**Assessing the information waste in maintenance management processes**

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**Abstract**

**Purpose –** Due to recent technological developments, many maintenance managers become overwhelmed by the vast amount of data available to support their decision making. This paper discusses identifying and eliminating waste in information management processes through a value stream mapping –based method.

**Design/methodology/approach –** A theoretical framework is constructed based upon a review of the previous academic literature. The application of the framework is demonstrated with an empirical case example of a maintenance information management process within a food manufacturing company.

**Findings –** The paper highlights existing examples of applying value stream mapping in information management, however, the knowledge is fragmented and has not been extensively applied in a maintenance context. The case example shows that the suggested process offers a feasible method of mapping and evaluating the inherent waste in information management processes.

**Originality/value –** The paper summarizes the existing body of knowledge on lean information management in maintenance, and presents a theoretical framework on how value stream mapping can be applied in the context. An empirical example is provided to show the method applied to a real industry case. The results will illustrate how the framework can support companies in identifying the waste and development potential in their maintenance information management.

**Keywords** Value creation, Maintenance performance, Information management, Lean maintenance

**Paper type** Research paper

**1 Introduction**

This paper addresses how value stream mapping (VSM) can be used in identifying development needs in maintenance data management processes. The amount of data available to maintenance decision makers has increased exponentially due to recent technological developments such as sensors, the Internet of Things, and eMaintenance (Baglee et al. 2015; Candell et al. 2009). The decision makers can become overwhelmed by the vast amount of data, and unable to optimally manage the process of gathering, integrating, analyzing, and exploiting the data (Kinnunen et al. 2016). This results in wasted resources and suboptimal decision making in maintenance management. To overcome this problem novel methods are needed to identify the waste in maintenance data management processes and to measure the value of data to support decision making.

In this paper a VSM-based solution is proposed to identify the waste. VSM is an extensively used method commonly associated with lean management (Sawhney et al. 2009). Traditionally VSM has been used to analyze e.g. manufacturing processes, and the main focus has been on mapping material flows in the process. Adopting VSM to map the information flows of a support service process (such as maintenance) has not been examined or discussed in detail. Exploiting VSM in the context of information flow analysis also requires theoretical work: the concepts of waste and value in information management have been addressed by authors including Bevilacqua et al. (2015), Hicks (2007), and Verhagen et al. (2015). However, there is a lack of commonly acknowledged definitions or typologies. This paper presents an up-to-date literature review on these key concepts. The paper answers to the following research question:

*How can information waste be identified and quantified in maintenance processes?*

 The paper contributes to the discussion on improving data-based maintenance management through presenting how the performance of the data management process can be analyzed with VSM. The main focus is on identifying the development needs in data management, which can be seen as the first step in the process of providing the maintenance decision makers new methods to assess the value of information and information-related actions. The paper focuses on the first phases of VSM where waste is identified and analyzed. The implementation of working plans to achieve the future state map will be briefly discussed.

The next section of the paper discusses the chosen research methods and data, after which a theoretical framework of VSM in maintenance data management is presented. Mapping maintenance data exploitation paths is presented through a case study in the following section, and the paper finishes with conclusions.

**2 Research design**

The paper presents an industrial case example to showcase the application of the theoretical framework. The case company operates in the food manufacturing industry, employing over 15.000 people at almost 50 production sites. The research focused on one of the case company’s factories in the United Kingdom (UK). The factory produces about 550,000 meals per week, and employs 400-500 people, depending on the need of flexible workforce to complete the orders. The data collected and analysed for the research includes maintenance work requests documented in the selected factory from mid-June 2017 until mid-March 2018 (a period of just under 9 months). The factory started to document their maintenance work requests in June 2017, aiming to find ways to increase the resource efficiency and value of their maintenance. In total, 10.053 work orders were recorded during this period. As shown in Figure 1, the number of work requests initially increased per month. Based on a discussion with the maintenance manager of the case company, this was due to the maintenance personnel gradually adopting the new process of documenting their work. Before the work order forms were introduced the maintenance personnel were not required to officially document their work, this was a new task for the maintenance technicians. However, after October 2017 the number of work orders per month has decreased. According to the maintenance manager this is due to the improved management of the documentation process (i.e. less double entries and erroneous work orders), but also to the better planning and organization of the maintenance tasks (i.e. slightly less asset breakdowns, and merging of small maintenance tasks).



