A Reference Model for Maintenance Processes

9

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Abstract

Effective maintenance has become increasingly important the last few decades. Competition is increasing because of globalization. Therefore, production is confronted with increasing requirements. In particular, machinery and plants have to produce faster and in greater volume. Nowadays, the high availability of equipment is a prerequisite to compete. In recent decades, maintenance has become its own business area. The Lean Management method Total Productive Management (TPM) provides a guideline for effective maintenance. The maintenance process itself is not adequately described in the literature. However, it is an efficient means of addressing unplanned maintenance tasks. This is the reason for creating a reference model for the maintenance process that can be implemented in companies. The process model is described using the language of subject-oriented business process management (S-BPM). This process language meets the requirements of TPM and maintenance experts. S-BPM is a communication system which focuses on the individual actors. Furthermore, the message flow of the communication is displayed to provide a structured and clear understanding of messages required within the reference model. The reference model created was verified by maintenance and S-BPM experts and is seen as a positive and important development in the field of maintenance. It is also pointed out that this reference model needs to be customized for every customer. Then it facilitates responding to customer requirements.

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9.1 Importance of Maintenance Processes

The DIN EN 13306 standard defines maintenance as the combination of every technical and administrative measure, as well as management measures, implemented to maintain a perfect condition or recreate a perfect condition during the entire lifecycle of a unit with the aim that this unit can fulfill its function (Beutler 2008; Arnold et al. 2008). Effective maintenance has become increasingly important over the last few decades. Competition is increasing because of globalization. Therefore, production is confronted with increasing requirements. In particular, machinery and plants have to produce faster and in greater volume. Nowadays, the high availability of equipment is a prerequisite to compete. In recent decades, maintenance has become its own business area (Arnold et al. 2008; Ijioui et al. 2010).

Thus, “doing more with less, better and smarter” has become the new slogan for maintenance (Matyas 2013). In 2008, 250 billion euros were invested in maintenance by German companies. Approximately 45 billion euros could be saved. It was detected that 18 % of the maintenance tasks executed by companies are not required and ineffective. In addition, up to 30 % of breakdowns could be avoided if the maintenance process was executed in a more intelligent way. By increasing the effectiveness of maintenance, workforce could be reduced in the maintenance field by 30–70 % (Kuhn et al. 2008).

Nowadays, maintenance has become very important to organizations. Not only are the availability of maintenance objects and the costs of maintenance activities of considerable interest, but also considering effectiveness, product quality, the maintenance service and safety is important. This means that the availability of required resources must be ensured to guarantee the availability of the maintenance object. The main objective of maintenance is the preservation of the availability and functionality of a unit (Arnold et al. 2008; Matyas 2013).

The Lean Management method supports companies in fulfilling these new market requirements and improving the effectiveness of production. As the name of this method suggests, production and the company as a whole are made lean. This means that the stock of a company should be as small as possible and the lead time should be as short as possible. Theoretically, equipment availability needs to be 100 % because any failure of a maintenance object leads to an increase in lead time. Every increase in lead time increases the amount of stock; that is, the link between Lean Production and maintenance, i.e., providing an efficient maintenance process, overproduction, large amounts of stock, inefficient processes, etc. can be prevented (Matyas and Sihn 2011).

Total Productive Management TPM is a Lean Management tool developed especially for maintenance to ensure the availability of equipment (Matyas 2013). According to Matyas (2013 p. 191), TPM relates to productivity-orientated maintenance which allows the efficiency of plants and machinery to continuously improve with the help of all employees. Thus, the aim of TPM is to achieve perfect

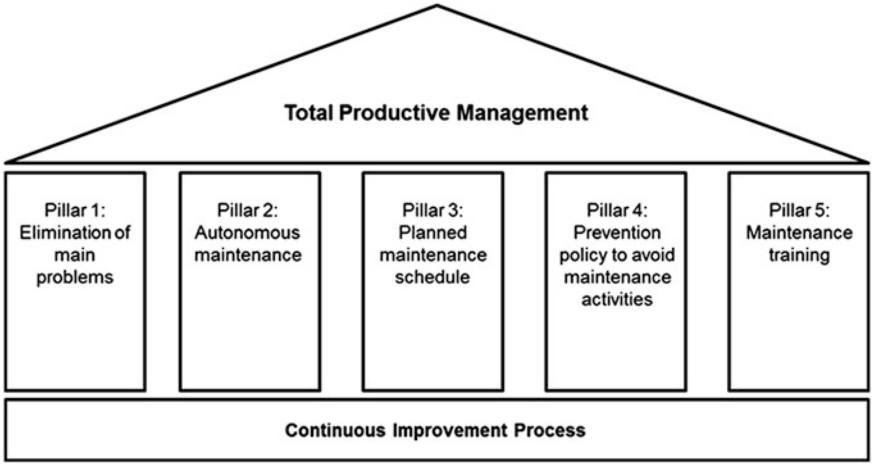

Fig. 9.1 Pillars of TPM [modified from Matyas (2013)]

equipment availability. The productivity orientation and the inclusion of all employees are two very important aspects not only for TPM but also for the entire set of Lean Management methods. The precise TPM process can be described in relation to five pillars. As can be seen in Fig. 9.1, the foundation of TPM is the Continuous Improvement Process (CIP) (Kamiske 2010).

