Intelligent Product States

Exploring the Synergy of Intelligent Products and State Characteristics in Collaborative Manufacturing

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***Abstract*—Along its lifecycle, a product passes through several states, which can be described by their characteristics. This concept of product state characteristics can be utilized in manufacturing process chains to improve the process quality by e.g., increasing transparency. The basic approach of describing a product state by its state-characteristics can be transferred into a collaborative manufacturing environment, however, in that case, a performing communication structure is indispensable. The goal of this paper is to explore if this concept is applicable for Intelligent Products and to what extent they can contribute to facilitate this endeavor. Accordingly, the idea of Intelligent Product States is introduced, including Intelligent Products sensing their own current state, interacting with the process and / or other products in order to achieve better results (e.g., quality) for themselves or following generations of products. Concluding, a classification model is presented to introduce a first structure of characteristics describing the different levels of Intelligent Product States (IPS).**

Keywords-Intelligent Products; Intelligent Product State; Product State Characteristics

I. Introduction

Effectivity and efficiency are terms that are repetitively taught in management seminars throughout the world. They imply the aim of maximizing the effect and minimize the use of resources in the actions of organizations. When transferred to the business objectives of a manufacturer, these principles manifest in the task of achieving the maximal product quality possible, with minimal use of resources. Both factors can be influenced by the actions of the manufacturer, which are taken within its manufacturing processes. The quality of these manufacturing processes is a key factor to determine the product quality and necessary effort of resources [1].

In a collaborative manufacturing network, qualitative manufacturing processes are not only important to evade costly manufacturing errors, but also to maintain a good reputation within the network. To achieve this, the improvement of process quality necessitates different types of knowledge to determine the current state, the targeted state, and the methodology to get there [2], [3]. From a deterministic point of view, these states can be described with certain characteristics that require knowledge about the current state of the product and the parameters of the process [4].

In order to gain and implement such viable knowledge within a collaborating manufacturing chain, certain capabilities are required. Upon sensing, communication, and interpretation, inter- and intra-organizational barriers may arise towards knowledge exchange [5].

This paper explores to what extent Intelligent Products can facilitate the crossing of the above mentioned barriers and support the measuring, storage, and communication of knowledge based on state-characteristics and process parameters within a collaborative manufacturing environment. Therefore, first, a brief introduction in product state and state-characteristics along with an application scenario in a collaborative environment is given. Followed by an introduction of Intelligent Products as the main pillars this paper is based on. Finally, these concepts are merged into a combined concept, named Intelligent Product State. Concluding, the impact of this new concept on collaborations and collaboration performance is explained.

II. Product State in Collaborative Manufacturing

To provide an overview on the possibilities of state-characteristics to support collaborative manufacturing process chains, this section provides a definition, depicts application scenarios, and introduces intelligent products as a possible approach to realize a knowledge transfer based on state-characteristics.

A manufacturing process chain's purpose is to transform raw materials to final products through different value adding processes in order to satisfy the customer requirements. Consequently, the overarching goal of every manufacturing process chain is to add value to a work piece, component or product [6], (hereinafter the term *product* will be used comprehensively for a physical item) with each process step. Adding value in manufacturing implies physical transformation of the physical product (e.g., transformation of form, hardness, chemical composition, etc.). The specific purpose of every process step is to execute a part of the physical transformation of the product. Thus, the state of the product is changed at least with every (value adding) process. Looking at a product by its state has the advantage of being able to describe or record the transformation. Therefore, looking at the product state along the whole manufacturing process chain accumulates a complete picture of realized measures and transforming processes.

A. *Product State-Characteristics*

The concept of the product state based view describes a product at certain times during a manufacturing process chain or after, through a combination of relevant state characteristics. As definable and ascertainable measures, state characteristics can be described in a quantitative or qualitative way. The state of a product changes due to external influence from one point in time to another when at least one descriptive state characteristic changes [4]. In other words, every product has a deterministic state that can be described at every time by its characteristics. These state-characteristics changes can appear during the whole product lifecycle, but are especially present during the beginning of life phase, the manufacturing stage.

The various characteristics can include measures of physical, chemical, or biological nature (e.g., location, dimensions, chemical composition, and internal tension).

