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Systematic maintenance action modularization for improved initiative prioritization

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Abstract

Maintenance action descriptions can easily contain large amounts of variation without describing variation in the actions taken. Especially when plants grow large, this variation makes it difficult to gain an overview and make decisions on initiative prioritization. This paper proposes a method for the decomposition of the maintenance actions into modules that can then give insight into the maintenance performance. The method evaluates the true variation of the maintenance actions and standardizes them, making it possible to show the true variation and performance of the maintenance activities

Keywords: modularisation, big data analysis, variant management, maintenance

1 Introduction

Increasing size and complexity of production facilities is putting a strain on informed decision making in maintenance. The difficulties arise from a lack of overview when hundreds of thousands of pieces of equipment need to be maintained (Agergaard et al., 2021; K. V. Sigsgaard et al., 2021). Such large facilities introduce larger amounts of variation in equipment types and conditions, making the maintenance actions required further varied. This variation makes it difficult to know what maintenance actions were actually performed during a maintenance job, decreasing the knowledge-basis for decision making (Agergaard et al., 2021, 2022). In product family management, modularization approaches have been applied to handle similar issues of large amounts of variation that makes it difficult to gain an overview that can allow standardization and improvement. A key has been to improve commonality among parts while balancing the varied demands of customers (Simpson et al., 2014; Thevenot & Simpson, 2006). While modularization is a widely studied subject in products, the application is new in more intangible areas such as services (de Mattos et al., 2021; Eissens-van der Laan et al., 2016; Johnson et al., 2021; Løkkegaard et al., 2016) and maintenance (Agergaard et al., 2022; K. V. Sigsgaard et al., 2021). Applications in maintenance have found that maintenance modules are multidimensional, spanning the dimensions physical, action, and process. Maintenance modules and interfaces must be defined in these three dimensions in order to modularize the maintenance (Agergaard et al., 2022). However, this is an initial proposal for the use of modularization approaches and definitions in maintenance. This paper therefore seeks to provide a more tangible example of how standardization of the action dimension can play a role in improving maintenance decision making. The focus of the study presented has been the following research question:

How can maintenance modularization in the action dimension be realized?

The study presented in this paper explores the research question through a literature study and a case study. During the case study, a method using the modularization approach for systematic evaluation of the maintenance actions to enable the mapping of the action architecture view was developed. The proposed method is based on a manual, systematic evaluation of the maintenance actions taken over a defined period of time. The outcome of the method is a list of distinct maintenance actions that describes the core of the actions performed historically. Using this list to map the maintenance in a case company, it was possible to achieve an overview that indicates performance based on the impact of the action on the equipment. As such, the result of the method is the basis for mapping out the maintenance action modules of the maintenance architecture, allowing prioritization of future improvement initiatives.

The remainder of this paper is structured as follows: the second section introduces the research method, the third section highlights relevant literature on the subjects of maintenance and modularization, the fourth section introduces the method, the fifth section shows the application of the method in the case company, and the sixth and seventh sections discuss and conclude on the study.

2 Research Method

The study described in this paper followed the Design Research Methodology (Blessing & Chakrabarti, 2009). The study started with an observation of a lack of overview of the maintenance process in a case company. As the study by Sigsgaard et al. (2021) had shown, such an overview could be gained through a maintenance architecture mapping of the aspects equipment, action, and process. However, mapping especially the action view became difficult as the amount of data was too big and difficult to compare. Looking to architecture and maintenance action literature, no methods for the standardization and evaluation of the value-addition was identified. The identified literature highlighted in section 3 was identified using relevant search terms using the Technical University of Denmark database DTU FindIt as well as Web of Science and Scopus. Web of Science and Scopus were especially useful for finding state-of-the-art research on the traditional definitions of modules and modularization. Based on the observation in industry and the findings from literature, a method for systematically modularizing the maintenance actions was developed. The method was developed and tested using the case company data and the resulting action view was verified by maintenance action planners from the company. The mapped action view was then used to identify and prioritize areas for optimization initiatives.

