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ScienceDirect

Procedia CIRP 118 (2023) 122–127

www.elsevier.com/locate/procedia

16th CIRP Conference on Intelligent Computation in Manufacturing Engineering, CIRP ICME ‘22, Italy

A Standardized Description Model for Predictive Maintenance Use Cases

Yannic Wolf[a,*], Lennard Sielaff[b], Dominik Lucke[b,c]

[a]Chair of Transportation Systems Engineering, Technical University of Munich, Arcisstraße 21, 80333 Munich, Germany

[b]Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Nobelstraße 12, 70569 Stuttgart, Germany

[c]Hochschule Reutlingen, ESB Business School, Alteburgstraße 150, 72762 Reutlingen, Germany

* Corresponding author. Tel.: +49-89-289-10460; fax: +49-89-289-10469; E-mail address: yannic.wolf@tum.de

Abstract

Using predictive maintenance, more efficient processes can be implemented, leading to fewer maintenance costs and increased availability. The development of a predictive maintenance solution currently requires high efforts in time and capacity as well as often interdisciplinary cooperation. This paper presents a standardized model to describe a predictive maintenance use case. The description model is used to collect, present, and document the required information for the implementation of predictive maintenance use cases by and for different stakeholders. Based on this model, predictive maintenance solutions can be introduced more efficiently. The method is validated across departments in the automotive sector.

Keywords: Smart factories; Maintenance strategy selection; Predictive maintenance

1. Introduction and Motivation

An increasing number of original equipment Manufacturers (OEM) see predictive maintenance (PdM) solutions as a competitive advantage, leading to increased availability and lower failure risk of products. Automobiles are a group of products where classic predetermined maintenance strategies are still dominant, like a regular checkup or an oil change after a certain number of kilometers or a certain amount of time.

Modern automobiles are already acquiring a large number of sensor data required to implement a broad range of functions such as the electronic stability system (ESP) or the heating, ventilation and air conditioning (HVAC) system. Most sensor data are processed locally in Electronic Control Units (ECUs) and current on-board network architectures enable sending selected sensor values to a database of the OEM [1]. Compared to other capital goods, automotive OEM have already a large data infrastructure set up and a high amount of data is available over different products and variants.

In addition to the multiple sensors in one car, the large fleet size of the vehicles allows scaling effects when developing and deploying services based on data and information gathering.

In recent years, artificial intelligence applications have made huge steps in performance and applicability. The evolution of supervised and unsupervised machine learning (ML) techniques towards powerful data analysis tools has opened up numerous new opportunities for PdM [1], [2]. However, the development of a predictive maintenance solution is still a highly component dependent, time consuming and interdisciplinary task. Here, a misunderstanding of the use case and communication problems between all involved development partners are common problems. Also, the development of a PdM solution for a similar component often starts all over again, instead of reusing and adapting existing solutions [3]. Therefore, new approaches and methods are required to accelerate and optimize the development of PdM solutions. Not only the tools needed to arrive at solutions but also the improvement of the developing process itself has great potential. One major field of possible improvement is standardization which itself enables further improvement

10.1016/j.procir.2023.06.022

possibilities. Standardized process are more easily controlled and compared to allow for example easier best practice documentation. The described communication issues and starting at scratch each time can also be addressed by a common, cross-domain standardized description of PdM use cases.

To overcome all these issues this paper presents such a standard description of a PdM use case, which also can be used to accompany and characterize the PdM solution during the entire development process from idea to roll out with the focus on simplifying communication between domains and possible reuse of certain necessary development steps.

2. Related Work

For the development of this standardized description model for PdM use cases, a two stage literature review has been conducted, using relevant key words to research related works in multiple scientific data bases (e.g. SCOPUS, Web of Science) and Google Scholar. The first goal is to provide an overview over the current developments in scientific works regarding PdM applications, with a focus on automotive PdM applications. In order to find relevant literature concerning the PdM applications with a focus on automotive the keywords “Predictive Maintenance”, “Automotive”, “Fleets” and “Review” delivered sufficient contents and two publications give a thorough and contemporary view on current scientific progresses. The results are summarized in the following.

