TOWARDS ROBUST ORDER PROCESSING THROUGH QUALITY INTELLIGENCE

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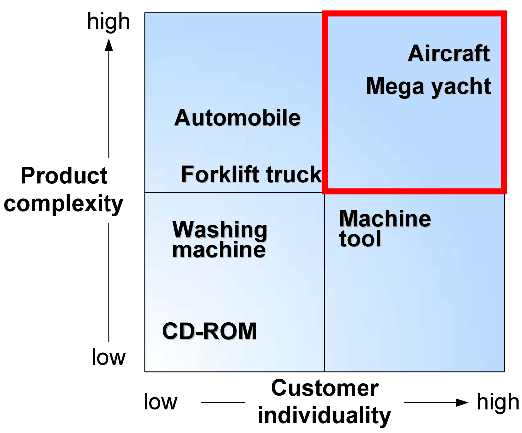
Abstract

In this paper we present our paradigm of quality intelligence, which is to make a better use of the companies' data for initiating improvements of the customisation process. The main target is to derive effective actions in order to realize a continuous improvement of products and processes; either reactive or preventive when handling new customer orders.

1. Introduction

A very special, customized aircraft interior is the main possibility of an airliner to stand out from its competitors. Hence the challenge for an aircraft manufacturer is to cope with the fact that almost every aircraft is unique, which is not only valid in terms of interiors but also in terms of air conditioning-, water/waste- or information-systems.

Fig. 1. Characteristics of Products



On the engineering side again and again complex technical solutions have to be developed and realised. From a manufacturing point of view the challenge is the high product complexity and that the equal versions of an aircraft are not being built in a single batch (mixed model assembly).

Considering the high product complexity it is obvious that disturbances in the assembly line can not be avoided. But, they have to be kept on a low level. To further this target an aircraft industry specific methodology is being developed at the Institute of Product Development and Engineering Design at the Hamburg University of Technology.

2. The Need for Quality Intelligence

What we have learned during our research project in the aircraft industry is that except for some very specific disturbances the majority of occurring disturbances are rather known or similar than new. This is not aircraft industry specific, because we observed the same effect in other industries like ship building industry. We also found out that 60% of the failures in manufacturing are known or at least similar [1].

2.1 Status

During our research project, we analysed the reasons of this problem by structured interviews and workshops with employees from different departments. What has always been primarily mentioned is that the following boundary conditions aggravate an effective elimination of disturbances:

- High product- and process complexity due to the variety of systems, huge product dimensions and the number of parts and components (Fig. 1).

- Highly customized, low volume products with many technically complex requirements in combination with late changes by the customer, even after start of production.

Of course every single disturbance is being systematically eliminated but still the question arises, why known or similar disturbances are recurring. Following our analysis the main cause is that information about disturbances is not being used in an optimal way to learn. This can be explained as follows:

The first reason is the missing possibility to consolidate information about similar disturbances. Changing a part or component will eliminate a specific cause for an individual disturbance. But, in the case of low-volume assembly and a highly customised product, not all parts or components are identical. Therefore an analysis regarding typical disturbances, which is based on part or component numbers, is not effective; similar disturbances can only be avoided if the systematic causes of the disturbances are known.

The second reason is that only very rough analysis of the disturbances can be done automatically, because the disturbances are described in text form without restrictions regarding the usable terms. In this context it is aggravating that the effects of the disturbances are difficult to quantify.

The third reason is the misleading calculation of potential savings. Generally, it is worth eliminating the root causes of a disturbance if the costs for recurring disturbances offset the costs for changing the product definition. Due to extended requirements regarding certification and documentation, the time and effort for a product change is high. In contrast, the potential savings are quite low in the low-volume assembly if only specific components are being considered and not a class of components.