The case company operates large offshore oil and gas facilities, that require maintenance to improve equipment availability and safety. Thus, decisions made about maintenance influence company profitability, safety of the employees, environmental impact, and company reputation should a major failure occur. The case company was chosen as their plants have a large amount and variation of equipment, which has made it hard to gain an overview of the process and the most critical improvement areas. The method was applied to maintenance operations extracted directly from the company Computerized Maintenance Management System (CMMS). Along with the text descriptions were practical information about the maintenance jobs such as maintenance location, skill requirements, work hours, and more. The resulting maintenance action modularization was verified through workshops and semi-structured interviews with maintenance action planners from the case company.

3 Literature review

3.1 Maintenance actions

This section introduces general relevant maintenance terminology, as well as research on maintenance actions. Maintenance is in this paper defined by the terminology defined in the DS/EN 13306:2017 (Dansk Standard, 2017). According to this standard, maintenance is the technical and managerial actions performed to keep equipment within the specifications of the intended function. Maintenance involves activities from invasive tasks such as repairing or replacing to non-invasive tasks such as inspection or measuring. Maintenance management is the term used to describe the activities involved in determining what, when, where, and who of the maintenance. Different approaches can be taken to decide these four W’s, most prominently there are corrective and preventive approaches. In corrective maintenance, the maintenance is planned based on an identified failure. A failure is an inability of the equipment to perform within the specified function. Preventive maintenance instead focuses on preventing failures before they happen, through both invasive and non-invasive actions. The objective on non-invasive actions is to identify and evaluate chances of failure before they occur. This can be through manual inspections or through sensors. Sensor inputs are used for other types of preventive maintenance such as predictive and condition based, where the maintenance need is determined by an algorithm that evaluates the sensor input (Dansk Standard, 2017).

In order to go from identified need to maintenance, be it corrective or preventive, some type of communication of the actions and resources is required. Historically, such instructions have been paper based (Toscano, 2000), but recent years have seen the introduction of technology based solutions using tablets and smartphones and augmented reality (AR) (Fiorentino et al., 2014). While studies on the use of AR in maintenance have shown usefulness in reduction of execution time (Fiorentino et al., 2014; Havard et al., 2021; Mourtzis et al., 2020), minimization of errors (Fiorentino et al., 2014), and improved input capture (Neges et al., 2015), these studies tend not to focus on how to determine what information to deliver and how this is developed from the instructions currently in use. To identify such information, Kindervater & Strobhar (2014) developed an approach using semantic analyses that created modules of procedures that revealed that for a single case study, only 10% of the operational content of the instructions was unique.

3.2 Technology architectures and modularization

Product architectures have been shown to give companies a framework for handling the complexity of the product portfolio while still delivering variety to the customers (Bask et al., 2010; Harlou, 2006; Meyer & Lehnerd, 1997; Simpson et al., 2014). An architecture is an arrangement of functional elements into building blocks with clearly defined, unchangeable interfaces (Andreasen et al., 2004; Harlou, 2006; Mortensen et al., 2016; Ulrich, 1995). This arrangement gives a systematic overview of the product structures, easing the development of new variants (Harlou, 2006). Applications of architectures and modularity in other areas such as services and maintenance have been introduced in more recent years. While the applications in these areas are showing initial promise, they are still case based and rely heavily on product architectures (de Mattos et al., 2021; Løkkegaard et al., 2016; K. V. Sigsgaard et al., 2021). de Mattos et al. (2021) combined studies on modularization of services to define service architecture and modularization. A service architecture is a modular architecture that describes the boundaries of service systems and the decomposition of modules, interfaces, boundaries, and resources. Here, a service module is a set of component elements that offers perceived value to the client. The interfaces between these service modules are then the connections between the component elements in the form of people, information, and rules for information flows (de Mattos et al., 2021). Maintenance is similar to services in that they are intangible and multidimensional compared to products. However, where maintenance differs from services is in the recipient of the delivered value. In maintenance the asset owner who needs a safe production that functions within the given specifications is the recipient of value (K. V. Sigsgaard et al., 2021). In services the recipient is typically an entity outside the company in the form of a client or customer (Løkkegaard et al., 2016). The studies by Sigsgaard et al. (2021) and Agergaard et al. (2022) propose defining maintenance modules by the dimensions action, physical, and process. The action dimension encompasses the steps taken during the maintenance execution. The physical dimension describes the characteristics of the systems and equipment being maintained. The process dimension pertains to the steps taken in managing the maintenance process (Agergaard et al., 2022; Sigsgaard et al., 2021). A step in modularization is the standardization and evaluation of commonality across components. Multiple indices for the evaluation of commonality (Simpson et al., 2014; Thevenot & Simpson, 2006) and drivers of value-adding variation have been proposed for product (Ericsson & Erixon, 1999) and production modularization (Brunoe et al., 2021). These are used to guide the evaluation of the variation found in the as-is program and to determine which should carry over into the modularized program (Ericsson & Erixon, 1999; Harlou, 2006). Commonality indices can also be used to evaluate to-be architecture configurations compared to each other and the as-is (Simpson et al., 2014; Thevenot & Simpson, 2006). Similar indices and drivers of variation have not been identified in service or maintenance literature.