A detailed overview over industrial PdM applications is offered by Zonta et al. [3] analyzing multiple PdM-related works in a structured manner. Zonta et al. identify a focus shift from engineering to methodological research including Lee et al. [4] and Gunes et al. [5]. Both are focusing on cyber-physical system applications, but have not proposed a standardized cross-domain description template for PdM use cases. Theissler et al. [6] confirm this drift in automotive PdM applications research, categorizing automotive PdM papers regarding their use case and machine learning perspective. Therefore, Theissler et al. classify their related works into the four categories “Maintenance Modelling”, “PdM & ML”, “Data-based models & PdM & Automotive” and “Automotive & ML” but confirms the lack of scientific focus on organizational and management focus [6].

The second step aims to supply an overview of different frameworks or standardizing structures applied in PdM and especially describing PdM use cases. Varying combinations of the keywords “Predictive Maintenance”, “Framework”, “Use Case Description” and “Methodology” gave the results represented in the following overview.

There are multiple approaches for use case descriptions in the broad spectrum of industrial AI. One early approach to formalize use cases in industrial software systems is applied by Bertolino et al. [8]. Referring to “system-families or product lines”, this work identifies cost saving opportunities utilizing similar software product architectures while respecting individual characteristics. In order to formalize use cases, a template by Cockburn [9] is applied, suggesting an Input-Output-Model with additional information regarding resources and limitations. Souza and Cavalcanti [10] apply the formalization to well-known software modeling languages like UML, MoLIC and ALaDIM and thus substantiate its generalizability. First applications of use case formalization in the context of predictive maintenance are found in the work of Grambau et al. [11]. While analyzing social media data to mine maintenance features for a power tool producer, this work proposes a reference architecture covering the characteristics of PdM for product service systems. With a special focus on the concept phase, Grambau et al. work introduces a PdM framework for the integration of multiple data sources to enrich existing PdM models. Their work is comprehensive and follows a structural approach showing its high relevance for industrial applications, but is not integrated into an overall framework for industrial predictive maintenance models especially focusing on AI applications [11].

In conclusion, regardless of the growing demand, there is no standardized approach for use case description, especially in the automotive PdM context which is highly specific in its environmental impact and industry characteristics. The results of this paper aim to close the identified gap.

3. Description Model

The idea is that the standardized use case description accompanies and characterizes the PdM solution during the whole development process. Therefore, it should be a living document, fulfilling the requirements of the different development phases. To address the described challenges of interdepartmental communication for the development of predictive maintenance solutions, it is necessary to develop a common understanding of the use case. Also, for reuse and adaption of existing PdM solutions a detailed characterization is required. Therefore, it is proposed to start with a high-level use case description (Fig. 1). The focus is to develop a common understanding of the use case between all stakeholders. In the

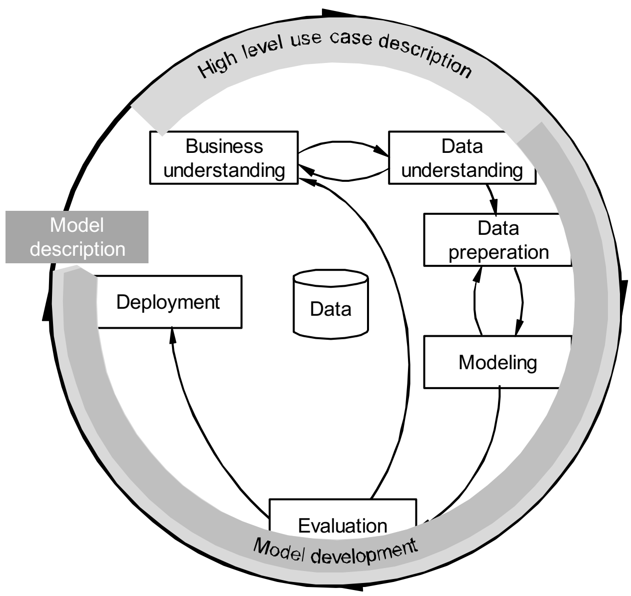

Fig. 1. Phases covering the use cases description based on the CRISP-DM according to [7].

following phase, the use case description has to be detailed for the model development mostly in terms of the input data and output data. At the same time, the high-level use case description is continuously updated, so that both specifications form a complete characterization of the PdM solution at the end.