Computer Aided Quality Assurance Systems (CAQ-Systems) should contribute to resolve these problems, because they specialise on the processing of quality- and disturbance information. An evaluation of commercial CAQ-Systems has revealed that the analysis of the information is basically limited to control charts (statistical process control), failure frequency or Pareto charts. The generated indicators sometimes have low informative value and it cannot be drilled-down into detailed information [2]. A more sophisticated approach in terms of analysing methods has been developed by Schrems, but it is specialised on the high-volume manufacturing and considers quantifiable measures like the deviation of the nominal diameter of machined parts [3]. All in all, these approaches focus on quantitative inspection features of the manufacturing domain. Hence the analysed tools and methods do not address the needs of companies with a low-volume assembly line. Data which can be gathered in the assembly is mainly categorical and cannot be collected automatically - especially in manual assembly.

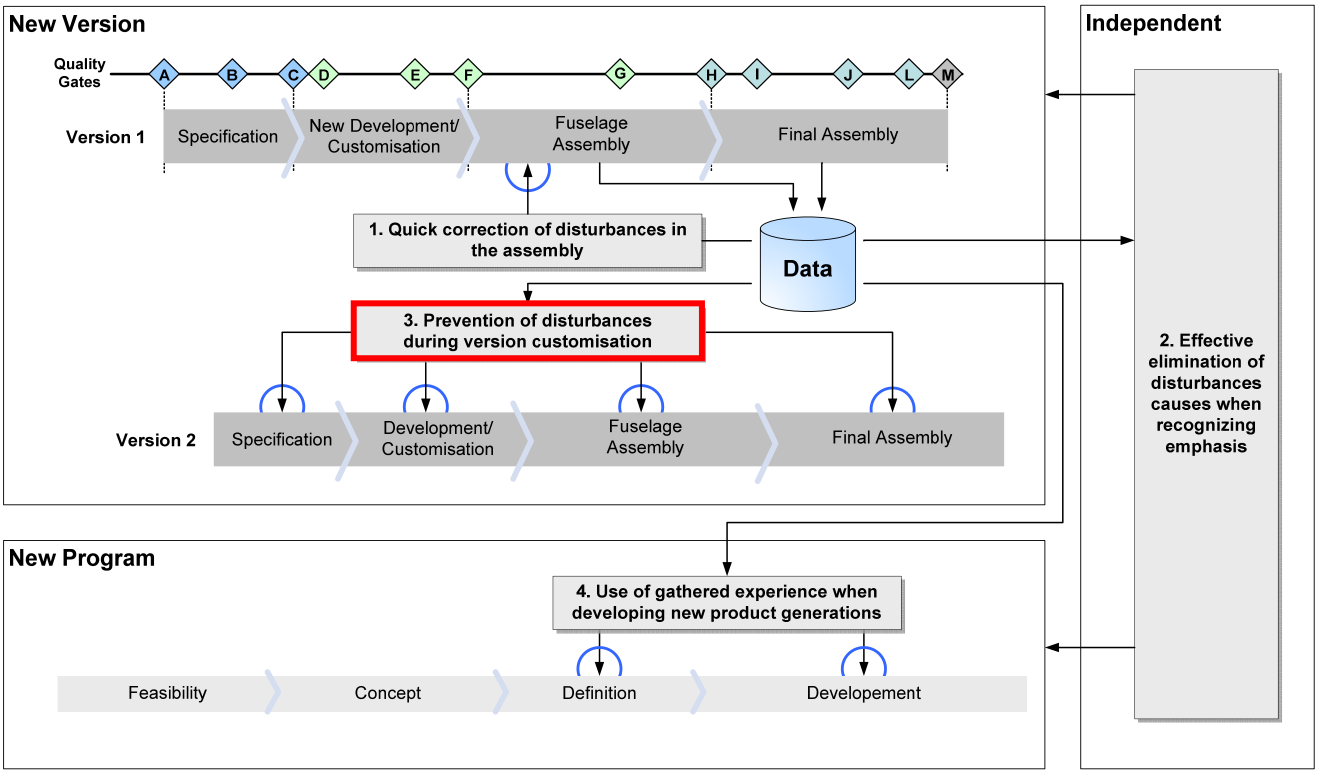
Other approaches are based on the Failure Modes and Effects Analysis (FMEA) method. Edler, for example, presents a concept where a Design-FMEA is being augmented with data from the use of the product, in order to get help on the development of the causal interrelations and by the objective risk assessment. Although this is a promising approach, it seems non-applicable for the use in the customer-specific variant design, because of the big effort to do a FMEA [4]. Kmenta et. al. developed a so-called mixed-model FMEA, whereby defects in the assembly should be reduced by asking questions on the basis of past assembly, service or warranty problems [5]. This is a promising approach even though the questions that are being asked are less detailed and no immediate actions are being taken if serious disturbances have been detected.