The first pillar requires the elimination of the main problems that occur in production to reduce the difficulty of maintenance tasks and prevent breakdowns, unplanned down time, etc. The next step is autonomous maintenance, in which standard maintenance tasks (e.g., refilling engine oil, regular cleaning, etc. in the automotive industry) is carried out independently by the workers. This requires maintenance plans as illustrated by the third pillar. The fourth pillar goes further and relates to the creation of a prevention policy. This means that during the planning and construction phases, aspects of maintenance should be considered, e.g., the accessibility of parts. The fifth pillar recommends maintenance training for employees to prepare personnel. With the implementation of TPM, corrective maintenance activities can be minimized. Furthermore, the occurrence of unplanned repair activities can be avoided (Kamiske 2010).

Following Lean Production methods, especially TPM, a company is perfectly prepared for maintenance tasks, besides accidents, which lead to unplanned down time. Exact measures for handling such cases are difficult to define, because unplanned down time, by its nature, cannot be planned for and tends to be due to random accidents. Nonetheless, reducing and managing unplanned down time is addressed in the model proposed herein.

9.2 Importance of a Reference Model

In 2009, Moayed presented a comparison of lean-producing and non-lean-producing companies. He recognized four main factors which have to be improved when becoming a lean manufacturer. First, it is important to have well-trained employees. Every employee who comes in contact with the area of maintenance should be given additional maintenance training. Second, the amount of stock and work in progress are highly important. Furthermore, the time between the occurrence of a failure and ordering of the required maintenance activity is an important factor if companies want to become lean. Finally, "the ratio of down-time to production time" is also a key factor. In particular, improving two specific factors—time between failure and ordering maintenance and the ratio of down time to production time—are typical aspects of process management. This means that an efficient maintenance process should be created in a way that it can be implemented to support perfect equipment availability (Matyas 2013; Matyas and Sihn 2011).

There already exists a standard model for the maintenance process. This model was created by Matyas (2013 p. 178ff) and is described using an event-driven process chain (EPC). In this paper, it serves as a basic model for the creation of a reference model. Matyas (2013 p. 178ff) defines eight main steps in maintenance: *Identify, Plan, Prepare, Execute, Restart, Check functionality, Approve* and *Close*. These eight sub processes were chosen based on the examination of maintenance projects that were based primarily on them (Matyas and Sihn 2011). This overview of the maintenance process is similar to the overview provided by Liebstückel (2011), who defined five steps: notification, planning, control, implementation and completion. These steps are a summary of the steps described by Matyas and confirm the eight sub processes.

However, only the functions and activities of the maintenance process are shown and described by Matyas (2013), as seen in Fig. 9.2. Little information is provided about the messages which have to be sent or received to run the process, or about the business objects which are necessary to complete the process in an effective manner. Furthermore, there is little information concerning the process participants. The lack of this information means that the maintenance process cannot be implemented and used by a company. However, the description of the maintenance process using an EPC can be used to present the concept of maintenance, giving the responsible maintenance personnel a first impression of maintenance activities (Weske 2007).

In summary, the standard model provided by Matyas represents the process stages of maintenance and serves as a form of overview in case the maintenance process is unknown. This description does not provide sufficient details to serve as a reference process.

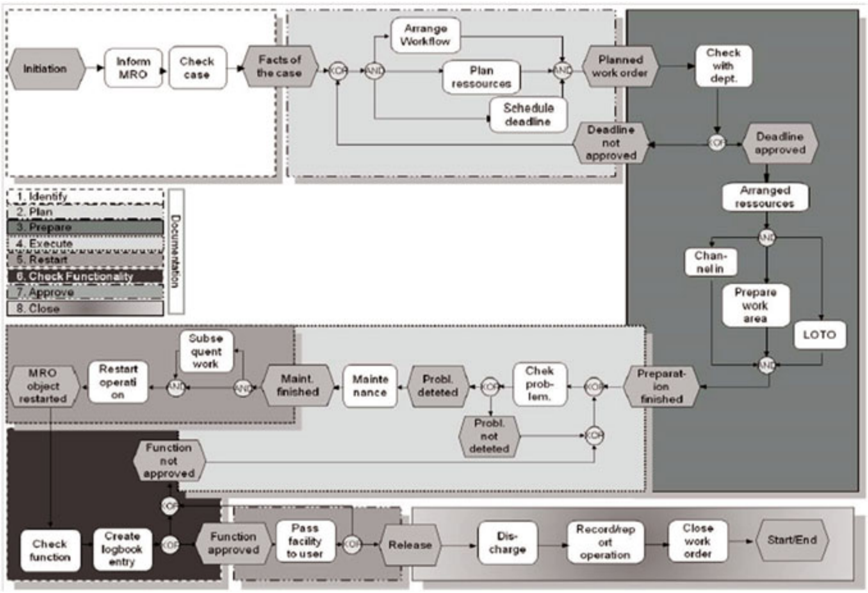

Fig. 9.2 Maintenance process according to Matyas and Sihn (2011)

9.3 Selecting S-BPM for Representation

For the creation of the reference model, S-BPM has been chosen. This process language meets both TPM requirements and reference model requirements as described now. The S-BPM notation consists of three core elements: subjects, predicates and objects (Fleischmann et al. 2011, 2013a, b). The EPC is a function-orientated process language and focuses on the functions and activities of a process. The participants and messages are less important and hardly considered. This means the EPC concentrates on the predicate of a sentence. In this approach, the process is built around the data structures which display the required operations (Fleischmann et al. 2011).