**Figure 1.** The studied maintenance work requests documented in the research period

From the 10.053 studied work requests, 93% were required (by the internal customer) to be completed on the same day the work request was created. This shows that decreasing the lead time of the maintenance process would be critical for the company. The hand back date (when the maintenance task has been completed and the work has been documented) matched the required completion date in 85% of the work orders. A majority of the work requests were related to relatively simple maintenance tasks, as no follow-up maintenance was recorded in 90% of the records. Also, in 69% of the work requests only one maintenance engineer was involved in completing the maintenance task.

**3 Value stream mapping in maintenance information management**

According to Gupta et al. (2016, p. 1026), lean can be defined as:

*“…an integrated multi-dimensional approach encompassing wide variety of management practices based on the philosophy of eliminating waste through continuous improvement”.*

Lean thinking is well known in manufacturing contexts, but the improvements tend to focus on production and logistics (in other words the material flows) and not on information management (Bevilacqua et al. 2015). The applicability of lean principles in contexts other than manufacturing processes has been debated within the academic literature. However, there are examples of lean service processes (e.g. Andersson et al. 2015; Jylhä & Junnila 2013), as well as empirical proof of the positive impact of lean on the performance of e.g. software projects (see Staats et al. 2011).

Hicks (2007) defined information management as adding value to information through various organization, representation, and communication tasks as it flows to the end user. To increase the efficiency of this process, waste (actions and inactivity not adding value) should be minimized. Thus in lean information management you should only gather and process valuable information, ensuring that the information users can understand and access the value provided by the information. Furthermore, the process should be demand-driven, as simple and as fast as possible, and minimize duplication and unnecessary tasks. (Hicks 2007)

According to Bevilacqua et al. (2015), lean information management starts with mapping the current state and the information waste in the system. Following this, improvements to the system can be suggested and implemented. This process is congruent with VSM, one of the most extensively used lean management tools that was developed to identify, visualize, and eliminate waste in material and information flows (Sawhney et al. 2009). Compared to most process mapping methods, VSM is more versatile in the sense that it can also be used to analyze information flows in addition to the flow of the physical product (Singh et al. 2010). The process of applying VSM includes several steps:

1) identifying a target process for improvement,

2) constructing a current state value stream map (identifying the waste),

3) constructing a future state value stream map (illustrating the process after the waste or at least part of it has been eliminated),

4) developing a working plan to achieve the future state, and

5) implementing and achieving the working plan (Lasa et al. 2008; Sawhney et al. 2009).

Congruent with this five-step process, Figure 2 presents a theoretical framework as a synthesis of the literature discussed in this section. The framework summarizes issues which should be taken into consideration when applying VSM in the context of maintenance information management processes.

***In the first phase*** of the VSM process a target process is selected. Due to the large number of complex processes, organizations are unable to map all of their processes, so the scarce resources should be allocated into analysing carefully selected and critical processes. Bonaccorsi et al. (2011) have studied VSM in service processes, and suggest conducting a Pareto analysis to find the services which are either produced most frequently or generate the most revenue. Following this logic, in maintenance contexts organisations should prioritise processes with the most maintenance (or asset failures), or the processes with the highest business value of production. In the previous literature there are examples of lean information management tools and methods: Verhagen et al. (2015) have introduced the IMPROVE method, which uses time as a performance indicator to assess the information waste in a process, and drafts business cases to address the development potential. This method conducts the analysis on two levels: the macro-level analysis which provides a high-level view to the key waste areas of the process, whereas the micro-level analysis identifies specific, detailed non-value added activities. This two-level approach would be beneficial also in the context of analyzing maintenance processes. The macro-level analysis would help the organization to understand the bottlenecks and the most potential areas for development, whereas the micro-level analysis would be needed to analyse the information flows of specific maintenance processes in detail.

