures can be integrated to Out of Control Action Plans (OCAP) [11], which are widely used in semiconductor manufacturing [12]. A practical implementation can take place for example in the manufacturing execution system [3].

## 2. Research Approach

Research in this conceptual paper has been organized by the information systems research framework (cf. Fig. 1) combining behavioral science and design science paradigms [13]. Relevance of the work is highlighted by the business needs of reacting to events systematically (cf. section 1) as well as the impact of events on businesses (cf. section 3.1). Foundations and methodologies from the knowledge base have been gathered by a literature review (cf. section 3).

The process of designing the approach for an enhanced classification of events has been executed as a cycle repeating the steps of development and evaluation. While the development was guided by literature identified from the knowledge base and its synthesis (cf. section 4) the results were challenged in the step of evaluation by industry experts from supply network planning, production planning, scheduling and manufacturing from semiconductor industry (cf. section 5). Evaluation results built the basis to refine the developed approach. Described in this paper are the final outcomes of this incremental process, not its intermediate results.

While contributions of this work to the knowledge base are outlined (cf. section 6), the application in the appropriate environment by a fully implemented information system is part of further research (cf. section 7).

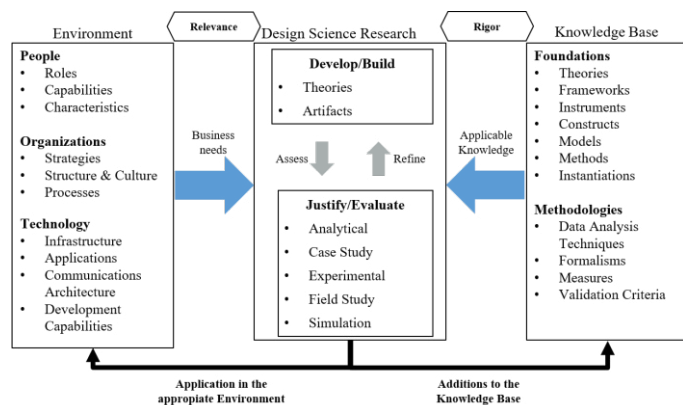


Fig. 1. Information systems research framework [13].

## 3. State of the Art

### 3.1. Event

A very generic definition of events can be gathered from stochastics. In stochastics, events are described as subsets of the result set of a random experiment with a finite number of possible outcomes. The likelihood of an event to happen can be described by its probability [14].

Software development describes a system as event-driven, when it reacts to received events and creates new events. Events are flowing across all components of the system [15]. Therefore, an event is an occurrence within a particular system as well as a programming entity that represents such an occurrence in a computing system, also referred to as an instance [16]. In this sense, an event can be understood as a message containing information about an activity in a system and may be related to other events [15]. The software-based reaction to events is also referred to as complex event processing. Complex event means that an event is the consequence of a multitude of previous events [15, 16]. The applications of event-driven approaches are diverse, also in supply chain management, logistics and production [17, 18].

Typical events in manufacturing companies among others are incoming calls or emails, placed or adjusted customer orders, changed states of machines or resource alarms [7, 16, 19]. Companies have therefore always been event-driven. Increasingly important, however, is the recognition of the value lying in events and their aggregation and correlation, inspired by the findings of software development [15].

The impact of events to manufacturing companies especially in the case of disturbances can be severe. To adapt production to the changed circumstances, re-planning or rush jobs might be necessary. Ultimately, a stop in production can be caused [20, 21]. Consequently, this can negatively impact delivery reliability and customer satisfaction [3, 5]. Therefore, events can result in substantial financial implications [9, 22]. While company-internal events are typically addressed by existing approaches of production control, there is a lack of integration between supply network and production control [5]. In semiconductor manufacturing as well as other industries, a high potential to improve decisions in production control is expected from this integration [20, 23].

### 3.2. Classification

Classification describes a grouping of entities according to some criteria [24, 25]. Therefore, it provides structure by labeling data. The grouping is perceived as quite natural as it is mostly made from a specific viewpoint. The purpose of a classification is to support a person or software in structuring or finding information [25]. Classifications can be distinguished by the number of classes into binary (two classes) and multiclass (more than two classes) as well as by the number of assigned labels into single-label and multi-label [26].

### 3.3. Existing Approaches to Classify Events

Literature provides existing approaches to classify events which are discussed in the following.

Wiendahl and Westkämper et al. [10] name events turbulence germs and binary classify them with regards to order management by two criteria. First, there is a distinction between internal and external causes for events. Secondly, a distinction is made as to whether the event affects planning or control. Not implicitly included, but noted as to be considered, is the subdivision into subjectively perceivable and objectively measurable turbulence caused by events.