2.2 Targets

Basically, two aspects have to be improved by developing and implementing new methods and tools. First of all, taking the complexity of the product and process into account, a better knowledge about the situation in the assembly is needed. Revealing hidden relationships, getting more detailed and quantified information about typical disturbances of past orders and enabling a company wide easy access to this information are corresponding challenges. The second challenge is to make sure that, based on this knowledge, the correct consequences and actions are being taken.

possible in the customisation process. It is characteristic of our approach that the learning from past disturbances is based on the analysis of existing data. The advantage is that data is used

Fig. 2. Basic Targets



We subsume this into the term Quality Intelligence, which is to use all available and relevant data within a company to derive effective actions for eliminating and avoiding disturbances as well as to improve the product and process (data-driven decision making).

In the named context the following targets can be derived (Fig. 2):

1. Quick correction of a single disturbance through the use of the experience from past disturbances.
2. Effective elimination of disturbances when recognizing emphasizes.
3. Prevention of disturbances during customization process.
4. Use of the gathered experience when developing new product generations.

In this paper we focus on the third part: Prevention of disturbances at the earliest stage that is needed anyway for the elimination of a special disturbance (secondary data analysis). This is an important factor when considering the employees' high workload and time restrictions. The extra time and effort that is needed for the rather strategic and long term problem solving activities has to be as low as possible.

3. Concept

Generally many sources for realising improvements exists: Customer claims, suggestions of improvements from the shop-floor worker or disturbance information (Fig. 3). In following sections we focus on the latter, but the approach would be the same for every additional category.

Our basic approach has five phases. It is to collect and consolidate data from different sources; analyse the data to find either order relevant data or to detect serious disturbances; learn about the root causes and act by developing actions in engineering and manufacturing.

3.1 Multidimensional, Hierarchical Data Model

As can be seen in Fig. 3 information from different sources is being collected. For us disturbances are every kind of deviation from the planned manufacturing- and assembly activities. A typical example for a disturbance in the aircraft industry is that a worker wants to fix a wiring, but he is not able to do so because a bracket obstructs the access. The causes of disturbances are wide ranging, e.g. a suboptimal assembly process, a wrong design or part distribution. Further causes for disturbances are omission, incorrect installation or installation of the wrong part [6]. The root cause for the mentioned example could be that during development of the wiring its surrounding area has not being taken into account carefully.

To derive effective actions, this information has to be detailed, precise and quantified. In addition, the information should be available throughout the company and on every hierarchy level. Because of the particular circumstances of low-volume assembly, the main challenge is to consolidate the information about similar disturbances. However, not only consolidated information but also information of an individual disturbance is needed during the learning process.

In order to meet these requirements, the data model has to be multidimensional and hierarchical. In this model, the data can be viewed as an n-dimensional data cube. A data cube consists of facts, dimensions and hierarchies. Facts, like *disturbance costs*, are numerical values, which are in the focus when consolidating the information. Unlike the facts, the dimensions are descriptive and allow different views on the facts. If the dimensions have a vertical relationship of the single elements, they are called concept hierarchies (Fig. 4).

