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# Planning of maintenance activities – A current state mapping in industry

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**Abstract**

Industrial Product Service System (PSS) thinking can be applied to production system by considering it as a product. Prior studies show that strategic planning of the maintenance activities in manufacturing industries holds great potential to increase productivity. Planning of maintenance activities is therefore an integral decision making aspect for maintenance engineers and it is important to analyze how industries are currently working with planning of maintenance activities and what additional support is needed. This paper aims at mapping the current state of the work procedures for maintenance engineers and planners in the industry and analyzes the gap from current practices to the strategic planning which could increase productivity. The study specifically focuses on how industries work today with finding critical resource, performing criticality analysis, and planning maintenance. A descriptive research approach is followed, where empirical data is collected in Swedish industry through three different data collection methods. The results show the state-of-art industrial practices and the gaps in maintenance planning.



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*Keywords:* maintenance planning; criticality analysis; system bottleneck

## 1. Introduction

Industrial Product Service Systems (PSS) offers business innovation and sustainable development for industries by integrating production and service for their products. Manufacturing industries have complex production systems producing different products. In order to produce products of high quality the production system needs maintenance [1]. However, overall equipment effectiveness (OEE) in manufacturing companies is about 50 – 55% in manufacturing industries [2]. These production losses are due to direct down time (failures) and system losses (blocked and idle states) of machines in flow-oriented production system. These result in economic sustainability losses to the company. Ecologic sustainable losses occur as 30% energy losses are due to system losses [3]. By considering the production system as a product, the PSS thinking can be employed to the production system. This will make the production system highly productive, sustainable, and reliable.

A prior study shows that through strategic planning of maintenance activities, productivity can be increased by about 5% [4]. Therefore maintenance activities planning is an integral decision making aspect for maintenance engineers, requiring support from modern methodologies, data analysis approaches, and Information and Communication Tools (ICT). Currently, the maintenance department in industries on the contrary use limited tools and analyses to assist their decision making on an everyday basis [5].

Critical sections of the production system should be effectively utilized. Dynamic decision support is needed for maintenance and existing maintenance management systems are insufficient [6]. There are different ways in which critical sections of the system could be classified. Failure mode effect and criticality analysis (FMECA) is the frequently method [7]. Throughput criticality classification can be used for decision support system for planning of maintenance tasks [8] and an analytic hierarchical process (AHP) based [9] can also be used for maintenance. Criticality analysis needs to be continuously updated every day to prioritize maintenance activities [10]

With complex production, prioritization of maintenance work-orders becomes crucial and challenging [11]. Throughput improvement can be achieved through


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prioritizing maintenance activities for the static and dynamic bottleneck machines [4]. The highest criticality is given to the equipment that is most important for a specific purpose, which normally is production. The equipment with the highest criticality gets the highest priority code and is thus scheduled first when performing maintenance [1]. Effectiveness is achieved through prioritizing machines' criticality, and focusing on specific components [9].

Hence there is strong motivation to understand the use of criticality classification and bottleneck detection in the industries in relation to planning of maintenance. In order to do that, a current state mapping of how companies currently working with planning of maintenance activities and the additional needed support is necessary. Therefore the authors formulate the following research questions (RQ):

*RQ1:* To what extent are companies working with criticality classification?

Finding the extent to which companies work with criticality classification is an important starting point as this will help in identifying the critical resource of the system, as in RQ2.

*RQ2:* What is criticality from a maintenance perspective, and how are critical resources identified?

Criticality classification can be created in many different ways and from different perspectives. Finding the critical resource from a maintenance perspective will help in prioritizing maintenance activities, as in RQ3.

*RQ3:* To what extent are maintenance activities prioritized, and how are the criticality classification used for this purpose?

Maintenance activities for production system needs effective planning. This paper will identify the extent to which maintenance activities are prioritized and the use of criticality classification for the same.