However it is a challenge to identify a set of relevant state characteristics, which are sufficient to describe the product completely. Furthermore, the complexity is increasing when taking the influencing factors, most of all the manufacturing processes, triggering the state change into account.

The state characteristic change can, among others, be characterized as *intentional (planed)*, an example for an intentional state change is through machining, or *unintentional (unplanned)*, e.g., state change through corrosion when a metal part is stored out in the open. A slightly different characterization of state change is if the observer is *aware*, e.g., diameter change after machining or *unaware*, e.g., inflicting residual stress through clamping, of the state change. This aspect is very closely related to the following knowledge reasons.

Further difficulties occur on the attempt to derive an information model on the basis of the product state. The state characteristics and the influencing factors on state change can be *known*, e.g., influence of heat treatment of the harness of steel or *unknown*, e.g., effects of residual stress allocation on distortion *(knowledge reasons)*.

Another aspect, which is more of a technical *nature*, is the state characteristic change *measureable*, e.g., weight or *unmeasureable*, e.g., in an economical sensible way during the manufacturing process (*technical and/or economic reasons*).

The above reasons may make it difficult to derive certain state characteristics; they might though be relevant by having a significant impact on the quality of a product and thus the success of a manufacturing process chain. This impact is described by an exemplary application scenario within the next section, against a collaborative background.

B. *Application Scenario for State-Characteristics in a Collaborative Manufacturing Environment*

In the past decades a trend in manufacturing led from single integrated companies over static supply-chains to dynamic collaborations [7]. It has therefore to be taken into consideration, that manufacturing process chains are not executed at a single location, but spread geographically as well as organizationally instead.

An application scenario for the application of state-characteristics has been described by [8], as in Figure 1. It describes the manufacturing of a steel disc through the different process groups of casting, forging, machining, and heat treatment. In this level of detail, the steel disc passes through five different states, which can be described by certain characteristics. Due to the final heat treatment, internal tensions may become visible by resulting in a change of the disc's geometry. If these geometries exceed acceptable limits, the disc is rendered a defective good. As no practical models to incorporate these changes are available, the geometry is usually adjusted approximately before the heat treatment.

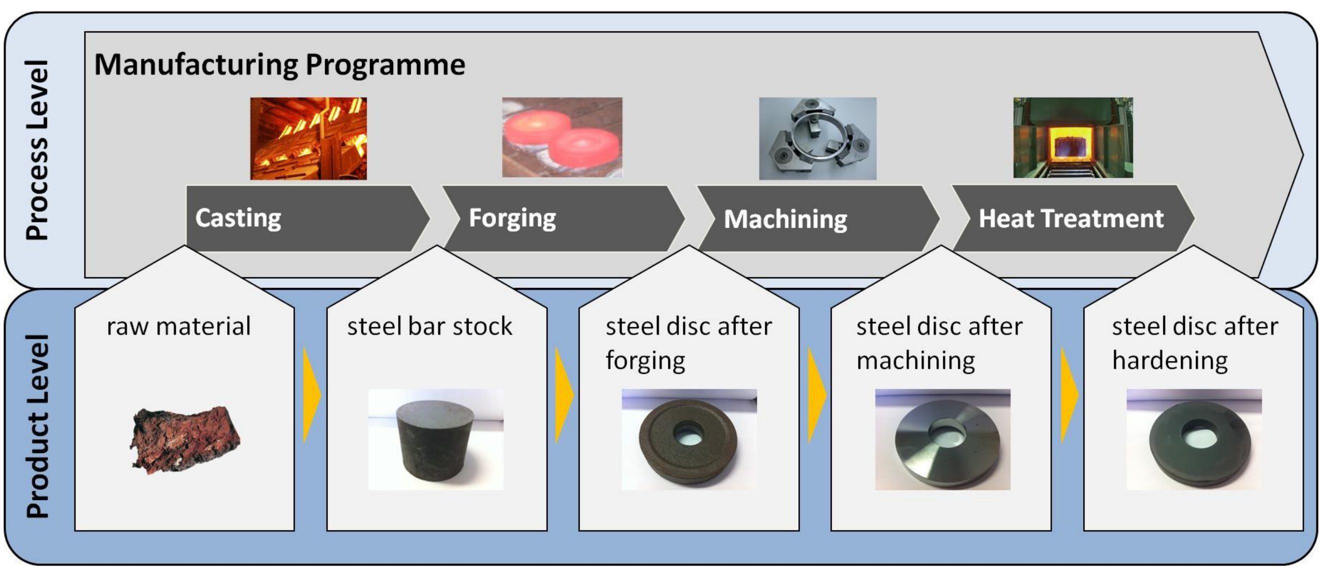

Figure 1. Transforming of a product during a multi-stage manufacturing programme [8]