Fig. 3. Five Phases to Improvement

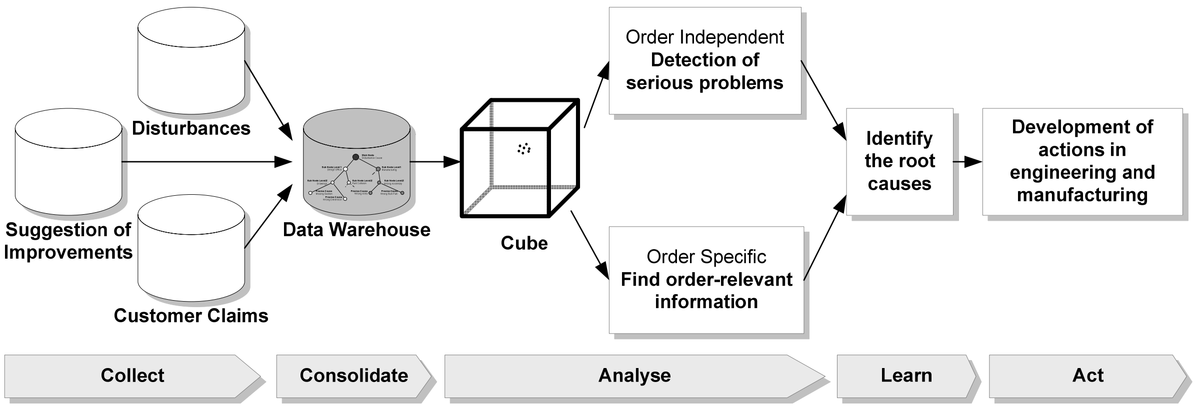
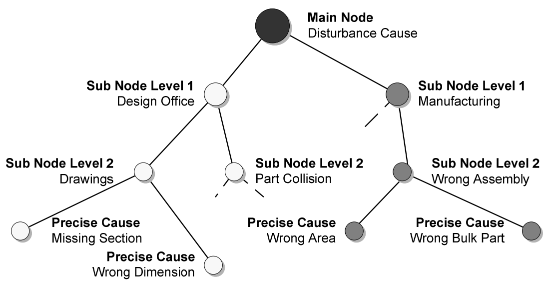


Fig. 4. Concept Hierarchy *disturbance cause*



In our research project we have initially generated this data model within several workshops with our industrial partners from the engineering and manufacturing domain. Following that, we filled the concept hierarchies based on an analysis of past disturbance descriptions.

Finally we verified the data model and the concept hierarchies based actual disturbance descriptions. Our concept hierarchies are sorted according to their process, but many others are also possible, e.g. outcome-based classification of Hinckley [7].

However, we have learned during this phase that the most effort is needed to define an unambiguous, easy to understand concept hierarchy with the right level of detail. But, nevertheless, we believe that this categorization is the best possibility to consolidate information about disturbances, customer claims or suggestions of improvements.

Based on the stored information, there are numerous methods available to analyse the data. Basically it can be distinguished between methods that are hypotheses based and hypotheses free, whereas a hypotheses is a user-query on the data. Hence in the first case, the user has an idea what he is looking for in the database and can define an appropriate query. In the second case, the user is not defining queries and instead a tool is uncovering unknown pattern and relationships semi-automatically, which the user has to assess regarding correctness and plausibility.