## 2. Methodology

Three mixed method research questions were stipulated, with the intent of increasing knowledge about how criticality and bottleneck detection is used from a maintenance perspective in industry. A descriptive survey research approach was adopted [12, 13], aiming to provide additional information about the use of these practices in industry, where the three questions serves to explore and explain the current situation. The three data collection methods were used to form empirical evidence to answer the research questions. Quantitative data was collected using a web-based questionnaire survey and structured interviews during a maintenance fair, and a combination of quantitative and qualitative data was collected using semi-structured interviews. Throughout the paper, the three data sets will be referred to as the "survey", "maintenance fair", and "interviews". The three data collection methods were chosen in order to investigate the subject area from both a general and a specific perspective. The survey and the maintenance fair describe the general perspective since it was collected from both small and large companies in various industrial branches and production contexts. In contrast, the interviews depict a specific perspective since they were conducted in two of Sweden's largest discrete manufacturing companies.

### *2.1. Survey*

Quantitative data was collected in Swedish industry through the use of a web-based questionnaire. Invitation to the questionnaire was sent by e-mail to selected respondents, and an open invitation was listed publicly on the website of Sustainability and Maintenance Global Centre (SMGC), as well as included in an SMGC e-mail newsletter. SMGC is a non-governmental maintenance organization with over 50 member companies. A non-probabilistic judgement sample was used [12], where the primary target group were maintenance or production experts.

62 out of 82 selected respondents answered, resulting in a response rate of 75 percent. The open invitation resulted in 22 additional responses. Out of the total 84 submissions, non-experts were excluded, and the respondents with the highest management level were chosen at plant-level for each company. The final selection consisted of 76 responses from 71 companies, where the 5 duplicates represent individual respondents from different plants within the same company, but separated geographically and operating with different management. A majority of the respondents can be classified as the maintenance department. The companies represent various production contexts such as manufacturing, energy, nuclear, paper and food industries. The questionnaire covered the topics of criticality, bottleneck detection, and maintenance prioritization. The remaining part of the questionnaire covered other areas such as production disturbances, tools and methods in maintenance etc.

### *2.2. Maintenance Fair*

Seven structured interviews were conducted during one day of Scandinavia's largest maintenance fair, which was held during 4 days in March in Gothenburg with 250 participating companies. These interviews were short (less than 10 minutes), and focused specifically on the topics of tools and methods used in maintenance planning, use of priorities, criticality, and bottleneck detection. The interview questions were formed as a combination of closed questions with multiple choices and open-ended question.

### *2.3. Interviews*

Four semi-structured face-to-face interviews [14] were conducted with personnel of the maintenance department from two of the partner companies in the research project "StreaMod". Three maintenance managers and one maintenance strategist were selected as interviewees since they represent high strategic level within large multi-national corporations, thus indicating a specific context that could benefit from using bottleneck and criticality analysis in maintenance. The interview template was created on the basis of the previous two data collection methods, and covered the topics of criticality and bottlenecks. The interviewees received information regarding the covered topics prior to the interviews. The concepts were not explained in further detail at this point, thus assumed to be familiar to the interviewees. The interviews were structured to first ask about the critical resources in the production system, followed by how they work with criticality classification and bottleneck detection from a maintenance perspective. Prompts and probes were used to increase the clarity of the answers, which led to that some answers related to critical resources developed towards discussions about bottlenecks.

A mixed method approach was also used within these interviews, where open-ended questions were asked in combination with a structured questionnaire. Through the use of 4-point Likert scales, the interviewees where instructed to assess the certainty regarding critical resources and bottlenecks. An additional probe followed with the intent to further clarify the reasoning of the chosen answer.

*2.4. Data analysis and presentation*

Following the data analysis methodology proposed by [13] and adhering to the descriptive research approach, quantitative data were analysed using SPSS and presented with descriptive statistics in terms of frequency of responses. For qualitative descriptive research, [15] advice to perform content analysis, where the outcome is a descriptive summary of the data organized in a way that best fits the data. Following the criteria described by [16], the interview data was chosen to be analysed by hand, and presented narratively with identified themes and illustrating quotes. Throughout the paper, the data from the four interviews are referred to in terms of the order they were conducted, i.e. data from Interviewee 1, 2, 3, and 4. The results from the three data collection methods are presented in chronological order in terms of each stipulated research question, starting with the survey and finishing with the interviews [17].