Subjects are the most important element in S-BPM. This means that each subject required for a process is defined and determined and each role must be defined before a process description can start (Fleischmann et al. 2013a, b). The central element of Lean Management methods is the active participation of employees (Kamiske 2010). The subject-orientated view of processes in S-BPM promotes this requirement. Accordingly, S-BPM seems to be suitable for implementing maintenance when viewed from the perspective of TPM. The second element of S-BPM is the predicate, which represents the subjects' behaviors. The behavior of each subject is described, which means that every subject knows exactly which activities and tasks are to be performed. Again, S-BPM supports the subject-based view of

Lean Management methods. The third element of S-BPM is the object. (Business) Objects are transferred between subjects. Objects can comprise messages as well as tangible goods, such as maintenance objects, etc. Objects are elements that are manipulated by subjects (Fleischmann et al. 2011).

One of the drawbacks of the EPC maintenance process was the lack of object representation. Less information is provided about objects if a process is described using an EPC (Weske 2007). If business objects and their flows are not created, a process cannot be created in S-BPM (Fleischmann et al. 2011). Unlike the standard model, S-BPM fulfills all the requirements of Lean Management methods and the maintenance process itself.

To transform the standard model described using an EPC by Matyas (2013) into a reference model described using S-BPM, a helpful case study was found in Cakar and Demirörs (2014). In this study, important transformation rules are given. Rules for basic structural elements and rules for more complex structures are listed. The creation of the reference model was initiated based on these rules. Furthermore, ten experts stemming from five different companies were interviewed (Aigner et al. 2014; Heimhilcher and Schwarz 2014; Matula and Markus 2014; Szalay 2014; Reinert 2014), in order to obtain qualitative verification of the constructed reference model.

9.4 The Maintenance Process Reference Model

In this section, the reference model is presented. First, the Subject Interaction Diagram (SID) created is shown. In Fig. 9.3, the SID of the reference model can be seen. For the maintenance process, five subjects have been defined: *Working System, Operations Manager, Maintenance Manager, Maintenance Workers* and *Warehouse/Procurement*.

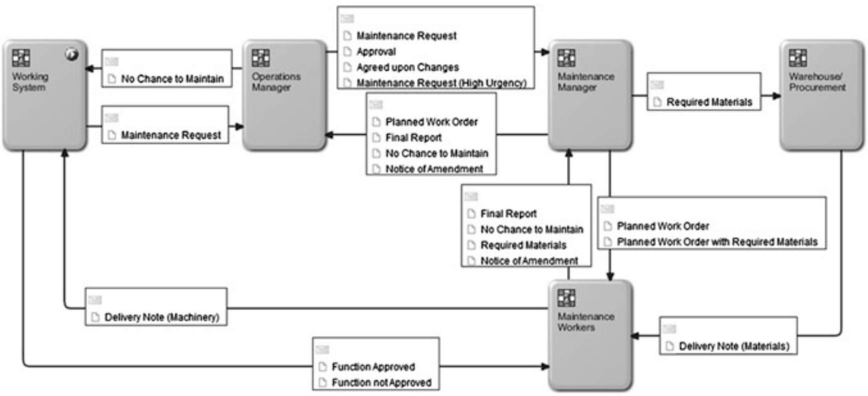

Fig. 9.3 SID of the maintenance process

The process starts with the subject *Working System*. The contact subject for the *Working System* is the *Operations Manager* who is responsible for a functioning operation. The Maintenance Manager is the responsible subject for maintenance activities. This subject creates maintenance plans, coordinates these plans and exchanges them with the *Operations Manager*, engages the *Maintenance Workers* to perform the maintenance activities, and orders the required materials from the *Warehouse/Procurement*. As can also be seen in Fig. 9.3, the *Maintenance Manager* is a central subject and therefore is important in this process. The *Warehouse/Procurement* is responsible for the correct delivery of the required materials. The *Maintenance Workers* are responsible for the maintenance activities. The contact subject for the *Maintenance Workers* is the *Maintenance Manager*.

We now turn to the behavior of each subject to explain the entire process and the messages required.

9.4.1 Subject Behavior Diagram (SBD) of the Working System

In Fig. 9.4, the behavior of the subject *Working System* can be seen. When a failure occurs or is detected, a report has to be filled out and appropriate activities must be set. The failure report consists of data such as details concerning the reference object available at the time, for example, data on the malfunction and details about the location and responsible persons. Appropriate activities are tasks which should be executed by the workers, and tasks which protect the machinery against additional damage.