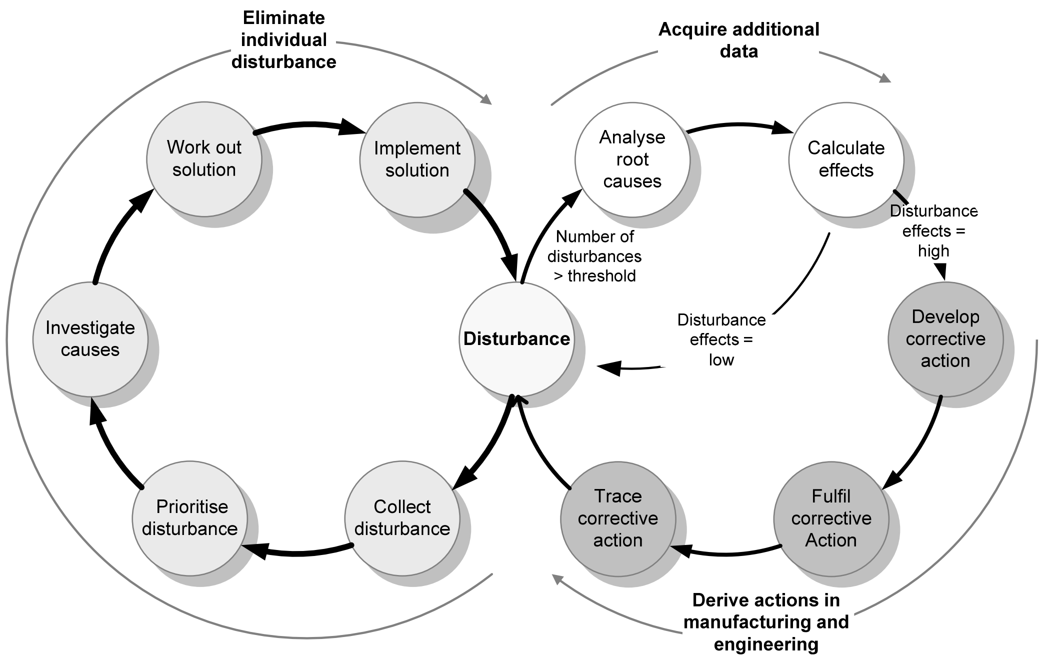
3.2 Escalation Principle

Generally to eliminate problems within the product or the process it is necessary initiate a process where root causes have to be analysed and corrective actions have to be developed. But, not always it is worthwhile to initiate this process, because there is a trade off between the effort for this process and the potential saving through the prevention of recurring disturbances. To support the employee by this decision the escalation principle has been developed.

This principle is implemented in an information-system: When a new kind of disturbance arises only the elimination of the single disturbance is being initiated and only the information that is needed for this purpose is being gathered. Necessary sub processes are: Collection of information about the disturbance on the shop-floor, prioritisation of the disturbance, investigation of the direct causes, work out and implementation of the solution.

Not until the threshold of the frequency of a disturbance category is exceeded further information about the root cause is being gathered. In this sub process it is the first time that

Fig. 5. Escalation Principle



extra information is being gathered, because information about the root causes is not needed to eliminate a single disturbance. However, the advantage is that the Information is being collected, when the employees are anyway working on a special problem; by this approach knowledge regarding a disturbance category is continuously added with quite a few effort. In this sub process also the effects of the disturbance is quantified. This information is being used for the decision, when to initiate the corrective action process. Because this process can take much time and effort it is important to quantify the potential savings in advance: If the disturbance effects are above a predefined threshold the corrective action process is started, where corrective actions are being developed, fulfilled and traced.

3.3 Deployed Methods

Main methods, which are being deployed are Online Analytical Processing and Data Mining that are known from the Business Intelligence domain. Business Intelligence targets to find actions, that leads to a competitive advantage, where extended use of the companies' data is the key [8].

Characteristic for Online Analytical Processing (OLAP) is that the aggregation of data is only possible for numerical data and the user has to decide which dimensions and measures should be analysed. Data Mining in contrast is a rather automatic.

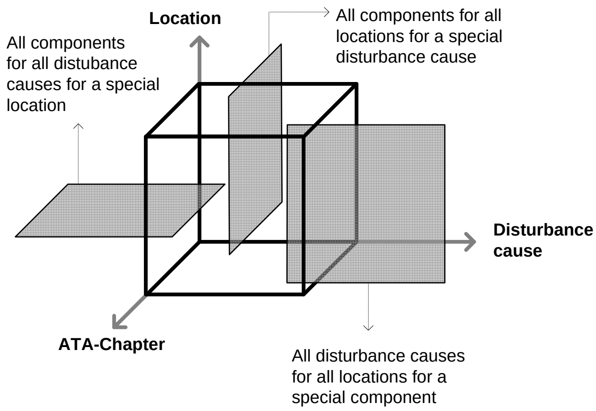
In this paper we focus on the use of OLAP Methods. Refer to our previous work for a more detailed description regarding the deployment of Data Mining methods within our concept [9].