One simple approach to manage this manufacturing process chain with state-characteristics is to establish a feedback loop about the geometrics of the steel disc after hardening to adjust the parameters of the machining process. This feedback adds transparency to the process chain and can thus increase its quality, assuming that the steel discs after forging have a sufficient homogeneous quality.

In a collaborative manufacturing environment, each process group of this manufacturing program can be executed by a different company. Such a feedback loop would therefore have to be established between organizations. This adds further complexity to the manufacturing, as additional logistics and information exchange needs to be implemented. This approach necessitates a clear structure within the organization of the collaboration to identify, share/distribute and use product and process information [9].

The shift towards collaboration in manufacturing paradigms is accompanied by an increasing development of ICT applications, which enable new approaches of operations management. Intelligent products are one outcome of this development, which can be combined with production states, to create the concept of Intelligent Product State (IPS), as described in the following section.

III. Intelligent Products to Support the Usage of State-Charateristics in Collaborative Manufacturing Environment

The management of a manufacturing process chain from a product state based view can be supported by the capabilities of Intelligent Products. To explore this approach, this section provides a definition of Intelligent Products, and describes the concept of the Intelligent Product State (IPS) along a classification model.

A. *Intelligent Products*

Intelligent Products, also known as Smart Products, are physical items, which may be transported, processed or used and which comprise the ability to act in an intelligent ("smart") manner. McFarlane et al. (2003) defines the Intelligent Product as "[...] a physical and information based representation of an item [...] which possesses a unique identification, is capable of communicating effectively with its environment, can retain or store data about itself, deploys a language to display its features, production requirements, etc., and is capable of participating in or making decisions relevant to its own destiny" [10].

[11] characterizes intelligent products by describing related attributes:

- **Situatedness:** recognition of situational and community contexts.
- **Personalization**: in terms of tailoring the product according to buyer's and consumer's needs and affects
- **Adaptiveness**: the ability to change product behavior according to buyer's and user's responses and tasks
- **Pro-activity**: anticipation of user's plans and intentions
- **Business-awareness**: consideration of business and legal constraints
- **Network capability**: the ability to communicate and bundle with other products

These attributes describe the abilities of Intelligent Products, but are somehow qualitatively and leave a certain variance in their degree of fulfillment. Another dimension to determine the degree of intelligence of Intelligent Products can be added by addressing the characteristics of their tasks. They may exhibit varies from simple data processing to complex pro-active behavior. This is the focus of the definitions in [10] and [12]. Three dimensions of charactering Intelligent Products are suggested by [13]: Level of Intelligence, Location of Intelligence and Aggregation Level of Intelligence, as shown in Figure 2.

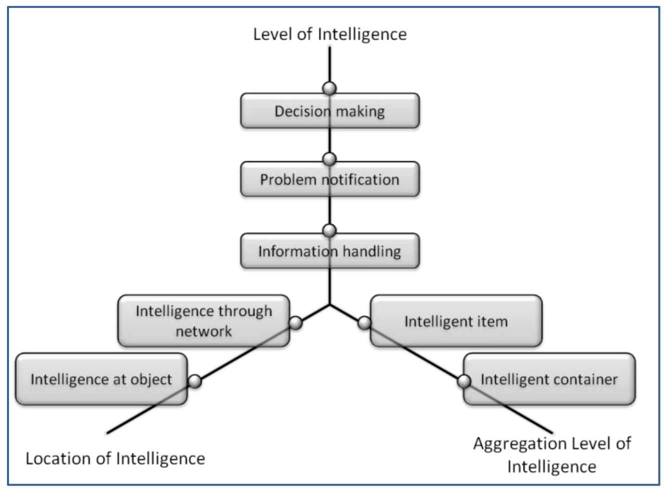

Figure 2. Classification model of Intelligent Products [13]

The first dimension describes whether the Intelligent Product exhibits information handling, problem notification, or decision making capabilities. The second shows whether the intelligence is built into the object, or whether it is located in the network. Finally, the aggregation level describes whether the item itself is intelligent, or whether intelligence is aggregated at container level.