When these initial tasks have been completed, a maintenance request is sent to the responsible *Operations Manager*. This is the first message sent by the *Working System* and can also be seen in the SID (see Fig. 9.3).

Then, the *Working System* receives either a note of the delivery of the machinery by the *Maintenance Workers* or the *Working System* receives the message that the machinery can no longer be maintained. If the *Working System* receives the latter message, the process ends at this point for this subject. Otherwise, if the *Working System* receives the machinery delivery message, the machinery has to be controlled (evaluated and monitored) in the next step.

If the functioning of the machinery is not approved by the *Working System*, a message is sent to the *Maintenance Workers*. In this message additional information, e.g., what exactly still does not work, is included. Then the *Working System* again waits for the completion of the maintenance. If the functioning of the machinery is approved by the Working System, confirmation is sent to the *Maintenance Workers* and the maintenance process ends at this point for the *Working System*.

As can be seen in the SID (Fig. 9.3) and in the subjects' behavior (Fig. 9.4), the following messages can be sent by the *Working System*: a maintenance request, an approval, and a non-approval message. The following messages can be received by the *Working System*: a no-chance-to-maintain message and a machinery delivery note.

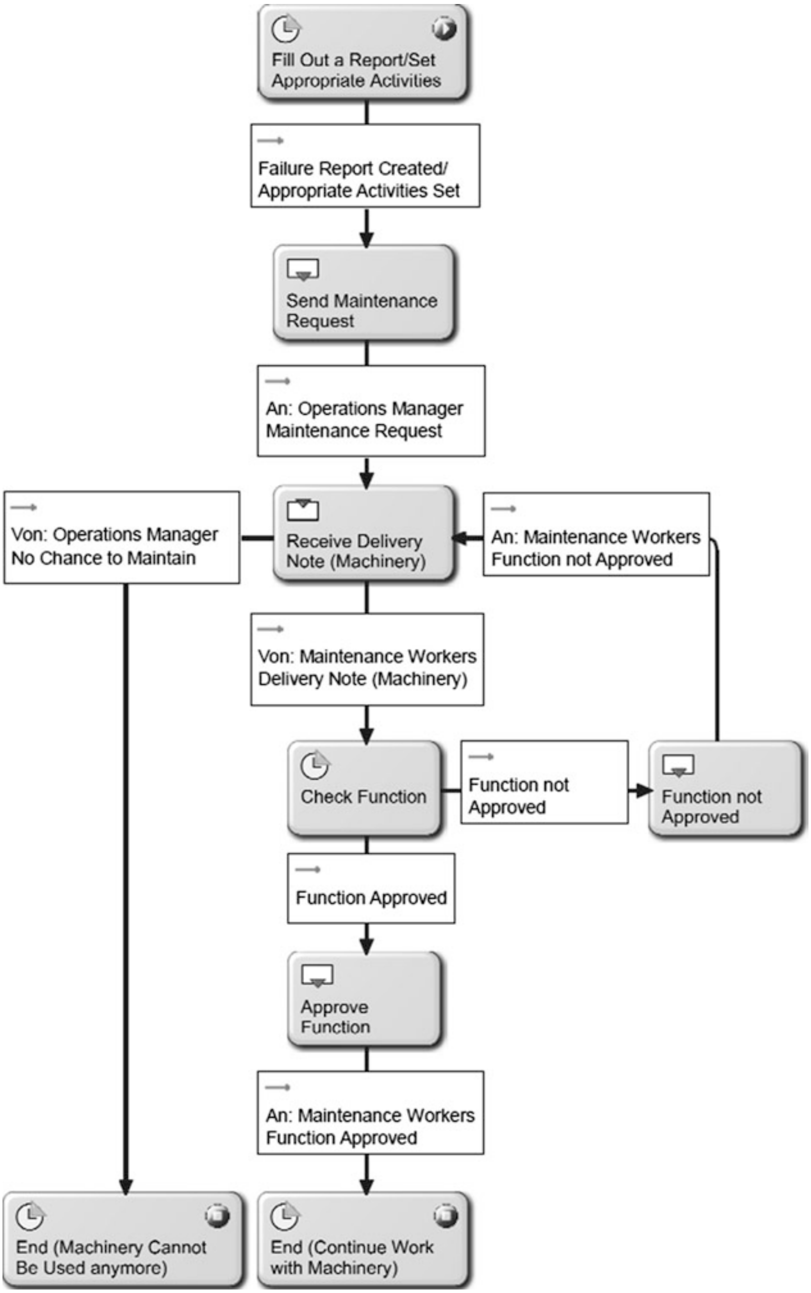

Fig. 9.4 SBD of the working system

9.4.2 SBD of the Operations Manager

As can be seen in Fig. 9.5, the process starts with the receipt of a maintenance request by the *Working System*. After receiving the message, the maintenance request has to be checked. If this request is not a high urgency request, all missing data is added, and the request is finally sent to the *Maintenance Manager*.