Corrective maintenance processes include recognizing and localizing the fault, conducting a diagnosis and repairing or replacing the faulty item, and returning the system to the service (Engineering Design Handbook 1975). Successful information management should reduce the time used in the process through, for example, faster fault recognition and location (Dhillon 2006). In predetermined maintenance, data analysis is used to study failure characteristics and to determine optimal maintenance policies. In condition-based maintenance on the other hand, the condition monitoring data is used to evaluate the asset condition in relation to the maintenance action limits. (Ahmad & Kamaruddin 2012) In both of these maintenance types information management, and thus also information waste, is more related to the design of the maintenance programme. Information waste affects the resource efficiency of the programme creation and re-evaluation, but not directly asset availability.

***The second phase*** of the VSM process is about constructing a map of the current state and identifying the information waste in the process. The definition of waste is crucial in applying lean in various contexts. Existing literature has categorized the main types of waste in lean production processes, lean maintenance, and lean information management. These are summarized in Table 1.

Based on Andersson et al. (2015), lean production aims to increase the value of the product by eliminating excessive production, stock, transportation, movement, waiting, and creative capacity of the personnel, as well as defect products and incorrect processing. Huang et al. (2012) and Mostafa et al. (2015) have transferred these waste types into the context of maintenance processes, where the objective is to keep the assets available for production with minimal risks and as cost efficiently as possible. Regarding terminology, the difference between Total Productive Maintenance (TPM) and lean maintenance is somewhat vague. Some authors use these two terms as synonyms, and TPM can be seen as an important part of lean maintenance, aiming to prevent losses, accidents, defects and breakdowns (see e.g. Andersson et al. 2015; Rolfsen & Langeland 2012).

Regarding lean information management, two different views on the main waste types could be found. The first one is that presented by Hicks (2007), identifying four main causes of information waste. These waste types describe the time and resources wasted in handling excessive information, identifying or generating the required information, as well as verifying inaccurate information and the suboptimal decisions based on poor quality information. Hicks (2007) has not defined counterparts for the lean production waste types “overstock”, “unnecessary material transportation”, and “unnecessary movement”, because the costs of transporting and storing electronic information is not dependent on the amount of data. In addition, the lean production waste type “unused employee creativity” was not included in Hicks’ analysis as it was not part of the original seven cardinal types of waste presented by Womack and Jones (1996). In this paper this additional waste is included to achieve a comprehensive view on information waste in maintenance processes.

The second view on information waste, presented by Verhagen et al. (2015), lists a counterpart for each waste type in lean production except “unused employee creativity”. Overall the waste types presented by Verhagen et al. (2015) are versatile, taking into account e.g. the resources used in digitalizing manual information, or the time when information is ready but waiting to be applied in the decision making process.

**Table 1.** The types of waste in different applications of lean

|  |  |  |  |
| --- | --- | --- | --- |
| **Lean production** (Andersson et al. 2015) | **Lean maintenance** (Huang et al. 2012; Mostafa et al. 2015) | **Lean information management** (Hicks 2007) | **Lean information management** (Verhagen et al. 2015) |
| Overproduction | Too much maintenance | Excessive information | Creating non-relevant, duplicate, or excessively detailed information |
| Overstock | Waiting for maintenance resources | N/A | Processing, transporting, and maintaining redundant information |
| Unnecessary material transportation | Centralised maintenance (excess transportation) | N/A | Conveying information between several sources and systems |
| Unnecessary movement | Non-standard maintenance | N/A | Moving information to ensure access, and digitalizing manual information |
| Waiting for next working procedure | Excessive stock | Identifying or accessing the required information | Process waiting for information, or information waiting to be applied in the process |
| Incorrect processing | Double handling | Generating additional information | Transforming the information into the required format |
| Unqualified products | Poor maintenance | Inaccurate information | Verifying, correcting, or hunting down information |
| Unused employee creativity | Under-utilisation of maintenance crew | N/A | N/A |