Intelligent Products have been shown to be applicable to various scenarios and business models. For instance, [12] describe the application of the concept to supply network information management problems. Other examples are the application of the Intelligent Products to supply chain [14], manufacturing control [10], and production, distribution and warehouse management logistics [15]. A comprehensive overview of fields of application for Intelligent Products can be found in survey paper by [13].

Thus, an Intelligent Product is more than just the physical product – it also includes the enabling information infrastructure. Intelligent Products can make use of available advanced information infrastructures enhancing the quality of information and accessibility for humans who interact with them. Furthermore, Intelligent Products can make use,

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e.g., of RFID, sensors, and embedded computing throughout their lifecycles in order to collect data for example about their usage, service, maintenance, upgrading, decommissioning and disposal. They thus can contribute significantly to closing the information loops throughout the product lifecycle and are fundamental to a holistic implementation of Closed-loop PLM in many products.

B. Intelligent Product State (IPS)

The gist of the Intelligent Product State (IPS) is the combination of Intelligent Products with the concept of the product state based view. This approach leads to Intelligent Products that support a product state based process management. Against this background, a product state can be intelligent, if its characteristics are monitored by an intelligent product. The extent of this support strongly depends on the product's capabilities. Their contribution can span from passive communication to corrective actions. The different levels of intelligence in managing with state-characteristic can be drawn according to the classification model of Intelligent Products, as shown in Figure 3.

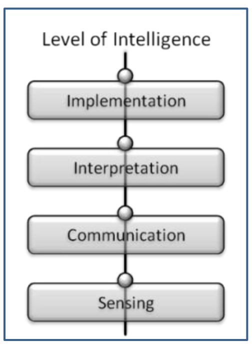

Figure 3. Levels of Intelligence of the Intelligent Product State

These levels of intelligence determine the ability of the intelligent products to process information about their state-characteristics:

- **Sensing capabilities** are the basic requirement to gather any information about state-characteristics. These capabilities require the knowledge about the relevant characteristics, and the methodology to measure them.
- **Communication** capabilities build upon the sensing state-characteristics. The ability of Intelligent Products to actively communicate the sensed information to an internal or external interpreter.
- **Interpretation** is the task of understanding the information by semantic analysis and contextualization.
- The **Implementation** of measures to change its own state is based on the previous interpretation and identified correction potential.

The latter determines a level of intelligence, at which products pro-actively participate in their own management. Based on one or multiple characteristics, they are capable of recognizing their own state, can identify an improved state, and possess the methodology to change accordingly.

Some exemplary applications of these capabilities could be:

- To enable an adjustment of functionalities during usage-phase (e.g., car-seat with settings management)
- To enable a complex customization of the product on instance level (e.g., a car-seat with memory functions for different users)
- To enable more complex functionalities (e.g., a car-seat providing settings in context of a driving situation)

When transferred to collaborative manufacturing, the IPS can be viewed from a different perspective that is described in the following section.

C. IPS in Collaborations

By equipping products with the ability to participate in the control of these processes, collaborators could facilitate the structure of their networks by reducing their necessary management efforts. This especially impacts on the early phase of collaboration. Nevertheless, a new layer of complexity occurs through the distributed process structure, but is accompanied by synergistic factors as well.