## 3. Results

All the three collected data are presented in this section. Note that "?" refers to the answer alternative "Do not know", and "N/A" refers to the combination of the alternative "Not applicable" and missing answers.

*3.1. RQ1*

*Survey:* Figure 1 illustrates to what extent the companies participating in the survey are establishing criticality levels for maintenance of processes, equipment, or components. It shows that 35% of the companies work with criticality classification to a relatively high or very high degree, and 55% to a relatively low degree or not at all.

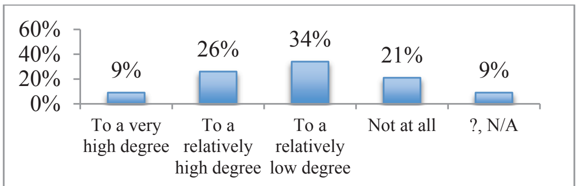


Fig.1. Establishing of criticality levels.

In connection to the establishing of criticality levels, Figure 2 displays to what extent these levels are continuously updated. It shows a similar distribution, where less than 30% of the companies continuously update the criticality levels to a relatively high or very high degree, and 65% to a relatively low degree or not at all.

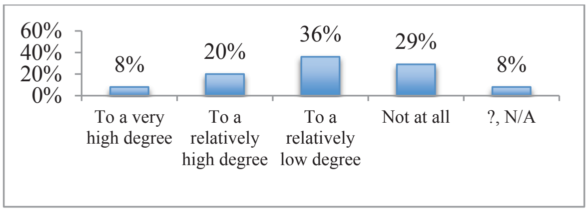


Fig.2. Updating of criticality levels

It is however important to note the results if the two questions regarding establishing and updating of criticality levels are cross-tabulated. The 4 main Likert-scale variables are recoded into 2 categories, "High degree", and "Low degree", and the "Do not know", "Not applicable", and missing answers are excluded. A Fisher's exact test on the recoded 2x2 matrix shows a two-tailed P value = 0.0001. This data indicates that a majority of the companies that are working with establishing of criticality levels to a high degree also consider that they continuously update the criticality levels to a high degree, and vice versa.

Furthermore, Figure 3 shows the survey data regarding to what extent companies are working with identifying and analysing bottlenecks in production. The data indicates that a majority of the companies, 56% in total, work with bottleneck detection to a relatively high or very high degree, and less than 10% do not work with it at all.

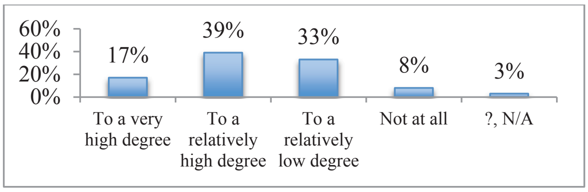


Fig 3. Bottleneck detection.

*Maintenance fair*: 4 out of 7 respondents indicated that they work with bottleneck detection, as well as mentioned that it is detected by Value Stream Mapping (VSM), operation monitoring, OEE, availability, throughput, and buffers.

*Interviews*: All four interviewees indicated that they work with establishing equipment criticality levels. Interviewee 1 explained that they create equipment priority numbers, which are created and updated when installing new machines or scrapping old ones. In contrast, interviewee 2, 3, and 4 indicated that the classification is a part of a technical specification carried out during the early project phase. When asked about bottleneck detection; all interviewees stated that it is performed. Interviewee 1 analyses both short term and long term bottlenecks based on data and meetings. Daily shop-floor meetings are used to decide short term bottlenecks, and long term bottlenecks are discussed on managerial level. Number of stops, short stops, and long stops are data considered for bottleneck detection. Interviewee 2 answered that their detection is based on facts and data. Interviewee 3 said that the production engineers are responsible for bottleneck detection, not the maintenance department and interviewee 4, said they use VSM to detect bottleneck conducted by production and maintenance personnel.