3.1. High-level use case description

For the high-level use case description, the fast and easy interdisciplinary applicability is one of the main requirements. In order to achieve this, the template presented is inspired by the idea of the business model canvas [12], including a recommended order to fill out the information. The PdM use case description template with the recommended order and its different fields is represented in fig. 2.

In order to be able to organize different use cases, the field at the top right contains the organizational details (field no. 0). The contact person, date and version of the use case description are recorded. Versioning the use case description allows the organization and clear documentation of the documents in retrospect. These fields should be updated each time the use case documentation is changed. First field to be filled (field no. 1), describes the technical system associated with the product or component for which the use case is developed. The goal is to describe the system in such a way, that other users can understand the system described without getting lost in details and at the same time to narrow it down as precisely as possible in order to be able to specifically address the technical challenges. Here, also a description chain can be used, starting at the superordinate and continuing in a chain going further into details. After the component of the use case is described, it is necessary to formulate the objective(s) of the use case, as they are seen by the customer (field no. 2). Here it needs to be specified whether the solution enhances or replaces an already existing service or if a new solution needs to be developed. The focus on the customer's perspective enables the development team to direct the focus on the customer benefit instead of only focusing on the technical possibilities. The customer of a use case is more likely interested in the benefits provided by a monitoring solution rather than the technical details of how the monitoring works. With the information about the component and the goal of the use case, the title can be formulated (field no. 3). The title should be as descriptive as possible and should not contain department-specific abbreviations or synonyms. It is also important to ensure that the title includes not only the component description but also the objective of the use case, so that different use cases on the same component, such as wear monitoring or wear prediction, can be distinguished on the basis of the title alone. For this, the title should be formulated after agreeing on the specific component and the objective of the use case. Once the title, component and objective have been formulated, the brief description of the use case can be filled in (field no. 4). The description summarizes the information that has not yet been required in the other fields, including all information available on the wear mechanism specific for the use case. If available, this field may also contain suggestions for technical specifications, required sensors, or other ideas that