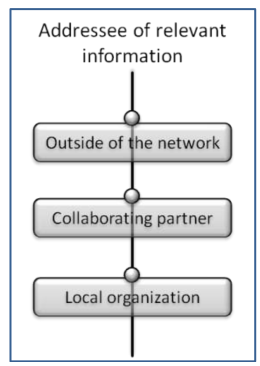

Figure 4. Addressee of Relevant Information of the IPS

If information concerning state-characteristics is obtained within a collaborative manufacturing environment, it might not be directly applicable, but instead address a process at another location. Thus, organizational barriers might be crossed from the sensing of a state-characteristic until the implementation of corrective measures. As visualized in Figure 4, the addressee of relevant information can be located:

- Within the local organization
- Aim at the processes of a collaborating partner
- Outside of the network

While information, addressing the local organization, might be easier to process, the interaction with partners and outsiders becomes more difficult, as not only intra- but inter-organizational barriers apply [5]. Although an Intelligent Product does not face barriers due to personal differences or a lack in encouragement, another layer of organizational barriers arises. Information has to be treated confidential according to the contractual basis and the level of trust in the collaboration [16]. When using IPS in collaborations, data protection should though be considered. Especially, if IPS are active outside of the network, e.g., an Intelligent Product interacts with a user.

One approach to manage communication between Intelligent Products and users is the Product Avatar since its initial introduction as a technical concept, it has evolved into the concept of a customisable "digital representation" of product-related information [17].

This product-user interaction is influenced by the location of intelligence. While an independent intelligent product could also be used offline, a connection to a network is necessary, if the product is depending on the network's intelligence. In collaborative manufacturing process chains, a network connection is mandatory to not only just take correcting or improving actions, but also to allow IPS to learn upstream the manufacturing process chain. The location of intelligence can therefore be considered another dimension to describe the IPS.

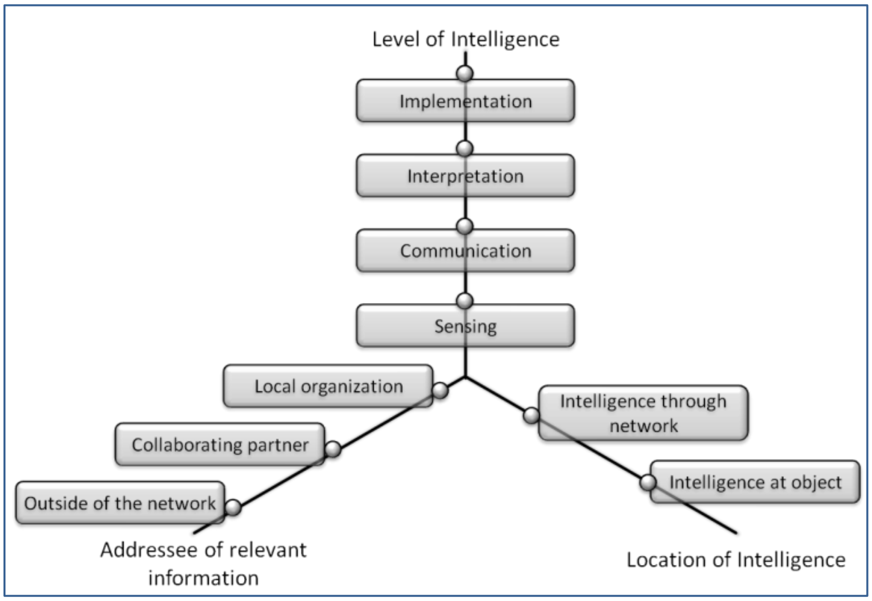

Figure 5. Classification Model of IPS

The Classification Model of IPS is comprised of the Level of Intelligence, the addressee of relevant information, and the location of intelligence. It has been summarized in Figure 5.

IV. CONCLUSION

The capabilities of Intelligent Products can contribute to increase the transparency and thus quality of a manufacturing process chain, based on the concept of product states. This combination has been described as IPS. In a collaborative manufacturing environment, these IPS can facilitate and improve a distributed management, but at the same time requires an open-minded culture throughout the process chain and faces concerns in sort of data protection.

The research of this paper was somehow limited, as only the application of IPS on the manufacturing of products has been considered. But also "virtual" state-characteristics, such as successful quality control, or customer satisfaction can be defined. Accordingly, an intelligent product-service combination, which is aware of its own state and is able to adjust itself to act in order to achieve a better result, could be applied to realize an Intelligent Service State.

This paper describes the concept of IPS, which is only the theoretical product of the combination of product states with Intelligent Products. This concept will be elaborated, and supported by a case study, which will be conducted for its application.

Upon this, future research will explore the characteristics of intra- and inter- organizational barriers to exchange information and knowledge against this background, as they significantly differ, as soon as the exchange is supported by the application of Intelligent Products.

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