 Based on the previous typologies of waste types discussed above, information waste in maintenance processes can be categorized as follows:

1. **Unnecessary data in decision making** (the decision maker faces an information overload and has to use additional time and resources to focus on the actually relevant data),
2. **Unnecessary data in other parts of the process** (duplicate, non-relevant, or too detailed information which will not be needed in decision making is gathered, stored, analysed and transferred in the process),
3. **Unnecessary transfer of data** (information is transferred between people, systems and organizations without creating additional value to anyone),
4. **Waiting for data** (the process actor needs to wait/look for data items, or the information is waiting to be applied to the process),
5. **Unnecessary processing of data** (information is processed without creating additional value, e.g. transforming it into the required format, ensuring access, copying, writing summaries and reports that no-one reads),
6. **Incorrect data** (resources are wasted by carrying the incorrect data through the whole process, and poor quality data can potentially lead to incorrect conclusions in decision making),
7. **Incorrect analysis** (errors in data analysis lead to suboptimal decisions), and
8. **Underutilized data management resources** (for instance unused IT systems or personnel create additional fixed costs).

The eight types of information waste presented above are primarily based on the view of Verhagen et al. (2015), however some changes and updates have been made. First of all, the waste type of excessive information has been divided into two categories: “unnecessary data in decision making” and “unnecessary data in other parts of the process”. This is because it can be beneficial to gather and analyse large amounts of data if the process creates additional value to the decision makers (see e.g. Kościelniak & Puto 2015). However regardless of the large amounts of raw data, in the decision-making situations one should never face information overload because humans have limited cognitive abilities to take various information into account in complex situations (see Brown-Liburd et al. 2015). Secondly, the waste related to poor quality has been divided into two waste types: “incorrect data” and “incorrect analysis”. The reason for this is that from a managerial perspective, different methods and actions are needed to identify and eliminate poor quality data and analyses: according to Wahyudi et al. (2018) improving data quality can include e.g. quality assessment, data cleaning and pre-processing, standardization, and semantics, whereas according to Gupta and George (2016) Big Data analytics resources include tangible resources, skills-based human resources, and intangible resources related to organizational learning and culture. Thirdly, the waste created by overstock and unnecessary movement is taken into consideration in the other categories, and thus no separate waste types were left for them. Finally, the waste type of underutilized resources was included in the framework to enable tracking the additional fixed costs created by this waste.

***In the third phase*** of the VSM process a future state map is constructed. When constructing the future state map and the working plan to achieve the planned state, some principles should be remembered: firstly the flow should be continuous, or if that is not possible it should be driven by pull systems based on the product demand. Secondly, there should be one pacemaker process which defines the pace for the flow in the entire value stream. And finally the overall goal should be to improve process efficiency. This can be achieved through launching different development projects related to e.g. operations and maintenance. (Lasa et al. 2008) The purpose of identifying and quantifying waste in information management processes is to eliminate it and thus increase the value of the information. The main objective of maintenance information management is to create more value for the maintenance decision makers (Marttonen-Arola & Baglee 2018). VSM identifies waste and accordingly divides processes and activities into value adding and non-value adding (Rohac & Januska 2015).