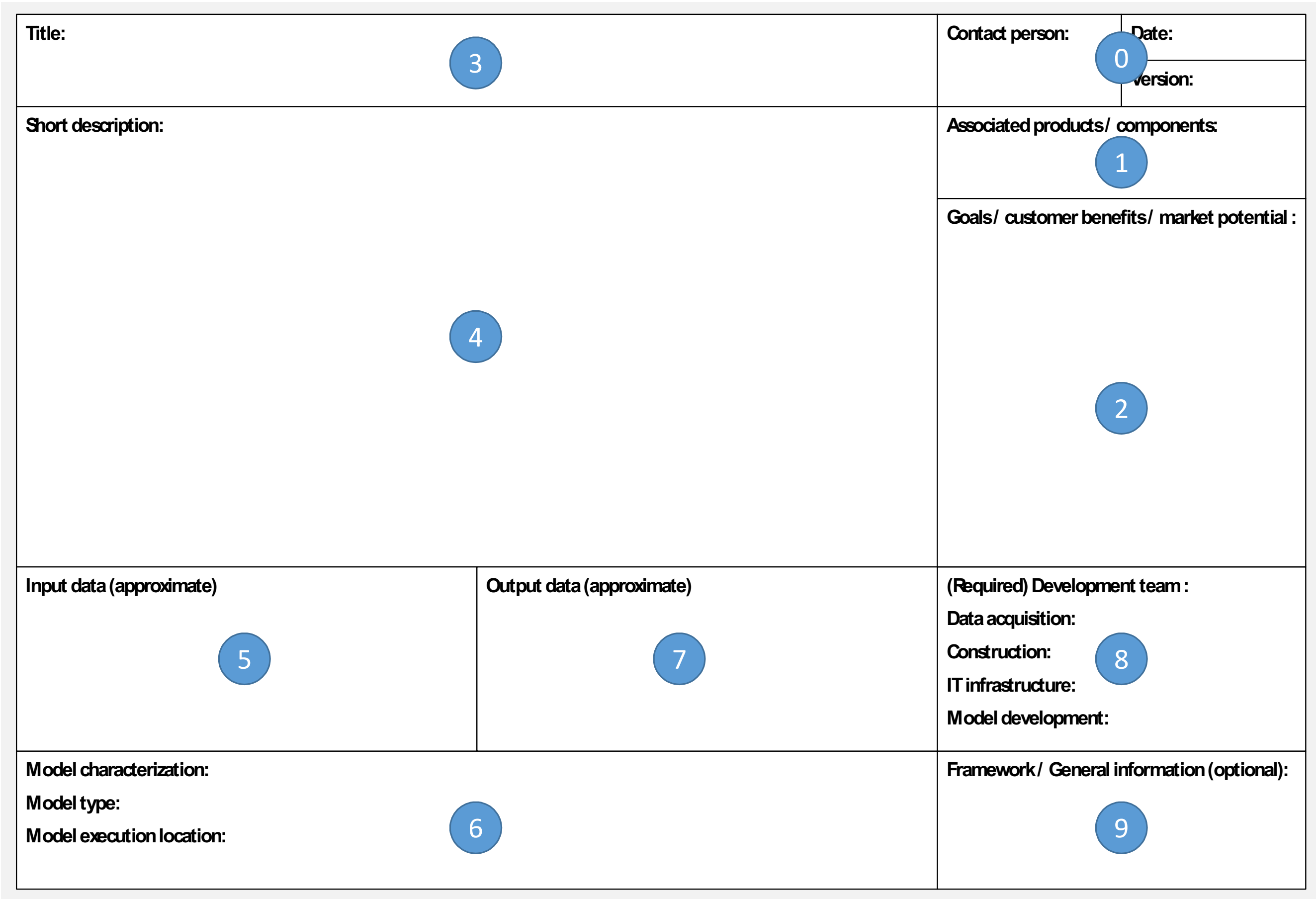

Fig. 2. Template for predictive maintenance use case description.

should be documented for the use case. In many cases, it is also advisable to insert a picture of the component under consideration to further clarify the use case. If available, it is also advisable to show the component in its original, as well as in its worn condition, in order to directly evoke the first associations of the monitoring possibility. The fifth field collects the required input data which should be described as well as possible at this point without anticipating technical details of the data needed. This field deals with the origin of the data, how this data is related and how it fits into the use case. For example, which values can be used to measure the wear of the component and which additional information such as the current driving situation, road conditions or changes over time must be included. The technical details of the data (frequency, accuracy, ...) are included in a separate data overview, detailed for the model development and not included in this high level use case description. Based on the necessary data recorded in this way, the details known about the model implementation are collected (field no. 6). This information should allow the model developers to gain an insight into how complex the execution will be and what kind of algorithms will be needed. Whether it is event detection or prediction, and what quality requirements are posted on the models. The field should also contain where the model will be executed in the future: Either in the individual vehicles, only during servicing or in the cloud using "over the air" communication. After describing what the model will be capable of, data output of the model needs to be specified in field no. 7. The information generated by the model should be described as detailed as possible, allowing subsequent interfaces a good impression of which information can be used. As with the input data, the technical details of the data like file and transmission format will be included in the separate data overview detailed for the model development. In the eighth field, the required competencies of the people working on the use case are collected. If the necessary competencies needed are not clear, a possible way to acertain them is showing the so far filled in template to different departments and asking them to describe what the mechanical, electronic, electro-technical, data processing and model creation competencies are needed. The template up to this point should include all the information for the departments to know the needed competences. If possible, not only the required competences should be listed, but also the names of the persons who can be called upon in the future to work on the use case. This field can be expanded in the course of the project if new competences and employees are required.