4 Systematic modularization of maintenance actions

As the proposal for defining maintenance modules by the dimensions action, physical, and process is a new proposal, the study in this paper was performed to see how this might be realized in an industrial context. This led to the development of the method for standardizing the maintenance actions presented in this section. Maintenance actions come from operational data in the form of maintenance instructions. Maintenance action information typically exists in a free text format attached to a unique maintenance job and location (Agergaard et al., 2021; K. v. Sigsgaard et al., 2021). A maintenance job is in this paper considered the collection of operational information required to perform a maintenance objective. The free text format of the maintenance actions can make it difficult to gain an overview of the historical and as-is practices when there are large amounts of data. However, such data is a valuable resource in understanding the maintenance performed, and makes it possible to pair this understanding with quantifiable measures such as costs or resource usage (Hodkiewicz & Ho, 2016). This paper proposes a method for modularizing the maintenance action data in order to standardize and remove non-value-adding variation (Thevenot & Simpson, 2006). The understanding of a module in maintenance is yet to be defined in maintenance architecture research (Sigsgaard et al., 2021). This paper therefore follows the definition of a service module by de Mattos et al. (2021) as a set of elements that deliver value to the client, the client in maintenance being the asset owner (Sigsgaard et al., 2021). However, instead of the service dimensions proposed by de Mattos et al. (2021), a maintenance module is understood in the dimensions physical, action, and process proposed by Sigsgaard et al. (2021).

The proposed method follows the following steps: 1) Split text into comparable blocks; 2) Split into individual words; 3) Sort out uncommon words; 4) Identify action words; 5) Convert to English lemma; 6) Verify results with experts. Each of the steps are described in more detail in the following subsections. Each step is explained using example maintenance jobs that were formulated for this paper (Table 1), i.e. they are synthetic but were created based on real maintenance jobs.

4.1 Split text into comparable blocks

The first step is to split the full maintenance jobs into comparable blocks that each describe an action. As seen in the examples in Table 1, a maintenance job includes the actual maintenance action such a replacement, lubrication, or measurements, but will likely also include supporting actions such as isolation, scaffolding, testing, or documentation. The table likewise reflects how such operations can be in multiple languages, further making comparison difficult. In order to identify the differences in these types of actions, the method starts by splitting the maintenance jobs into blocks that describe these steps. Such a delimitation is not uncommon in a CMMS, meaning this step will sometimes already be incorporated in the data. For situations where this is not the case, the split can be at bullet points, line changes or into individual sentences. For large amounts of data it is preferable that it is a split that can be automated. Number or otherwise indicate the chronological order of the blocks in the original text. Table 1 shows how this was done for the example jobs. Prior to the delimitation shown in Table 1, each operation was instead a new-line in one long text. Each line change in the original text was assumed a separate action. This is an approximation and will not be perfect, but is sufficient with large amounts of data. Compare for example action 4 in job A (A.4) and action 4 in job C (C.1) to the same actions, test and document, in job B actions 8 and 9.

Table 1: Splitting the example jobs into chunks with a given sequence.