The value of information has received little coordinated attention in literature and remains a vague concept. Hicks (2007) stated that novel tools are needed for assessing information value. The Value of Information (VoI) –theory has been applied in a variety of e.g. health, ecologic, and economic decision-making contexts, however the practical contribution has so far been limited due to its mathematical and decision-theoretic nature (see Canessa et al. 2015). Evaluating the value and benefits of lean information is challenging, and according to Bevilacqua et al. (2015) each company would need specific performance indicators integrated to their overall objectives. For example, Günther et al. (2017) address both social and economic value of big data to study the impact on industry and society. Bucherer and Uckelmann (2011) have presented a view on value propositions in information services, according to which the value of information consists of having the right information items, in the right amount, quality, format, time, place, and for an appropriate price. Moody and Walsh (2002) listed seven laws of information, highlighting the differences in valuing information items instead of traditional physical products or even services (these laws state e.g. that sharing information does not make it lose its value, using information increases its value, and combining information with other information may increase its value). One of the features significantly affecting the value of information is its quality. Information quality can be addressed through three specific dimensions: syntactic quality (conformity to the requirements set by the metadata, e.g. grammatical rules), semantic quality (corresponding to what the information represents, e.g. the domain of interest is mapped completely and consistently), and pragmatic quality (suitability for a particular use, e.g. accessible, complete, flexible, secure, and in a useful format) (BS ISO 8000-8 2015). Ensuring the pragmatic quality of information is particularly difficult due to the subjectivity of the concept. For instance Tayi and Ballou (1998) present data quality as fitness for use, which is a highly context dependent and abstract measure. Because decision makers often find it challenging to assess information quality objectively, they tend to simply trust the quality of the information without properly addressing it (Cappiello et al. 2004).

Lean information management in the specific context of maintenance processes has not been extensively studied. Sawhney et al. (2009) have addressed lean in maintenance in general, and discussed Mean Maintenance Lead Time (MMLT) as a performance indicator for corrective maintenance. This is the time between identifying the need for maintenance, and getting the asset to produce good quality products again. MMLT consists of: 1) the organizing phase before the actual maintenance work, 2) the corrective maintenance, as well as 3) restarting the production process and ensuring the product quality. Sawhney et al. (2009) point out that out of these phases, the only one adding value is the actual maintenance work, whereas the other two phases can be seen as non-value added time.

Measuring the performance of the process in terms of time provides a quantitative way of assessing the information waste, which is beneficial when the value of information is case specific and difficult to evaluate. The monetary value of the wasted time should then be evidenced through a context-specific business case.

***The fourth and fifth phase*** of the VSM process focus on designing and implementing a working plan to achieve the planned future state. A detailed analysis of these phases is left out of the scope of this paper, as the main focus is on identifying and quantifying the information waste in maintenance processes.



**Figure 2**. The theoretical framework of applying VSM in maintenance information management

The theoretical framework summarizes the body of knowledge on different aspects of applying VSM in maintenance information management processes. According to Erkoyuncu et al. (2017) most existing maintenance models are case-specific optimizations of direct maintenance costs, which do not take e.g. the resources spent in data collection into account. This framework contributes to this by presenting updated waste types in lean maintenance information management, and by suggesting time-based performance measurement for quantitative results.

**4 Map of maintenance data exploitation paths**

*4.1 Identifying a target process*

This case study presents a macro-level analysis on the maintenance management process of the case company. The aim is to obtain an overall understanding of the state of information management. The maintenance process is triggered by detecting a failure (corrective maintenance), implementing the preset maintenance frequency (predetermined maintenance), or exceeding the preset action limits on specific parameters (condition-based maintenance). A maintenance work request is created, the required maintenance tasks are conducted, and the engineers document their work using manual forms. If there is a need for follow-up maintenance tasks, the engineers create another work request. The manual forms filled by maintenance engineers are taken to the maintenance management team, who take time once a week to insert the data into electronic spreadsheets. The data gathered into the spreadsheets is analyzed and summarized at least once a week for a weekly report, and the maintenance managers also conduct additional analyses to identify bottlenecks and development needs in the maintenance processes.

*4.2 Current state map*

Figure 3 presents the current state of this maintenance process in terms of information management. Six main activities were identified in the process: 1) creating maintenance work requests, 2) executing the maintenance work, 3) documenting the maintenance work, 4) turning the data electronic, 5) data analysis, and 6) reporting and exploitation. For each activity, a number of key figures have been listed when applicable and possible based on the data used. These figures are:

*t* the average processing time required for the activity per maintenance work request,

*n* the average number the activity is repeated in a month,

*SD* the standard deviation of the processing time per maintenance work request, and

*NVAT* the average non-value added time per maintenance work request or task, meaning the time used in something that does not produce additional value for the decision makers.