Wiendahl [27] builds on this classification and differentiates between cause, stage of supply network and affected decision. Causes are hereby described very detailed for order management and distinguished into variation, fluctuation, adaption, inconsistency and deviation between target and actual value. While the first three are affecting planning, the last one is affecting control. Inconsistency refers to the interface between planning and control. Stage of supply network is mostly analogue to [7] and includes procurement, manufacturing and distribution.

Vakharia et al. [9] focus on disturbances in supply networks and define them as events with negative consequences for normal supply network operations. A multiclass classification is achieved by the criteria cause, life cycle stage, type and decision focus. Cause describes whether the event is caused by acts of nature such as flooding and earthquake or by acts of human, e.g. terrorism or quality problems. The supply network's life cycle stage is inspired by the product life cycle and covers e.g. creation, operation and termination of a supply network. In this sense, a supply network is regarded as a product-specific and temporary individual construct. The type of events is divided into changes in quantity, lead time, quality and technology. The decision focus, on the other hand, ranges from long-term to short-term impact and therefore requires strategical, tactical or operative decision as a reaction.

As regards observation, events can be observed either directly or indirectly through other events [28]. Additionally, events can be classified by their predictability. Thereby, a distinction can be made between expected and unexpected events [16]. Whereas especially unexpected events are often referred to as disturbances or breakdowns, both, expected and unexpected events, can also be neutral or positive [7, 16].

## 4. Concept

### 4.1. Life Cycle of Events

Analogue to the life cycle of supply networks [9, 29] or products [30] there is also a life cycle of events which can be described by emergence, effect and countermeasure (cf. Fig. 2). First, events emerge from a source and are thereby created. Secondly, events are starting to have an effect on their relevant stakeholders. Usually, this is the life cycle stage when these events are detected. Thirdly, countermeasures need to be taken to react on the event. Feedback to the effects

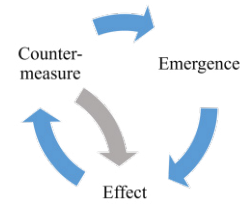


Fig. 2. Life cycle of events.

may occur. Additionally, taken countermeasures can lead to the emergence of new events.

In the sense of this life cycle events are described as occurrences that need to be responded to. Thereby, an event signifies an activity. This understanding is in line with the definition of events in software development, more precisely in event-driven software architectures [15, 16]. Consequently, event handling routines are also necessary for manufacturing companies in order to react to events that have arisen. Countermeasures are therefore always taken when a particular event occurs. Nevertheless, this does not contradict the definition of events in stochastics. On the contrary, events in the sense of software development can also be supplemented by measurements for their probability of occurrence.

Countermeasures suggest disturbances. In an event-driven way of thinking, however, the receipt of a customer order, for example, is also an event that needs to be reacted to. Countermeasures are then not a reaction to an escalation, but to a daily business transaction.

In order to react on events systematically there are four steps necessary (cf. Fig. 3). To start, detected events need to be classified by analyzing their root-cause and effect. The second step consists of a plausibility check that is necessary to filter erroneous outliers. Then countermeasures need to be taken. They are very similar to event handling routines in software development as their boundaries are set by an exact classification of the causing event. In a fourth step, the control variables are derived by means of which processes can be influenced and countermeasures implemented. Ideally, for events causing disturbances this procedure aims at preventing future events instead of only responding to them.

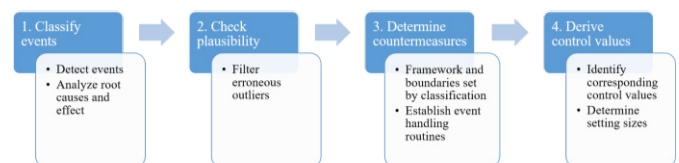


Fig. 3. Step-by-step procedure for event handling.

### 4.2. Classification of Events

Reflecting approaches for the classification of events in literature, they cover only parts of the life cycle described in the previous section. The approaches are mostly low-dimensional. Therefore, they are not able to describe events holistically implicating that the criteria have to be merged and brought together by a new and enhanced approach to classify events. This in mind, the following attributes were synthesized from the literature [7–10, 16, 27–29] (cf. section

3.3) to reflect the entire life cycle of events. The attributes' order is aligned to the life cycle of events from their emergence followed by their effect and leading to a derived countermeasure (cf. section 4.1).