### 3.2. RQ2

*Survey:* Table 1 indicates that the most common primary basis for establishing criticality levels is using an ABC-classification. Furthermore, it shows that constructing the levels on other basis, such as bottleneck analysis, is not used to the same extent. Note that the respondents could only choose one alternative.

Table 1. Basis for establishing criticality levels.

| Primary basis for criticality levels | n | % |
|---|---|---|
| ABC-classification | 23 | 30% |
| Operator influence | 8 | 11% |
| Bottleneck analysis | 7 | 9% |
| Cost-based priority | 5 | 7% |
| Time of purchase | 4 | 5% |
| Other basis | 9 | 12% |
| Do not know/ "N/A" /Missing answer | 20 | 26% |

If answering "other basis", the respondents were asked to clarify the answer. These 9 respondents commented that their criticality levels are established on the following basis: *"demand controlled", "from the business system", "cost of root cause category", "similar to ABC but with 1-5 classification where 5 is highest", "product mix", "RCM/FMECA", "reactor safety (nuclear)", "safety", "equipment with importance for nuclear safety".*

*Maintenance fair:* In relation, when asked about how they establish criticality levels, all the respondents indicated that they establish using ABC-classification. Apart from that, 2 respondents answered operator influence and bottleneck and 1 answered for cost, upon purchase, and machine health as the basis of criticality levels. Note that the respondents could choose more than one answer alternative.

*Interviews:* When asked how they work with criticality classification, all four interviewees said that their company work with an ABC-type classification. Interviewee 1 mentioned that they use a 1 – 5 numbered equipment priority code for the classification, and the other three uses exactly ABC-classification. When the interviewees were asked how the criticality levels are set, they answered differently. Interviewee 1 said that the equipment priority codes are dependent on the production set-up, e.g. single or parallel flow. Similarly, interviewee 4 explained that they have a general thinking about the ABC classification where A – single line machine, B – a parallel machine, and C – spare machine. Interviewee 2 explained that establish the criticality classification on a component level through a risk analysis, which is based on fault frequency, mean time between failure (MTBF), and its consequences. Interviewee 3 uses a classification model with a tree-structure of questions, where the answers to redundancy, safety, productivity, environment, etc. generate the criticality level .When asked what the critical resource of the production system is, the answers were random at first. After prompting, interviewee 1 talked about an old robot in a particular line as being critical. When specifically asked why, the answer was that the robot was a bottleneck and it was throughput critical. However, interviewee 1 also mentioned that the critical measure from a maintenance perspective is availability. Interviewee 2 said "*It's really difficult for me to point out one that is critical [...] Critical for me is focus. I mean it's not always the machines. It's the people around it"*. However, when questioned further, it was indicated that bottlenecks could be critical, but the question of the bottleneck being the true bottleneck was raised. Interviewee 3 answered that "*if you look at the assembly line from an overall perspective, then that is very critical. If we get a stop here, it always affects the end customer directly"*. They have A classified all the machines in that particular line. Interviewee 4 answered "*The layout is very unfortunate and the parts move back and forth making it hard to understand the flow and analyse the losses*". On further questioning, interviewee 4 also mentioned bottlenecks as critical and explained that a bottleneck machine is A classified.

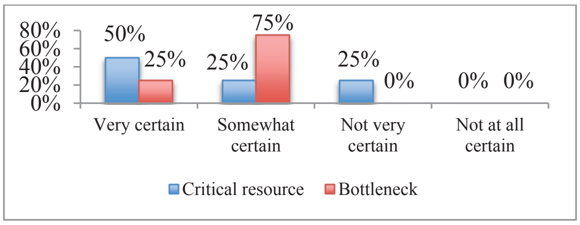


Fig. 4. Interviewee's perception on critical and bottleneck resources

Figure 4 shows the data from the Likert-scale follow up questions, and it indicates that the interviewees are not always certain about their bottlenecks and critical resources. Enquiring about bottlenecks in particular, Interviewee 1 talked about known and unknown bottlenecks, short term and long term bottlenecks, and says there are many bottlenecks in different areas. Interviewee 2 talked about true bottlenecks. They were certain where their bottlenecks were but not convinced at all time. Interviewee 3 talked about moving bottleneck and said they have a good control over their bottleneck. Interviewee 4 said that they were rather certain, but that maintenance and production can have different views about bottlenecks since they measure them differently.