For *creating maintenance work requests*, the processing time *t* is an estimate based on a discussion with the maintenance manager of the case company. For this activity *n* is the average number of maintenance work requests per month. *NVAT* was marked as zero because there is no idle time in the activity. For *executing the maintenance work*, the average maintenance work time calculated from the studied work orders was 54 minutes, with a *SD* of 97 minutes (the work orders with insufficient or clearly erroneous work times were omitted). Based on the data, the asset downtime after the maintenance work had started but which had not been used for the work (the *NVAT* for this activity) was on average 8 minutes per work order. *Documenting the maintenance work* and *turning the data electronic* are activities very similar to the creation of the work requests: there is no idle time, and the *SD* could not be calculated because they are manual processes which have been incorrectly documented in the case company. The average processing times are based on estimates made by the researchers and approved by the maintenance manager of the company. *Data analysis* and *reporting and exploitation* are not well established activities in the case company as there are no structured processes and methods for using the maintenance data. Accordingly, the *SD* and *NVAT* could not be calculated and the average processing times and number of tasks are based on estimates taken from a discussion with the maintenance manager of the company.

The red line below the process map shows the time required by each activity, and the time spent between activities (all of this idle time is non-value added time). The time between creating a work request and conducting the maintenance includes informing the maintenance department of the work request, maintenance scheduling and resourcing, as well as transferring the personnel and resources to the location of the fault. After the visibly erroneous work orders were excluded, the average for this time, calculated from 8885 work order forms, is 65 minutes. The time between finishing the maintenance work and documenting it includes the maintenance engineers handing the work order form back to the customer and the customer signing it. This time is one of the biggest development areas for the case company, as the times were usually not reported appropriately and even when they were, 13% of the forms were returned more than eight hours after the maintenance work had been finished. There were several work order forms that were returned months after the actual maintenance work. The time before turning the data electronic, analyzing and reporting it was estimated based on a discussion with the maintenance manager. The data from the manual forms is inserted into a spreadsheet approximately once a week, and data analysis and summaries are made at least once a week for weekly reports and for some additional analyses. It was assumed that the reports are written immediately after conducting the data analyses.

As a summary it can be said that between a maintenance work order being created and the related information being exploited in maintenance decision making, the case company currently uses 26200 minutes (over 18 days). Out of this lead time, 61% can be categorized as non-value added time.



**Figure 3.** The current state map of the maintenance information management process

Table 2 summarizes the waste identified in the process, which comprise the *NVAT* quantified in the map. Below a brief introduction to each waste (A-G) is given.

1. The time spent transferring the information about a maintenance work request to the maintenance engineers, and waiting for the engineer to prepare and start the task.
2. The data forms showed asset downtime after the start of the maintenance work which was not used for actual maintenance work.
3. The time after the maintenance work when the engineers hands the form to the (internal) customer and the customer approves the work. For most work orders this time was nonexistent, but in 13% of the cases the waiting time was more than eight hours.
4. The manually collected data is inserted into the spreadsheets approximately once a week, so the following phases of the process are left waiting for the newest information.
5. The maintenance engineers go through the manual forms when documenting their work. The maintenance management team has to go through each form again when turning the information electronic, which can be seen as unnecessary processing of data.
6. On average, information is analyzed and summarized once a week for a weekly report.
7. The waste caused by incorrect data cannot be seen in the *NVAT* but is significant nevertheless. 12% of the studied forms had visible quality problems related to the reported start and end times of the maintenance work (the most common issue was that the reported finish was earlier than the reported start time). This makes the information unreliable regarding data analysis. After the maintenance work is documented this incorrect data is carried through the remaining process, wasting resources and compromising the validity of the data-based decisions.