Job ID	Maintenance objective	Sequence #	Maintenance actions
A	Repair leaking valve	1	Isolate valve from production flow
		2	Replace valve
		3	De-isolate valve
		4	Test and document
B	Pump vibrations over threshold	1	Build scaffold
		2	Safing of pump
		3	Rig up
		4	De-mount pump
		5	Mount new pump
		6	Rig down
		7	Desaf pujmp
		8	Test
		9	Document
		10	Deconstruct stillads
C	Ventil åbner for langsomt	1	Safing af ventil
		2	Smøring ventil
		3	De-safing af ventil
		4	Funktionstest og documentation

4.2 Split into individual words

The next step is to split the blocks into individual words. This helps minimize the amount of variation caused by the context of the word. Ensure the link back to the original block in the data documentation. This can for example be done with a lookup table in excel or using data matching in a BI software. For the example jobs a code can be made using the job ID and sequence number, e.g. C.1 for the first task in job C. For the example jobs 43 different words were used with 32 variants total. E.g. the sentences ‘Safing of pump’ and ‘Safing af ventil’ would result in the list of words, Safing, of, af, pump, and ventil.

4.3 Sort out uncommon words

In cases of large amounts of data it may be necessary to sort out words that were used rarely. This can be achieved by any appropriate threshold and depends on the context. A threshold can for example be the number of maintenance jobs the word was used in. Setting such a threshold will depend on the amount of variation present in the data and the amount of resources available for the evaluation. As the example only include three jobs this will not be necessary. However, in many cases where the application of this method will be relevant there will be such a large amount of data that it will be necessary.

4.4 Identify action words

The fourth step starts editing the words included by identifying the words that describe the action taken. Action words are the words that describe the action taken. The types of words being identified depends on the context and industry. The terminology used to describe an action in a continuous hydrocarbon production will likely not be the same in a seasonal agricultural production setting, making it important to define what actions are being identified. This makes it necessary that the person analyzing the data has knowledge of the terms used in the context and any differences in languages used in the text. In cases of doubt, examples of the original context can be used to determine the ambiguity of an action term. As the results will be combined with experience of maintenance experts, it is likely better to include terms that can both be and not be an action than leaving them out. As an example the term lubrication can refer to the action of lubricating, the lubrication fluid itself, or be a descriptive part of the name of a lubrication system. However, no matter which of the three cases it still concerns lubrication, and as such should be marked as lubrication. For the example jobs, 18 action words were identified from the 32 distinct words: Build, Deconstruct, De-isolate, De-mount, Desaf, De-safing, document, documentation, Funktionstest, Isolate, Mount, Replace, Rig, Safing, scaffold, Smøring, stillads, Test.

4.5 Convert to English lemma

The next step is to standardize the actions words used. As can be seen from the example action words identified in the previous step, there is some variation present in the selected action words that does not present functional variation. Removing the non-value-adding variation by using only one term per distinct maintenance action makes the data further comparable. To make the jobs comparable the standardized word is added in a new column next to the original action words, ensuring a link back to the original text. For the three example jobs, the 18 action words were standardized down to 14 action words. An example is the words document and documentation were both changed to Document, the words Desaf and De-safing where both changed to De-safe, and so forth.

4.6 Verify with experts

By verifying the resulting collection of words with maintenance action experts the true variation of the final list can be fully evaluated. Some terms may indicate the same action in practice though the words seem very different. If this step is skipped, the resulting overview may not reflect the true variation of the maintenance, which in turn will have an effect in the effectiveness of the overview gained from the maintenance architecture mapping. The evaluation of true variation with experts can also help further minimize the list of action words, which in turn improves the simplicity of the architecture mapping overview. For the example jobs it was discovered that the terms isolation and safing indicating the same action: isolating the piece of equipment from the production flow in order to be able to open the piping. The use of both replace and mount plus de-mount was also discussed, but for the context it was decided to keep them separate. This made the final list of action words from the example jobs: Construct, Deconstruct, De-isolate, De-mount, Document, Isolate, Lubricate, Mount, Replace, Rig, Scaffold, Test. For the three example jobs, 18 blocks with 43 words could be described using just the 12 words listed above. 12 words that represent the true variation then makes it possible to compare performance across different types of maintenance that actually have true functional variance. This was not possible with the original 43 words, as the comparison might end up comparing two things that actually have the same function such as isolate and safing.

4.7 Effect of the method on the action variation

Throughout the steps in the method the maintenance action text is standardized to make the information comparable. This is achieved through decreasing the amount of variation and more correctly reflecting the true variation in the actions taken. The graph in **Error! Reference source not found.** shows the development of the variation present in the data versus the amount of maintenance actions that are explained using the method. By applying the method the amount of variation that must be compared is reduced, making the data comparable without losing the overview of the maintenance actions.