In the next step, the planned work order created by the *Maintenance Manager* is received. This work order consists of the time in which the maintenance is to be executed and the personnel and material are required. If any of these planned resources have to be changed by the *Operations Manager* because of other important tasks being accomplished by the responsible department, these changes are filed, and sent to the *Maintenance Manager*.

If the planned work order is checked and approved, an approval is sent to the *Maintenance Manager*, which can be seen as an order. This communication between the *Operations Manager* and the *Maintenance Manager* is the coordination of planned work orders. Then, the production plan is updated to change important scheduled tasks and shift resources in time. If the maintenance request by the *Working System* is a highly urgent request, an order is sent immediately to the *Maintenance Manager* and the production plan is then updated. When the production plan has been updated, the *Operations Manager* receives a response from the *Maintenance Manager*. There are three possible messages: a notice of amendment, a no-chance-to-maintain message, or a final report.

If a notice of amendment is received, the production plan has to be updated again. This notice of amendment can be a change of the completion date or a change in human and material resources required. If a no-chance-to-maintain message is received, the *Working System* has to be informed and the maintenance process ends. If a final report is received from the *Maintenance Manager*, the process is also complete.

The following messages can be sent by the *Operations Manager* (see Figs. 9.3 and 9.5): a maintenance request, a maintenance request of high urgency, an approval, an agreed-upon-changes message, or a no-chance-to-maintain message. The following messages can be received by the *Operations Manager* (see Figs. 9.3 and 9.5): a maintenance request, a planned work order, a notice of amendment, a no-chance-to-maintain message, or a final report.

9.4.3 SBD of the Maintenance Manager

As can be seen from Fig. 9.6, the process involving the Maintenance Manager starts with the receipt of a maintenance request from the *Operations Manager*. It is initially controlled (evaluated) whether it is a simple request or a highly urgent order. In case the message received is a simple maintenance request, the maintenance is scheduled. Human resources, necessary materials and a schedule have to be determined and summarized in a prospective work order. This work order is sent