3.3.1 Basics of Online Analytical Processing

In our concept we want to provide a data source for many users throughout the company, who should be able to analyse the data intuitively with short response times. This is the function which can be done by OLAP methods.

The most important function for filtering the data in a data cube is the slice operation. As can be seen in Fig. 6, the slice operator generates a two dimensional table by keeping one value fixed.

Fig. 6. OLAP Operator *Slice*



OLAP operations are rather used for order specific, preventive actions in our concept.

3.3.2 Prevention of Disturbances in the Customisation Process

In order to avoid disturbances when dealing with new customer orders information of past disturbances should be used for preventive actions as early as possible.

But the derived actions can only be based on past information of disturbances. Hence, the challenge is to find completed orders, that are similar. But, in the very early phases of the process the available information regarding the new order is not detailed enough to map it onto the completed ones. Having this in mind, we selected two scenarios about when to use the information:

a. In the early phases, when the customer has specified its requirements
b. During Detailed Design Phase

a. In the Early Phases

Questions that arise in the early phases of customisation are:

Which are the most critical claims of a specific customer during his last project? This is of interest when handling a new customer project to create preventive actions.

Which customer requirements caused the main disturbances in the assembly? Knowing this will help to prevent disturbances when a new customer has the same requirement like a known customer.

In addition to the consolidation of one dimension, also different dimensions can be consolidated. We use this possibility to consolidate the disturbances on the path *drawing*, *modification* and *customer requirement*. Thereby we can analyse which disturbances a customer requirement has caused.

Furthermore it is of interest to find information regarding similar requirements of other customer requirements.

If potential disturbance have to be searched, a similar customer order has to be found, which can be done as follows:

- Classification: In our case the customer requirements are being classified. This is the direct way to find similar requirements. Once the new customer requirements are being classified, the information about past problems can be retrieved.
- Text based search: An employee who is engaged in the early phases, can search the database with similar key words to find relevant customer requirements.
- Experience: A very experienced employee knows which customer requirements are similar and can directly search for relevant data.

If relevant data has been found checklists and reports can be generated to make sure the problems will not occur again. In some cases it might be necessary to further analyse the root causes of the disturbance categories before defining appropriate actions. Finally the effectiveness of the actions has to be checked.

As we know from our research project, it has to be distinguished between product specific and product independent disturbances. An example for product specific disturbances is that a component cannot be assembled. Product independent disturbances are for example missing information. Only information about product specific disturbances should be referred to the customer requirement; information product independent disturbances is always relevant.

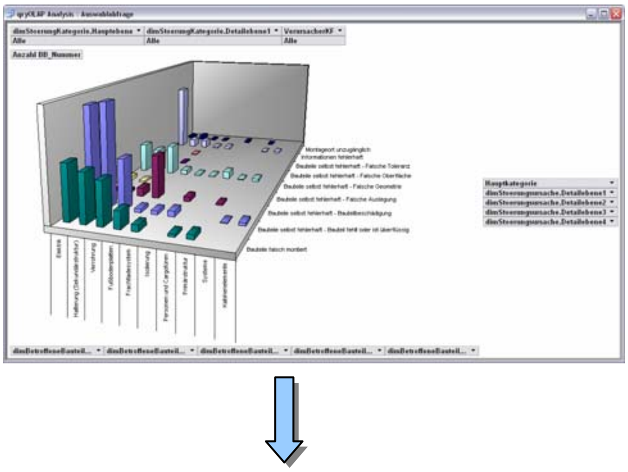
b. In the Detailed Design Phase

Compared to the preceding approach, the use of disturbance information is easier during detailed design. The reason is that the product is already specified very well.

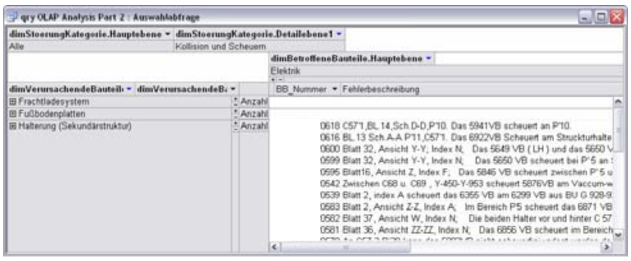
Typically a designer is responsible for a specific group of components and a specific location. Giving the possibility to analyse what kind of disturbances are being caused in this area will help a designer to prevent disturbances when adjusting a related component. To do so, detailed information, e.g. the full text disturbance description is needed. Because of the high capability of the OLAP method it is possible to retrieve this information on click.