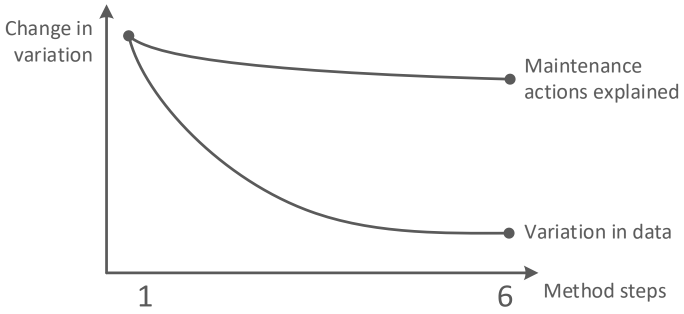

Figure 1: Development of the amount of variation throughout the application of the method proposed in this paper. The method was developed to significantly reduce the amount of variation present in the data while still being able to describe the majority of the maintenance actions.

The following section shows how this method was applied in the case company and used to create the action view proposed by K. V. Sigsgaard et al. (2021) and (AB.7).

5 Case study

The method was applied to the corrective maintenance actions taken at the case company over three years. At the case company, every corrective maintenance action is described from scratch in a free text format when the need for maintenance arises. This means, that if someone wanted to know anything about the maintenance performed or map out the maintenance architecture, it would be necessary to read every individual operation description. The CMMS data from 2016-2018 contains 112.537 corrective maintenance operations with an average of 4,4 words per operation. In order to map out these operations, the analyzer must read and understand all of these. At a reading speed of 180 words per minute (Ziefle, 1998) it would take about 46 hours just to read. As this is not a plausible timeframe in a daily or even specific analytical context, the information from the operations remained unutilized. The action descriptions include multiple languages, industry specific terms, and numerous abbreviations and typos, making the text difficult to evaluate automatically as proposed by (Kindervater & Strobhar, 2014). The method was applied to gain an insight into the maintenance actions that was not previously available due to data quality and time constraints. By applying the method suggested in this paper, the maintenance actions taken in all the operations were extracted and included in the database within 12 hours of work time. The 72% of the original maintenance actions could be describe using just 165 distinct action words, which is 0.03% of the original variation (Figure 2). These 165 distinct action words amount to about 2% of the 8253 word variants originally used to describe the final 72% of maintenance actions. The following sections describe how the method was applied using the company data and how the resulting studies that were possible due to the results from the analysis. The following section describes the application of the method in further details.

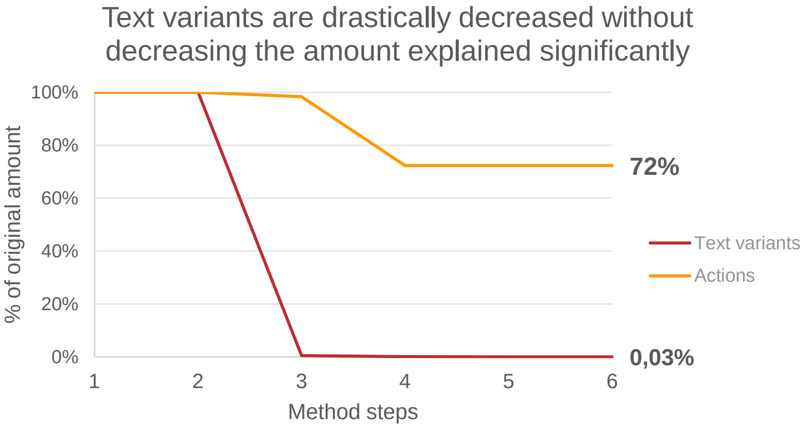

Figure 2: Development in the number of variants and the number of operations explained throughout the application of the proposed method.