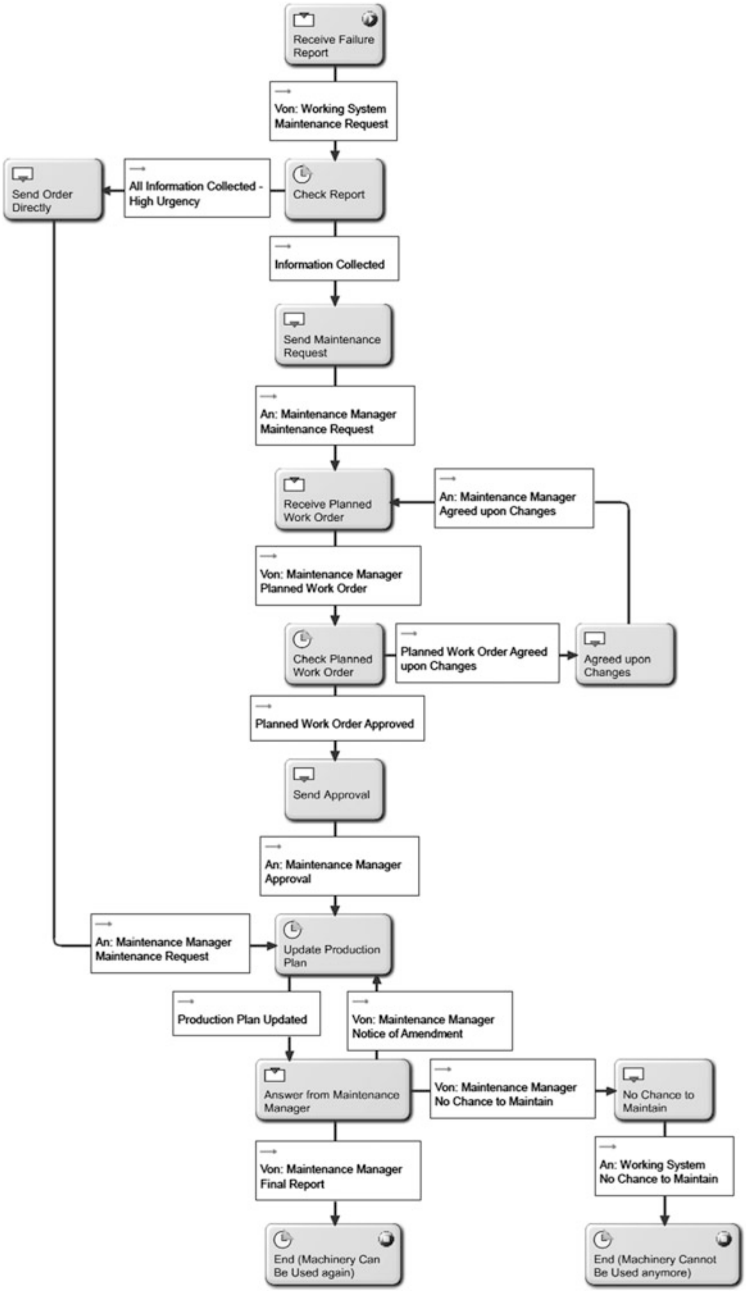

Fig. 9.5 SBD of the operations manager

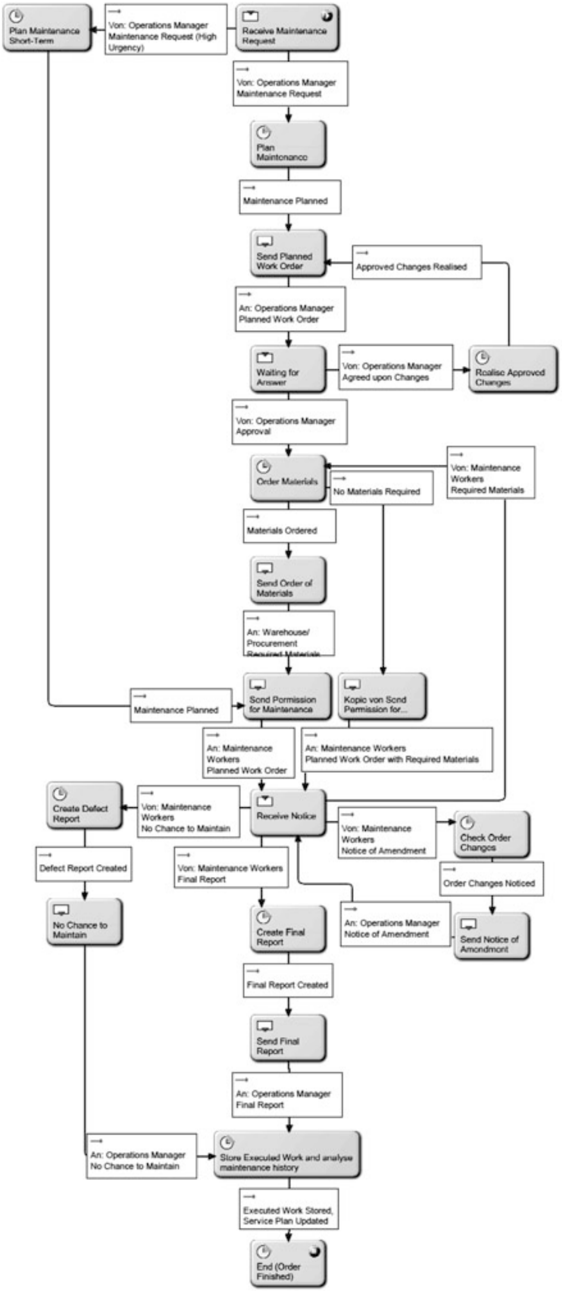

Fig. 9.6 SBD of the maintenance manager

to the *Operations Manager*, who sends either an agreed-upon-changes message or an approval. If some changes are required by the *Operations Manager*, these changes are realized and the updated work order is sent again to the *Operations Manager*. It also coordinates the *Operations Manager* and the *Maintenance Manager*. If an approval is received from the *Operations Manager*, the materials required are ordered. It is important that this order not only contains the necessary materials but also the place of delivery and responsible persons. Subsequently, the permission for maintenance is given to the *Maintenance Workers*.

If the *Operations Manager* has sent an order directly because of a high degree of urgency, the maintenance is planned for the short term and permission is sent immediately to the *Maintenance Workers*.

Four of the interviewed experts (see Appendix), Aigner et al. (2014), pointed out that, before a good maintenance plan can be made, an expert has to check the maintenance object. The maintenance expert, i.e., an expert in the machinery, is the only person with the appropriate knowledge to select relevant personnel, materials and time in the best way. Furthermore, two interviewed experts, Matula and Markus (2014), proposed that better differentiation could be made between maintenance orders. For example, different escalation stages can be defined in terms of how urgent a maintenance order is and how many experts are required, etc.

When permission is given, the *Maintenance Manager* waits for an answer from the Maintenance Workers. There are four possible answers: an order for materials, a notice of amendment, a no-chance-to-maintain message, or a final report. If an order for materials is received, materials are ordered from the *Warehouse/Procurement*. It is important that in this case the *Maintenance Workers* be informed when the material is ordered. If a notice of amendment is received, the necessary order changes are checked and the amendment is sent to the *Operations Manager*. These amendments can be either a change in the human resources required or a postponement.

If the *Maintenance Workers* confirm that the machinery cannot be repaired, the *Maintenance Manager* creates a defect report and sends the message to the *Operations Manager*. The executed work is then stored and the maintenance process ends. The process steps are similar if the Maintenance Manager receives a final report from the *Maintenance Workers*. The final report is completed and sent to the *Operations Manager*. The executed work is stored and the process ends. According to Matula and Markus (2014) and Heimhilcher and Schwarz (2014), it is important to analyze the work executed for every maintenance object to create perfectly tuned service plans.

The following messages can be sent by the *Maintenance Manager* (see Figs. 9.3 and 9.6): a planned work order (to the *Operations Manager* as well as to the *Maintenance Workers*), a notice of amendment, a no-chance-to-maintain message, a final report, or an order for materials.