**Table 2.** A summary of the information waste identified in the process *(waste types: 1 Unnecessary data in decision making; 2 Unnecessary data in other parts of the process; 3 Unnecessary transfer of data; 4 Waiting for data; 5 Unnecessary processing of data; 6 Incorrect data; 7 Incorrect analysis; 8 Underutilized data management resources)*

|  |  |
| --- | --- |
| PROCESS PHASE | WASTE TYPES |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Activity 1: Maintenance work request |  |  |  |  |  |  |  |  |
| *Transition from activity 1 to activity 2* |  |  | A |  |  |  |  |
| Activity 2: Executing the maintenance work |  |  |  | B |  |  |  |  |
| *Transition from activity 2 to activity 3* |  |  | C |  |  |  |  |
| Activity 3: Documenting the maintenance work |  |  |  |  |  | G |  |  |
| *Transition from activity 3 to activity 4* |  |  |  | D |  |  |  |
| Activity 4: Turning the data electronic |  |  |  |  | E |  |  |
| *Transition from activity 4 to activity 5* |  |  |  | F |  |  |  |
| Activity 5: Data analysis |  |  |  |  |  |  |  |
| *Transition from activity 5 to activity 6* |  |  |  |  |  |  |  |
| Activity 6: Reporting and exploitation |  |  |  |  |  |  |  |

*4.3 Future state map*

In the ideal future state data analysis, followed immediately by data exploitation, would be the pacemaker process of the data-based maintenance management in the case company. Thus the data management system should pull data according to the demand emerging at the data exploitation phase. To decrease the waste in the current process, four changes are suggested. ***Firstly***, by adopting an electronic system to record the maintenance data (and by training the engineers to report their work immediately), a significant amount of time can be saved. This would eliminate the need for activity “turning the data electronic”. ***Secondly***, a quick data analysis could be conducted daily to identify potential issues swiftly. Reporting can still be run on a weekly basis, but additional reports should be written if anomalies are detected in the daily analysis. ***Thirdly***, the process of exploiting the reports in decision making (reacting to potential issues by making changes to the maintenance process) should be quicker. Our assumption is that in the current state this phase takes on average seven days. In the future state map an average of two days is used. A faster process would give the company a chance to use the data for proactive decision making in addition to monitoring past performance. ***Fourthly***, information quality must be improved. This can be supported by adopting an electronic information system which e.g. does not accept clearly flawed maintenance time records.

These four changes would eliminate waste C, D, and E as well as reduce waste F and G (see Table 2). A and B are related to the actual maintenance work and should probably be targeted through developments in e.g. logistics, spare part availability, or the work load of the maintenance engineers. Figure 4 shows the future state map, where the total lead time of the process is 3787 minutes (2.6 days) which is less than 15% of the current lead time. Even more importantly, the share of *NVAT* is 21%, as opposed to 61% in the current state.



**Figure 4.** The future state map of the maintenance information management process

*4.4 Working plan for the future*

To support the development of the future state map into a working plan, more analyses are needed regarding, for example, the impacts of the suggested changes on business and the production equipment. Following the VSM analysis, a quantitative assessment of the monetary impact of the suggested changes on the business value of the case company would be valuable (see Singh et al. 2010). Table 3 presents a preliminary analysis of the additional costs and benefits likely to be caused by the suggested changes. The detailed analysis of the costs and benefits would require the construction of a cost model and is left for further research. Table 3 lists some preliminary estimates of the additional costs and benefits caused by the suggested changes. The assumptions made when calculating the figures are discussed in the footnotes of the table. Although this brief analysis of the costs and benefits includes uncertainty and is sensitive to changes in the parameters, it can be noted that the value of the potential benefits is significant compared to the additional costs. The benefits related to improved quality (the last two rows of the benefits) have not been quantitatively estimated in this paper because they are indirect and would require extensive additional knowledge on the decision making situations in which the improved quality data would be used. Thus the monetary impact of increased quality should be based on micro-level analyses.