5.1 Applying systematic text evaluation

The proposed method was applied to corrective maintenance operations from the years 2016, 2017, and 2018. This time period was used in this paper due to the confidentiality of current data. The extracted data included information from all the assets managed by the company. Each operation were linked to a chronological order and a maintenance job. The maintenance jobs were all linked to other information from the CMMS such as the location of the work, the type of equipment being maintained, planned man hours, and more. Following the first step of the proposed method, the maintenance jobs were split into comparable chunks. The structure from the company CMMS included a numbering system that placed individual descriptions of maintenance actions into chronological order. Each operation was in a short text format similar to those used in the example (Table 1). Moving onto the second step, the chunks were split into individual words. Each of the comparable chunks were split into individual words. The link back to the original maintenance job number and chronological order identifier was kept. The final data set included about 490.000 distinct words. The third step was to sort out uncommon words. As 490.000 distinct words was too much to manually evaluate, words used in less than 10 maintenance jobs over the three years across more than 300.000 pieces of equipment were considered outliers. This gave 2.434 distinct words ready for evaluation. In the fourth step, action words were identified. This was achieved by going through the list of words and only keeping words that describe the action taken in the maintenance job. In a copy of the original list, words such as lubrication, isolate, scaffold, replace, etc. and their variants were identified. The remaining words like location names, equipment descriptions, stop words, etc. were removed from the list. When there was doubt about a word it was looked up in the original operations to gauge the context. As the type of some words can be context dependent, all words that might sometimes describe an action were included. As an example an operation describing the scaffolding of an area might be multiple variants: Erect scaffold, Build scaffold, Scaffold area. In order to capture all three as well as the use of the words erect/build in other contexts, all three words erect, build, and scaffold were kept on the list. The final list of raw action words included 396 distinct words. With the identified action words, the fifth step of converting to English lemma was applied. In order for the list of distinct action words to truly represent the functional variation of the operations the words had to be standardized. Variants in language, spelling, and abbreviation were converted to a single representative word. For examples lubricate, lubric, lub., smøring were covered by the word lubricate. This took the distinct number of words to 203. To ensure true variation was reflected in the modularized actions, the sixth step was to verify with company experts. The resulting 203 words were shown to maintenance planners who write the maintenance operations on a daily basis. Discussing the results some of the words were further simplified as they pointed to the same action. For example, grease and lubricate were converted both to lubricate, and isolate and safe or de-isolate and de-safe turned out to be the same action and was standardized under isolate and de-isolate. The final list of distinct words included 165 variants describing the original 112.537 maintenance operations containing 490.000 words in the original data. 59 of these words describe a maintenance action such as replace, clean, lubricate, or inspect. 106 of the words describe supporting actions such as isolate or scaffold.

5.2 Prioritizing initiatives based on modularized maintenance actions

The modularized maintenance actions were used to create an overview of the impact of the actions on the equipment compared to the effect on the system condition. This view was used to identify the areas where a possible optimization initiative would have a bigger effect. The effect on the condition of the equipment was evaluated for each of the 59 maintenance actions on a scale from 1 to 5:

1. No effect: visual inspections, measurement, etc.
2. Little effect: sample, attach, etc.
3. Some effect: clean, lubricate, service, etc.
4. Large effect: adjust, calibrate, dismantle, etc.
5. Good-as-new effect: replace, paint, etc.

This evaluation was then loaded into a data model in a BI tool. Here, the effect on the condition was linked to information on the maintenance jobs from the CMMS. This included information such as effect on production and the amount of work hours the maintenance took. The effect on production was classified from 0 through 9 where 0 is a total shutdown and 9 is no effect. The amount of hours required on average for orders in that group was used to evaluate the effect on the condition against the impact on the system as the amount of hours can indicate the costs of the maintenance. Table 2 shows the resulting overview for the years 2017 and 2018. The results represent 2107 maintenance jobs over all assets and equipment types managed by the company.

Table 2: Cost in average hours per job by effect on equipment condition and system impact. Exact amounts have been randomized for confidentiality, but identified areas (green outline) reflect case study results.