The following messages can be received by the *Maintenance Manager* (see Figs. 9.3 and 9.6): a maintenance request, a maintenance request of high urgency, an approval, an agreed-upon-changes message, a no-chance-to-maintain message, a notice of amendment, an order for materials, or a final report.

9.4.4 SBD of the Maintenance Workers

The maintenance process for the Maintenance Workers starts with the receipt of a maintenance order by the *Maintenance Manager* (see Fig. 9.7). If extra material is required to handle this order, it is mentioned in the order and the material is received from the *Warehouse/Procurement*. In the next step, all the resources required have to be arranged. This includes not only material required but also the tools, as well as responsible persons and specialists. Then the maintenance work itself can be started. In this case a checklist can be created, which the *Maintenance Workers* can go through during the maintenance procedure. This checklist can consist of points such as correct channeling in, preparation of the work area, lockout–tagout (LOTO), etc.

During the maintenance process two possible issues can occur. First, additional or further material may be required. In this case an order is sent to the *Maintenance Manager* and the material is received from the *Warehouse/Procurement.* Second, a complete defect may be detected. In this case, a message is sent to the *Maintenance Manager*. The workplace is then discharged and cleaned up, and the maintenance process ends.

If the maintenance can be completed and the functioning of the machinery is checked by the *Maintenance Workers*, a delivery note is created for the Working System. After the machinery is transferred to the *Working System*, the workplace should be cleaned up completely and an answer from the Working System is awaited. If the Working System does not approve the functioning of the repaired machinery, maintenance work recommences. If the functioning of the machinery is approved, a final report has to be created, generating a timeout of 24 h. This means that no more than 24 h can pass before an answer is received from the Working System to ensure the process is completed as fast as possible. The final report is sent to the *Maintenance Manager* and the maintenance process ends here for the *Maintenance Workers*.

Four of the interviewed experts, Aigner et al. (2014), pointed out that the final inspection of a maintenance object is not done by the user alone, but together with the responsible maintenance worker. This should be marked in the process by companies in terms of how it is done, as Heimhilcher and Schwarz (2014) pointed out that the inspection of their products takes between one and two months. In this case, it is nearly impossible for the responsible maintenance workers to undertake this final trial together with the customer; furthermore, a timeout function seems to be unnecessary.

The following messages can be sent by the *Maintenance Workers* (see Figs. 9.3 and 9.7): a delivery note of the repaired machinery, a no-chance-to-maintain message, an order for materials, a notice of amendment, or a final report. The following messages can be received by the *Maintenance Workers* (see Figs. 9.3 and 9.7): a maintenance order, a delivery note of the materials, an approval, or a non-approval message.