Origin describes the spatial location of the origin causing an event. It can be divided into an internal and an external origin from a company's point of view. While the internal describes events emerging from within the company, the external includes all events from the supply network – both from supplier and customer side.

Cause distinguishes between acts of nature and acts of human that trigger an event. This distinction has a strong influence on the external framework conditions since acts of nature such as earthquakes usually do not only influence the respective supply network but also its surroundings.

Life cycle stage of the supply network describes whether an event happens in design or operation of a supply network. However, these stages must not only be sequential, they can also overlap when an operating supply network is adapted due to changing circumstances. In literature events regarding design are also called conversion drivers. In terms of operation they are described as turbulence germs [10, 27].

Predictability of occurrence specifies the accuracy of a prognosis for the occurrence of an event. It can either be stochastic or deterministic. Stochastic covers a wide range since the accuracy of the forecast can vary vastly. Nevertheless, in practice only a small number of events is deterministically predictable.

Predictability of subject outlines if the subject of an event can be determined by a prognosis. Consequently, it can be completely unforeseen or out of a known set of subjects.

Subject itself characterizes what the event affects. Supply networks include flows of goods, information and money that interact [29]. Ultimately, however, information flows serve to better control material flows and thus optimize cash flows. Therefore, information flows can be regarded as an input, cash flows as an output. This means that all events can be traced back to changes in quantity or time including unexpected examples such as quality problems, which either lead to a time delay due to rework or to a change in quantity due to scrap.

Decision-making horizon decisively determines the scope for the design of countermeasures. It can be distinguished between short-term and long-term. This links back to the management process of supply networks [3] where long-term decisions are considered as planning and short-term decisions as control. It can also accordingly be described as strategic or operative decisions.

Table 1 shows a summary of the attributes with their categorical values. The characteristics for events can also be visualized as shown in the next section.

Table 1. Classification of events for manufacturing companies in supply networks.

Attribute	Category A	Category B
Origin	Internal	External
Cause	Act of nature	Act of human
Life cycle stage	Design	Operation
Predictability of occurrence	Stochastic	Deterministic
Predictability of subject	None	Known set
Subject	Quantity	Time
Decision-making horizon	Short-term	Long-term

## 5. Evaluation

An example for a globally-distributed and complex supply network is semiconductor manufacturing [3, 31]. A semiconductor chip is a highly miniaturized, integrated electronic circuit. To produce up to 40 required layers per chip, up to 700 process steps on more than 100 machines are necessary. This results in a lead time of up to three months [3]. However, with an increasing time horizon, planning accuracy decreases significantly [32]. For example, research at Intel has shown a significant deviation between forecasts and actual demand. Within a time period of ten years they have only matched for 35 minutes [33]. Deviations between forecasts and actual demands result in a large number of events. Additionally, complex chip manufacturing itself is a source of multiple events caused by machine breakdowns and other disturbances [3, 20]. All those factors mentioned above are the reason the novel classification approach has been evaluated with a leading semiconductor manufacturer.

Events compromising the production performance and therefore also the supply networks performance have been discussed in an expert workshop. Involved were experts from supply network planning, production planning, scheduling and manufacturing. The workshop was based on historical company data on the effects of events on supply network performance gathered from existing information systems such as supply chain management and manufacturing execution system. The data were supplemented and put into context by the many years of experience of the experts involved.

The classification presented in the previous section has been successfully applied to all identified events. An exemplary excerpt is visualized in Fig. 4. Thereby, the axis labeling on the left represents category A, on the right category B from Table 1. The similarities and differences between the two events are expressed by the deviations of the characteristic curves.

The exemplary excerpt contains two events. First, a demand change regarding target delivery date resulting from a deviation between forecast and actual customer demand. Second, a change in technology affecting processes in manufacturing. The following explanations refer to the change in demand, since the focus of the paper on automatable tactical decisions is implicitly considered here.



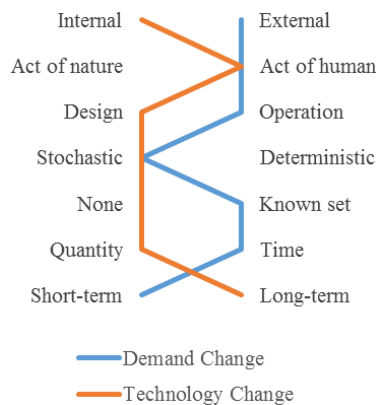


Fig. 4. Exemplary application of the classification for two events.