In the last field at the bottom right, additional information and general conditions can be added. In this way, for example references to cross-connections or other use cases that still need to be considered can be placed in a prominent position without being overlooked in the short description. This field is optional and does not have to be filled in for a complete description of the use case.

3.2. Model development

For the model development phase, a much more detailed view compared to the high-level description of the input and output data is necessary. Since a different number of data sources can be used for each PdM use case, the documentation of the required input data must be correspondingly flexible. A documentation form in table format, in which the required information per data source is recorded per row and the entire row block for a data source can be copied for additional sources, has proven itself successful.

Descriptive information such as title, data source, data format, security class, data ownership, access rights, data structure and storage location is then initially entered per data source. For each of the individual pieces of information, sub-rows can be inserted to add further details. For important further information, especially for the storage location, the distinction between local and cloud solutions needs to be documented. The storage location should be described in more detail, which respectively includes the sub-information regarding the administrator, the expected available storage duration, the access information, and detailed information about the expected data growth over the course of the project. The data growth rate can again be divided into sample constancy, frequency, aggregation, size and whether the data is collected automatically or after a triggered event.

The extended output data can be documented in tabular form, similarly to the input data. Here, it makes sense to create a data block for each model developed. On the top level, the information for each model includes the purpose of the model, what the model is able to explain, how precise the model is, whether internal or external customers continue to work with the model information and whether the model is complete in itself or whether the model should be improved by further situations employing machine learning on future data. Again, further sub-items can be added to each piece of information, which can be used by future model users to work out either their interface to the model or their processes. For the level of detail of the additional information, the level of detail of the input data can be used as a guideline. Thus, depending on the model and the service to be developed on the basis of the model, data format, frequency and data size can also play an important role and therefore should also be included.

4. Validation

In order to validate the proposed use case description model in a real-world environment, an existing use case is described in the presented form. Furthermore, the evaluation is done by considering feedback from domain experts and the example use case owners as well as a self-evaluation by observing the process describing the use case. In this section, the validation is described by first giving an overview over the use case, followed by a detailed description of it in the presented template. The chosen use case has the objective to improve the understanding of vehicle brake noises. Therefore, possible brake noises are categorized into different clusters. Those different noise clusters are used in a manual labeling process of acoustic vehicle data in order to generate a training data set which is then applied by an artificial neural network to be used as a classifier for unlabeled fleet data. In the following, the content of the filled PdM use case description template is briefly presented:

- Associated Products/Components:
  In big organizations, many components or even products share the same data pipelines and different requirements, or specifics can be derived by a specification of the concerned component. It is essential for the use case description to specify this as graphic as possible in order to get quick context information. In this work's example, the components are model-independent passenger vehicle braking systems. The system consist of the brake disc, the brake pads, the actuator and all compontes associated with them.
- Goals/Customer Benefits/Market Potential:
  To estimate the business value of the use case, the use case goal is stated in an easy-to-understand and background-knowledge-independent sentence. In this example, it is described as the detection of customer vehicles in regard of break noises. The goal is to identify which customers vehicle, under which external condidions makes what kind of brake noise.
- Title:
  The use case title helps to quickly classify the use case into the right context and is agreed upon to be used in all kinds of communication. This works example use case title is "Brake Noise Detection".
- Short Description:
  In the short description firstly a picture of the components is shown, detailing the components integration into the vehicle and the connections and functionality between the components. This information is followed by the possible known origins of brake noise and speculations on how it is effected by different compontens and context. Then already existing sensors delivering input data are noted which can be used to gather information concerning the components and the possible origins of the noise. Additional information about the sensor data, its availability and performance are also filled into this field. Especially in automotive context, the information on how the data can be accessed is essential, due to the complexity of the technical information communication system. Because of this the internal steps and required permissions to access the sensor data are descriped. Then, the target of the use case is described with resprect to the information given so far. In this example it is to count the events where unexpected braking noise appears in the car and decide on if and when to inform the service partners to check the brakes in a routine service check. At the end other essential information regarding the affected components is supplied. The possible reasons for braking noise were gathered and transcribed from interviews with employees and experts not directly associated with the PdM use case.
- Input and Output:
  The training and online input data are described quantitatively. In this example, audio data recorded in the vehicle chassis during test drives is used jointly with communication bus data as a training set. For a quantitative and technical description, the data description attachment is referred to. The output is described as a model in order to identify and classify brake noises. Again, for the more detailed description, the output data description is referred to.
- Model Description:
  The model is described via a short characterization, the model type and the location of deployment and execution. In this work's example, a convolutional neural network (cnn) is applied as a classification algorithm. The algorithm type is classified in the group of neural networks and the deployment location is in the company backend server infrastructure, implying two-way communication between the backend and the vehicle fleets.
- Requirements:
  The requirements which need to be fulfilled in order to ensure a successful use case execution are divided into the categories team skills, data acquisition, construction, IT-infrastructure and model development. For this use case experts from all the categories are required.
- General Conditions:
  At last, an optional field is supplied for general comments about the use case, which are important for the individual case, but not generalizable. In this example alredy existing internal work in the area of brak noise is refered as well as other potential use cases that might use the same data sources.

Due to the real world environment of this work, feedback from different expert domains surrounding the use case is collected. Model driven experts focus on clear technological context information in order to classify the required competencies. The categories Short Description and Associated Products/Components successfully supplied the required context. Data engineers require the overview over model Input and Output information. While the qualitative description helps to identify responsibilities, especially the data description attachment supports a quantitative assessment of the use case. Data scientists primarily profit from the prerequisites described in the Model Description section. Especially when there were model design decisions in advance of the use case execution. Also, the Requirements help to understand available resources and allow first model designs. Business owners are enabled to estimate the cost benefit ratio of the use case by deriving estimations from the description categories Goals/Customer, Benefits/Market Potential and Requirements. Finally, the product owner is able to form and manage the team by using input from the Short Description as well as the Requirements. It is their job to keep an overview of the use case and consider and possibly redirect additional information stated in the General Conditions.

The feedback from the team and external employees on the use of the template is consistently positive. Particular positive emphasis was placed on the fact that the suggested order of filling in the various boxes allows a logical structure to be maintained when creating the use case ideas so that the required information is already available for certain decisions. The simple structure and the clarity of the information is also frequently mentioned positively in the feedback from the employees. The communication regarding the use case outside of the team also proved to be successful, as within the organization, colleagues who were not involved were able to gain a quick and uncomplicated insight. Suggestions for improvement went less in the direction of the template itself but more in the technical implementation. In the validation example, the template was filled either in slides or in table form in common office systems. The suggestions for improvement went in the direction of creating special PDF templates and designing simpler versioning.Overall, the validation confirms the thoroughness of this approach. The stakeholders are satisfied with the description categories of the template of the example use case and content suggestions have been integrated successfully.

5. Conclusions and Outlook

This paper presents a standardized model to describe a predictive maintenance use case. The description model is used to collect, present, and document the required information for the implementation of PdM use cases by and for different stakeholders. Also, it accompanies and characterizes the PdM solution during all development phases starting with the first idea to the deployment. Apart from supporting traditional data mining process models such as CRISP-DM, the description model has the potential to accelerate and simplify the adaption of existing PdM solutions to new components. The validation showed the beneficial use of the description model in the selected use case in the automotive sector. Further research will focus on further validation in other sectors and the integration of the description model in a new process model considering the multidisciplinary, process and stakeholder distribution as well as current technological development processes in the cloud.

Acknowledgements

The authors thank all the partners of the project who contribute to this research work. The PANAMERA project is funded by the BMWi in the program „Neue Fahrzeug- und Systemtechnologien“ (19I21016).

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