### 3.3. RQ3

*Survey:* Figure 5 shows that a majority of the companies prioritize maintenance work orders. In detail, 67% of the respondents indicated that this is done to a relatively high or very high degree; whilst 25% answered that it is only done to a relatively low degree or not at all. However, this data do not connect to how the priorities are set.

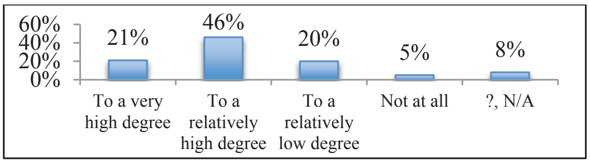


Fig. 5. Prioritizing work orders.

*Maintenance fair:* When questioned how reactive and preventive maintenance work orders are prioritized 4 out of 7 answered fixed priorities, 2 out of 7 answered continuously updated priority, only one answered first-come-first-served basis, and one did not answer the question.

*Interviews:* When asked in general about the priorities they set for their maintenance activities, interviewee 1 descried that an equipment priority routine is followed in their company by meeting with people from different departments. It is also noted that the maintenance engineer sets the equipment priority based on the routine that is created in the meetings along with different things. Interviewee 2 explained that they decide on a department priority in a factory meeting, where the priority is fixed and based on "*what is crucial for us right now*". Interviewee 4 says that the logistics department sets a plant or line priority based on a delivery perspective.

When asked in particular how reactive maintenance is prioritized, all interviewees said they are largely situation dependent. They react to alarms, and sometimes morning meeting results in deviations from the priority plan. Interviewee 1 said that the maintenance technician combines how the situation looks in the factory with the equipment priority number, and then sets the priority. They also have bridges with alarm operators, where the severity of the alarm decides if an operator is called. Interviewee 3 also said they have similar alarms, but similarly indicated that the person who creates the work order finally decides which machines get what alarm Interviewee 1's statement sums this up: "*For reactive maintenance work orders, it is up to each maintenance technician to prioritize*".

Regarding preventive maintenance priorities, interviewee 1 clarified that they combine the equipment priority a "type of maintenance priority" to prioritize preventive maintenance (e.g. preventive maintenance for safety reasons vs. availability reasons). In contrast, interviewee 2, 3, and 4 answered typically: "*We have special windows within production where we stop the production*". Interviewee 2 said that they focus on getting all planned maintenance done during the allotted time. Interviewee 3 indicated that they use a 24 hour / 1 week / 2 week priority for allocating the work during the windows, but clarified yet again that it is the person who schedules the work who sets the final priority. Interviewee 4 said they find the activity that are closest in time and then work upwards.

From three of the interviewees, it is observed that the criticality classification is not directly used for prioritization of maintenance activities, despite the fact that the criticality levels for the equipment are printed on each work order. The priorities are instead set based primarily on the personnel's own experience and knowledge. Interviewee 3 exemplifies this: *"If we use the criticality classification for prioritizing? Hmm, I don't know… The people who are running around have pretty good awareness of the equipment, and they know what's critical and not. So that's pretty much how we control and plan"*. Instead, they use it more for managing the equipment and try to make them less critical. Interviewee 3 explains: *"we find a way to attack our already critical equipment, make them less critical and the most important"*.

The interviewees were also asked on how bottleneck detection is used for maintenance planning. Only interviewee 1 clearly described how bottlenecks are directly used for this purpose. It was explained that they have identified different long term bottlenecks for which they have decided to spend more maintenance hours, and that their ABC alarms are based on the current short term bottlenecks in the factory. The VSMs that are done according to interviewee 4 are used to ensure that they are spending maintenance work in the right place. However, the role of the maintenance department in resolving bottlenecks varies depending different issues. Interviewee 2 said, they do not work with bottlenecks directly for maintenance planning, and instead emphasised that they are focusing on what is necessary for their line. Interviewee 3 explains that bottlenecks are more production related, and thus not performed by the maintenance department.