Analyzing the event of a demand change, based on the state of the art (e.g. classification by [10]), the event would have been characterized as an externally caused event that affects short-term decisions. However, the usage of the classification approach presented in the previous section allows a more differentiated view. Countermeasures can be derived more fine granular and systematic due to the multi-criteria classification. In addition, their implementation can be better tackled.

For example, the information that the occurrence of the event can be stochastically predicted together with the fact that the event is out of a known set and affects short-term decisions lays the foundation for the automation of countermeasures. Another example is that the grouping into a life cycle stage shows that the cause for the occurrence of the event is more likely to be found in operation than in design of the supply chain. Both insights would not have been gained with the low-dimensional classification approaches described by the state of the art. The clear benefit of the approach presented in this paper is therefore the holistic consideration of events by linking multi-dimensional criteria.

An exemplary excerpt of corresponding countermeasures and control values for the event of a demand change derived by this approach is presented in Fig. 5. The decisive factor here is that not only can events be dependent, but that, depending on the nature of the events, combinations of countermeasures may also be necessary.

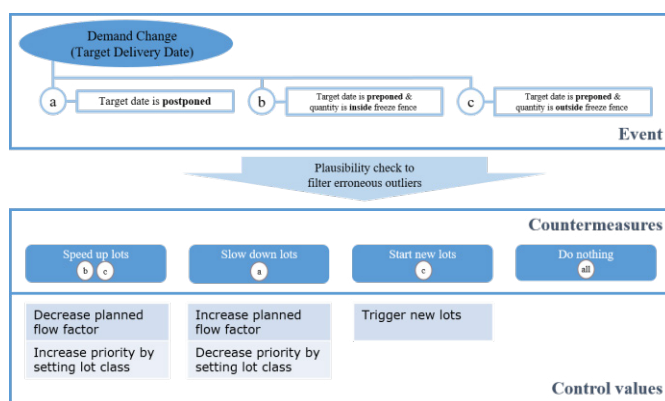


Fig. 5. Exemplary analysis of countermeasures and control variables.

## 6. Conclusion and Contribution

By reviewing and consolidating existing approaches to classify events, this paper presents a unified and enhanced approach to classify events for manufacturing companies in supply networks by seven criteria. Namely these are origin, cause, life cycle stage, predictability of occurrence, predictability of subject, subject and decision-making horizon. The classification is based on the life cycle of events to holistically address all stages. To validate the approach, it has been evaluated with a leading semiconductor manufacturer.

The work contributes to the knowledge base in supply chain management as well as production control by enabling a more differentiated view on events and respective countermeasures. Therefore, previously separated classification approaches from literature have been synthesized to a holistic view. Additionally, this enhanced classification enables a closer integration between the areas of supply chain management and production control. Furthermore, by recognizing the value of events and designing an appropriate systematic reaction this work also contributes to the understanding of event-driven processes for companies in organizational theory.

## 7. Future Research

However, research in this field has not yet been completed. There are further research directions that are currently investigated by the authors. For instance, while a classification provides a basic structure by labeling data, an ontology provides hierarchical structures for classes, assigns attributes and defines relationships. It provides a common, referenceable set of concepts for use in communication [25]. Therefore, the presented classification will be developed further to an ontology that will lay the basis for implementation in information systems.

Additionally, the presented concept will be combined with methods of machine learning [34]. Algorithms of supervised learning (classification) can be used to classify upcoming events on the basis of the classes presented in this paper. This implies that strategies to label training data are necessary. Furthermore, reinforcement learning can assist in deriving goal-oriented countermeasures for events including supervised learning (regression) to determine values for control variables to implement countermeasures.

Moreover, based on the combination with machine learning the concept will be integrated into information systems for planning and control of supply networks and their manufacturing sites. This aims at a closer integration between supply network and manufacturing as well as the automation of systematically responding to events [35]. This offers enormous opportunities to increase cost efficiency in supply networks due to a better control of stocks [23]. However, automation can only be achieved in connected and integrated systems. Therefore, an ongoing digitalization of manufacturing and supply network is necessary for the automation of event detection followed by applying the classification and implementing respective countermeasures. Regarding current state of the art in machine learning, short-

term control decisions are more likely to be fully automated than strategical long-term decisions.

To finish, the generalizability of the approach will be assessed by examining the transferability to other applications and industries. A promising scenario for example is the coupling of production control with energy markets depicted by company-external events containing a price signal to realize an automated demand-side management [36]. While events are expected to be covered by the proposed classification approach, specific countermeasures need to be developed. Nevertheless, attributes and categories for the classification need to be evaluated for additional applications and industries too.

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