The considerations presented above and in Table 3 could form the starting point for building the cost model, and need to be taken into account by the company before committing to a working plan to implement the changes suggested in this paper. The company will need to conduct micro-level analyses to ascertain the impact and feasibility of the suggested changes. For example, the responsibilities and time use of different stakeholder groups of the information management process (asset operators, maintenance engineers, maintenance managers, decision makers) before and after the adoption of an IT system could be mapped to assess the value of the change.

**Table 3.** A preliminary evaluation of the yearly business impact of the suggested changes

|  |  |
| --- | --- |
| **ADDITIONAL COSTS** | **ADDITIONAL BENEFITS/COST SAVINGS** |
| License for the IT system:*Estimated costs1 £10000.* | Shorter lead time, possibility for proactive decisions in maintenance management:*Estimated value of increased production5 £78100.* |
| User training for the IT system:*Estimated costs2 £2100.* | Less manual work in information gathering and processing:*Estimated value of saved time6 £77400.* |
| More work to conduct data analysis on a daily basis:*Estimated value of time3 £4200.* | Reactive improvements are implemented faster after detecting an issue, which can lead to cost savings, better quality products, etc. |
| Decision makers and maintenance managers need to be flexible and use a bit more time reacting quickly to the results of data analysis:*Estimated value of time4 £3400.* | Improved data quality, leading to more reliable analyses and valid conclusions in decision making. |
| *1Based on Labib (2004).**2The estimate is based on a training day for eight maintenance engineers and two maintenance managers, with hourly costs of £13.2/h and £16.0/h, respectively. The hourly costs have been estimated based on public information on employer total costs (using payscale.com and stafftax.co.uk). Also a training consultancy fee of £1000 has been included.**3Congruent with Figures 3 and 4, the time used in data analysis is assumed to increase from 8 h/month to 30 h/month. An hourly cost of £16.0/h (based on payscale.com and stafftax.co.uk) has been used to estimate the value of this additional time used by the maintenance managers.**4The increase in the time used for data-based decision making has been assumed to be equal to the increase in time used for data analysis (from 1 h/week to 3.75 h/week). An hourly cost of £24.1/h (based on payscale.com and stafftax.co.uk) has been used to estimate the value of this additional time used by a production manager.**5The estimate is based on an assumption that the proactive decisions would help eliminate 25% of the breakdowns (see e.g. Chen 2013) of a selected 20% of the production lines. The value of an additional hour of production is a rough estimate based on the gross profit margin and tax rate reported in the 2018 financial statement of the case company.**6The estimate has been calculated assuming that the maintenance managers would save the time currently used in turning the data electronic (5 minutes per work order). An hourly cost of £16.0/h (based on payscale.com and stafftax.co.uk) has been used to estimate the value of this time.* |

**5 Conclusion**

This paper studied how VSM can be adopted to identify waste in maintenance information management processes. A theoretical framework was presented to summarize the existing knowledge on the topic, and an empirical case example was used to demonstrate how the method supports lean information management in maintenance through mapping and quantifying different types of information waste.

The main theoretical contribution of the paper is depicted by the framework which summarizes recommendations on what should be taken into account when applying VSM in this specific context. This includes e.g. conducting analyses on both macro and micro levels to achieve comprehensive understanding, the updated waste types in lean (maintenance) information management, and the suggestion to use time-based performance measurement to receive quantitative results without evaluating the monetary value of information. The paper contributes to industry through introducing a theory-based, visual method to identify waste in maintenance information management. To solve the problems caused by the waste, a cost model is needed to present feasible business cases.

The paper has two main limitations. Firstly the analysis examines the first phases of the VSM process. The design and implementation of a working plan to achieve the future state map is left for further research. Secondly, the case example presented in the paper examines a macro-level analysis of the maintenance information management process. In practice this should be supported by a number of micro-level analyses focused on specific parts of the process, selected e.g. on the basis of the preliminary macro-level analysis.

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| *https://europa.eu/european-union/sites/europaeu/files/docs/body/flag_yellow_high.jpg* | *This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 751622.* |

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