## 4. Discussion

RQ1: Criticality classification is used for different maintenance related purposes [7, 9]. Instantaneous bottleneck detection which updates bottleneck every day is used in maintenance decision support system [8]. However, the data from the survey and maintenance fair showed that few companies work with criticality classification for maintenance purposes to a high degree. Criticality analysis needs to be continuously updated every day from maintenance perspective [10], and the companies working with criticality classification also update their classification to a high degree. Majority of the companies works with bottleneck detection. All the interviewees who belong to major organizations told that they worked with criticality classification and bottleneck detection. This lays the foundation to find what critical resource of the system is (RQ2) is.

RQ2: There are different methods in which criticality classification of resources can be done. There are system value based, AHP based [9], and FMECA based [7] criticality analyses. All the methods are not based on equipment level. Instead it is from an overall system's perspective including all equipment in the system. In this study, all three data sources indicate that criticality classifications are mostly established by an ABC-type classification. From the interviews, which were big industries, the classification found to be based on production layout such as parallel flow, single flown as well as redundancy, safety, productivity, environment, etc. Again these are not equipment specific strategies but a system level. Despite this, the term critical resource was ambiguous initially to all the participants. There was no clear connection with criticality classification. Only on further explanation with examples, the interviewees mentioned what they perceive critical from maintenance perspective. Two of them mentioned bottlenecks could be perceived critical. Evidently the interviewees were not 100% certain about which were their critical and bottleneck resources. However, the maintenance activities need prioritization (RQ3).

RQ3: Prioritizing maintenance work orders is crucial for handling product variety [11]. Maintenance operation efficiency is improved by prioritizing tasks [6]. The survey and maintenance fair also showed that vast majority of the companies prioritize maintenance work orders. The interviewees as well agreed on some sort of prioritization for preventive and reactive maintenance work orders. According to [1], equipment with the highest criticality should get the highest priority code and thus be scheduled first when performing maintenance. However in companies interviewed the priority for the work order doesn't come from criticality classification or the critical resource. Instead the priorities are set by the person who creates work orders. The criticality classifications are used for asset management purposes. Interviewee 1's work procedure was a good example as they use the criticality classification in setting priorities for maintenance work orders. Also interviewee 1 strongly pointed out the connection between priorities and bottlenecks. The results of all 3 research questions are summarized in table 2.

The results show the gap in industries' practices with respect to criticality classification and maintenance planning. Even in literature the connection between them are not always clear. One reason could be the criticality classification is not made for planning. There is also difference between criticality classification and the term critical resources. Dynamic decision support is needed for effective maintenance and it can be achieved through criticality classification and using it for planning maintenance. Effective planning will lead towards productivity and reliability for the production system.

Table 2. Summary of results.

| RQ | Result |
|---|---|
| RQ1 | According to the survey and maintenance fair, majority of the companies work with bottleneck detection to high degree. Companies do not work with criticality classification to a high degree, however the one's using it updates it. All 4 companies from interview data worked with criticality classification and bottleneck detection. |
| RQ2 | According to all three data sources, the most common criticality classification is ABC-type. During interviews the term "critical resource" resulted in random answers, and not everyone was sure what are critical and bottleneck resources. |
| RQ3 | According to the survey and maintenance fair, the vast majority prioritize maintenance work orders, and all interviewed companies does it. From the interviews, prioritization of reactive maintenance is largely situation-dependent, criticality classification is not always used to prioritize maintenance, and bottlenecks are not extensively used in maintenance work. |

## 5. Conclusion

This paper describes the current state practices of manufacturing industries towards planning maintenance activities. That includes finding critical resource, how are they classified, and the gap between criticality classification and maintenance planning in industries. Overall, criticality classification is not extensively used in industry however bottleneck detection is widely used. The industries that use criticality classification have an ABC-type approach. The term critical resource is vague in industries at the moment, and not connected to the critical classification. Most industries prioritize maintenance activity. However, criticality classification and bottleneck detection are seldom used to make priorities.

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