Effect on equipment condition (1-5)	System condition									
	Total shutdown									No effect
	0	1	2	3	4	5	6	7	8	9
1				216	111	216	171	43	79	
2							4	46	44	1
3					298	75	38	50	100	
4	200			76	236	149	25	28	62	90
5	68			32	181	128	34	14	75	

Marked with green outlines in Table 2 are actions taken on the offshore plants where a large amount of hours are spent on average. A large amount of hours on average indicates an opportunity for effective optimization, especially when the maintenance results in large effects on the system. While a job that takes many hours but has little effect on the equipment is costly in resources, similarly long jobs with large effects on the production also result in the loss of sales opportunities. The first initiative opportunity is seen in the bottom left corner where an average of 200 and 68 hours is spent on jobs. While the effect of the actions has a larger impact on the equipment, the need for 50+ hour complete shutdowns of the production equipment is very costly. To offset the impact of such invasive shutdowns the company plans summer shutdowns where sales prices are lower, but still these jobs were not grouped in this shutdown. This indicated a strong need for a better overview of the impact of maintenance than was currently in place. The second identified area is represented by the green outline in the top middle part of Table 2. Here, maintenance that has little to no effect on the condition of the equipment is taking many hours on average and the production flow. This indicated a need to reevaluate the importance of the non-invasive actions taken, as they were more expensive to perform than previously identified. The final initiative option is marked by the green outline in the bottom middle of Table 2. Here, jobs that do have some effect on the equipment is causing medium impact on the system condition. Especially the average for actions with level 3 equipment effect are more costly.

6 Discussion

This paper introduced a study into the realization of modularization in maintenance. The study focused on expanding the use of modularization approaches in maintenance. Specifically, the focus was on how modules might be identified from the perspective of the action dimension. The study combined insight from literature with experiences from industry and lead to the introduction of a method for standardizing maintenance action descriptions. The modularization definition used in maintenance is based on the definition of a service module (de Mattos et al., 2021), however in the case of maintenance the client is not considered a customer entity outside of the organization. In maintenance the recipient of the value of the maintenance is the owner of the assets that requires the equipment to be functioning as designed. The study of this paper focused on companies where the maintenance is managed in-house with no outsourcing of the maintenance activities. More studies in this area is necessary to further define the definition of maintenance modularization. Looking to the definition of product modules where the product is decomposed into physical elements that have a function and clearly defined interfaces (Andreasen et al., 2004; Harlou, 2006; Mortensen et al., 2016; Ulrich, 1995), this is similarly reflected in the resulting modularized maintenance. Each action module delivers a functional result to the end goal of the maintenance job. The interrelations of the maintenance functions is clearly defined, as an isolation is necessary for a replacement of a valve at the physical location, and testing and documentation must be performed after the de-isolation of the part and is needed for the maintenance process. Compared to product interfaces, this shows connection between multiple dimensions instead of only the physical dimension. As proposed by K. V.Sigsgaard et al. (2021), maintenance exists in the three dimensions physical, action, and process, making it necessary to consider all three when decomposing maintenance modules. The method proposed in this study focused on the action dimension, but effects from and on the physical and process dimensions is visible. The sequential order of maintenance comes from the physical constraints, as you for example cannot physically replace a valve that has not been isolated. Likewise the impact on the system condition is determined by the requirements of the physical dimension: some inspections can be performed without any impact while some require equipment shutdowns. From the process perspective, all of the jobs analyzed were past the execution and close-out phases as the maintenance actions had been executed and all the documentation actions performed. The initial goal of the process was to show an as-is picture of the maintenance, but further studies into the details of the requirements of such initiatives will likely require more insight into specific physical contexts as well as different stages in the process. Overall the study presented in this paper shows benefits of applying modularization principles in maintenance management. However, the study is an initial, case based look into the benefits and definitions of architectures and modularization in maintenance. As such, more studies into different companies and industries as well as more longitudinal studies into the long term benefits of identifying opportunities this way are needed.

7 Conclusion

The study presented in this paper was performed in order to expand upon the use of modularization approaches in maintenance. Specifically, the focus was on the following research question:

How can maintenance modularization in the action dimension be realized?

The study led to the development of a method for the standardization of maintenance action descriptions. The application of the method helped achieve modularization of maintenance in the action dimensions, which in turn enabled an overview that made it possible to identify opportunities for improvement based on the effect of the maintenance on the equipment and the system. The proposed method helps decompose maintenance actions into modules that show the true variety of the maintenance actions taken. The method was applied in a case company where the number of variants was reduced to 0,03% of the original amount while still describing the majority of the maintenance operations. The actions were used to identify and prioritize opportunities for future optimization initiatives in the case company. This was achieved by mapping out the historical maintenance performance based on the impact of the actions on the state of the equipment and the condition of the system as a whole. Areas of poor performance then indicated specific areas of the maintenance process that required improvement.

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