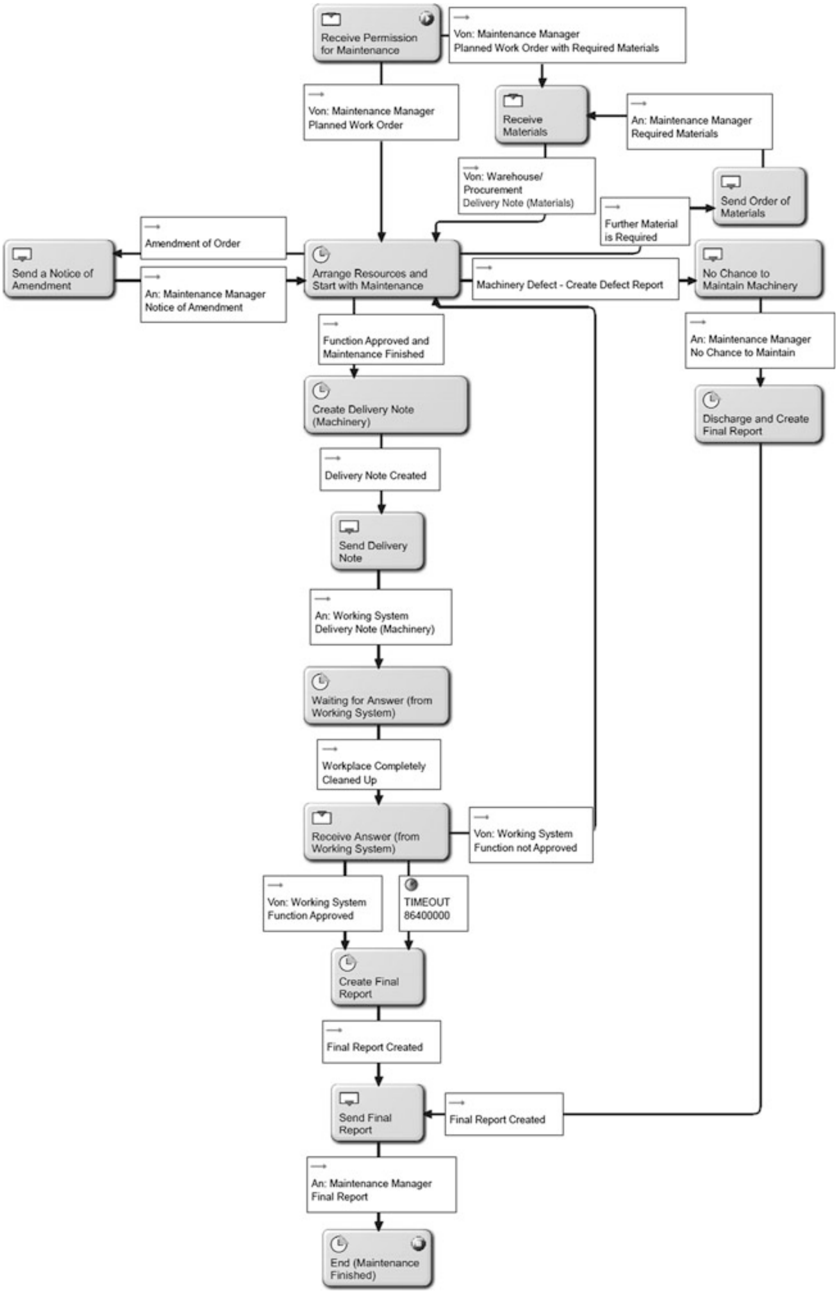

Fig. 9.7 SBD of the maintenance workers

9.4.5 SBD of the Warehouse/Procurement

As can be seen in Fig. 9.8, the process starts with the receipt of an order for materials from the *Maintenance Manager*. The materials required are sent to the *Maintenance Workers* and the process ends because the order is complete as far as the *Warehouse/Procurement* is concerned. There is one message, which can be sent by the *Warehouse/Procurement* "no delivery of materials" and one message which can be received by the *Warehouse/Procurement* "an order" for materials (see Figs. 9.3 and 9.8).

This SBD completes the reference model for the maintenance process. Each subject is solely responsible for its behavior. A technical verification was undertaken using the Metasonic Flow and the Metasonic Proof, both verification systems

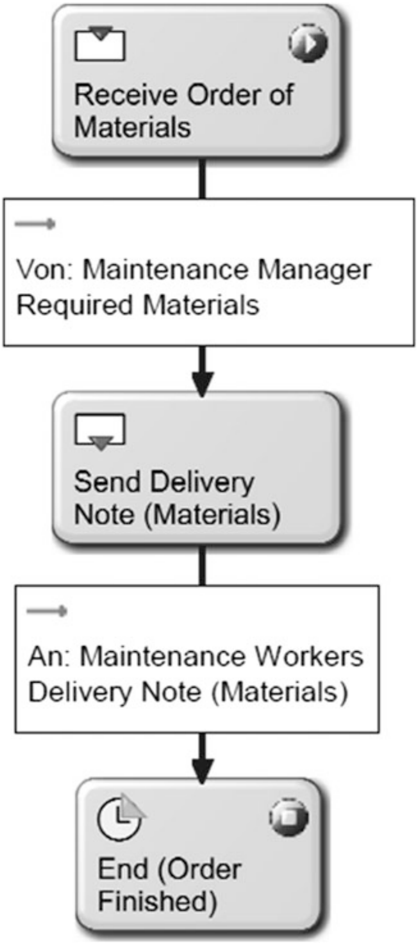

Fig. 9.8 SBD of the warehouse/procurement

included in the Metasonic Build. The process was implemented to detect logical errors. Furthermore, a qualitative verification was undertaken by interviewing maintenance and S-BPM experts.

9.5 Outlook

In this chapter a reference model has been introduced which can be implemented by companies in various sectors. The maintenance experts mainly appreciated this attempt and the model. They also mentioned that the reference model needs to be customized for each company when utilizing it. This indicates the next steps that need to be taken. There should be an intensive knowledge exchange between maintenance experts and S-BPM experts to verify the reference model in relation to different contexts, to modify it and make it more universally accepted. In addition, first implementations in companies help in receiving feedback on the model. With the consent of different companies, a survey could be developed to accompany the implementation of the reference model and examine its application. In this case, important data can be collected to study the "customization factor" of the reference model and its overall acceptability. Furthermore, additional investigation would be worthwhile in the areas of messages and business objects as only a short overview is given in this chapter.

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Appendix: Guideline for the Expert Interviews

Interviewer:	Date:
Experts:	Company:

- Introduction (name, UAS, Master's Thesis)
- Objectives of the expert interviews
- Usage of this interview in the thesis
- No internally or confidentially information about the company necessary
- Agenda

1. Standard model of maintenance (according to Matyas)
   (a) Presentation
   (b) Process understandable
   (c) Advantages, disadvantages of implementing this standard model
2. Created reference model
   (a) Presentation
   (b) With "Metasonic Flow"

   (c) Gaps, complaints, suggestions for improvement
3. Messages within the reference model
   (a) Existing parameters sufficient?
   (b) Additional documents necessary?
4. Organisational embedding
   (a) Confrontation of internal and external processes (Service Level Agree-ments
   (b) Advantages, disadvantages of the implementation
   (c) Is an improvement of maintenance possible?

Date, Signature

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