Fig. 7. Screenshot of the Software Prototype

a) First step: Overview regarding the relation *component* and *disturbance causes*



b) Second step: On-Click Drill down into detailed disturbance information



Getting information of past disturbances based on ATA-Chapter and location will provide the designer with useful information. The sample query would be like:

Which disturbances have been caused by which ATA-Chapter at a specific location in the aircraft? With the aid of the detailed information the designer knows for example that the components he is responsible for very often clashes with a specific component at a specific location. A possible preventive action would be the systematic check of the Digital Mock-Up.

3.3.3 Verification of the Method

During our research projects we have validated this method by integrating sample data into a software prototype (Fig. 7). The discussions with the domain experts have shown that an OLAP based analysis is an important milestone to get a better insight into the typical assembly-disturbances.

4. Summary and Outlook

In order to win through on a competitive market companies need robust and lean processes.

In this paper, we have presented our paradigm of quality intelligence where, the information about disturbances is being used to derive preventive actions, when handling new customer orders. Sophisticated tools are available to implement the OLAP and Data Mining methods in an industrial environment. At present a software-prototype is being developed that will be used to demonstrate the usefulness of these methods.

It has to be emphasized that the systematic collection, analysis and provision of consolidated information cannot automatically achieve an improvement. Spear mentions that one of the success factors of the Toyota Production System is the extensive, direct observation of the assembly [10]. Our data-driven approach does not contradict this; with our approach we even support this idea by giving hints where to look in more detail. In addition, to derive effective corrective actions, the related processes and organisational circumstances have to be considered as well as the methodical support and motivation of the people involved. To analyse these soft aspects in more detail and to identify possible solutions is one of our upcoming research activities.

References

[1] Pfeifer, T., *Qualitätsmanagement: Strategien, Methoden, Techniken.* 2001, München [u.a.]: Hanser.

[2] Nyendick, M., *Vom Leidsystem zum Leitsystem - Qualitäts- und Produktionskennzahlen.* Quality Engineering, 10/05, pp. 8-10.

[3] Schrems, O., *Die Fertigung als Versuchsfeld für die qualitätsgerechte Produktoptimierung.* Berichte aus dem Institut für Maschinenelemente. Universität Stuttgart, 2001, Stuttgart.

[4] Edler, A., *Nutzung von Felddaten in der qualitätsgetriebenen Produktentwicklung und im Service.* Berichte aus dem Produktionstechnischen Zentrum Berlin. 2001, Berlin.

[5] Kmenta, S., Cheldelin, B., and Ishii, K. Assembly FMEA: *A Simplified approach for evaluating assembly errors.* In: 2003 ASME International Mechanical Engineering Congress & Exposition, November 16 -21, 2003, Washington D.C.

[6] Cheldelin, B. and Ishii, K. *Mixed model assembly quality: an approach to prevent human errors.* In: 2004 ASME International Mechanical Engineering Congress & Exposition, November 13 - 19, 2004, Anaheim, California, USA.

[7] Hinckley, C.M., *Make no mistake*. 2001, Portland, OR: Productivity Press.

[8] Knoke, S., *Durchblick erwünscht: Alles über Business Intelligence, OLAP und Data Warehouse*. Der Entwickler, 05/05: pp. 19 - 24.

[9] Wuenscher, T., Feldmann, D.G., and Krause, D. *Product and process improvements based on data mining of shop-floor information.* In: Proceedings of the 9th International Design Conference DESIGN 2006, May 15 - 18, 2006, Dubrovnik.

[10] Spear, S., *Management à la Toyota.* Harvard Business manager, 2004. 08/04.

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