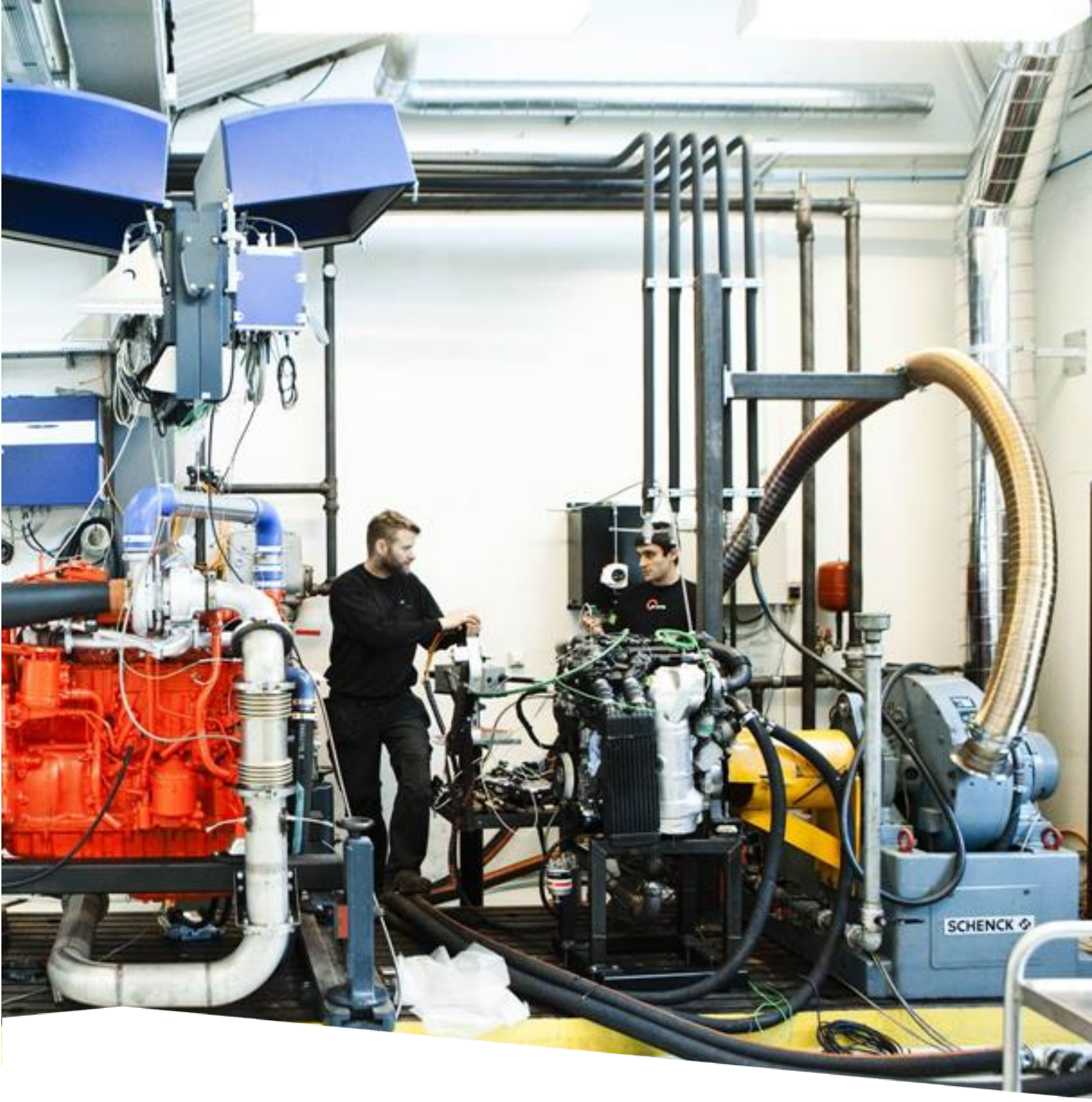

MADE PROJECT

EFFECTIVE MAINTENANCE DATA STRUCTURE, RECORDING AND USAGE

December 20th, 2019

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"When you're short on maintenance ressources, which you typically are, you must place your efforts where they benefit the most."

EFFECTIVE MAINTENANCE DATA STRUCTURE, RECORDING AND USAGE

A case study

Made for:
MADE – Manufacturing Academy of Denmark
Vesterbrogade 1E,
Blok D, 2. sal
1620 København V

Made by:
Danish Technological Institute
Production and Innovation
Forskerparken 10 F
5230 Odense M
Denmark

www.dti.dk

December 20th, 2019

Authors: Michael Stæhr and Palle Grøndahl

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Preface

The project described in this report has been supported financially through MADE: Manufacturing Academy of Denmark and was carried out in the autumn and winter 2019.

The project was developed in a cooperation between a large Danish company and Danish Technological Institute. The company allowed us to use their maintenance data as foundation for a case study. As these data can provide key business information the company demanded to stay anonymous to participate in the project.

We are happy to have had the possibility to take a big dive into freshly collected maintenance data and send our thanks to the company behind.

The authors

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Introduction

Investments in new production equipment and investments in keeping the existing production equipment effective through maintenance forms a large part of a company's budget.

In general, direct maintenance costs, as having maintenance technicians employed, buying spare parts, having spare parts inventories, workshops, management systems and more, sums up to 5 percent of the total insurance value of a plant per year.

To the above-mentioned direct maintenance costs the indirect maintenance costs can be added. Indirect maintenance costs as lost production due to breakdowns and reduced yield i.e. through small stops and missing capability of running full speed. This indicates that being able to perform effective maintenance is important to a company's financial result.

Many companies place large amounts of both time and money, in collecting maintenance data. But do they get value for money. Are the companies using the collected data for improving equipment effectiveness and for planning future investments in new equipment or refurbishment of existing solutions? If not – a large part of the time and money spent on collecting data can be categorized as waste.

To be able to use maintenance data the data structure must correspond to the needed information for improving organizational and technical issues and the data must be valid. Furthermore, an organization must have structures and standards to perform targeted assessments and following improvements.

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Project structure

The goal of this project was to create a generic model for structuring, collecting, recording and using maintenance data as basis for improvements. A part of this is to know the limitations and possibilities of the recorded data.

The project has been structured as a collaborative project and has been carried out in close cooperation between the project owner Danish Technological Institute (DTI) and a large Danish company.
The close cooperation has not only giving DTI the opportunity to access large maintenance datasets but has also supplied great insight in the structure and organization of the maintenance area of a large global organization.

DTI project team have had the main role of planning and executing the different project milestones where the project partner role has been to support and provide the project with maintenance data and information's of how the maintenance area is structured and organized.

The project has been structured in below 3 main phases

Data collection

The project partner is in this phase of the project providing maintenance data to the project based on the project partner's existing data structure.

Data analysis

DTI has in this phase of the project performed a deep dive analysis of the provided maintenance data. The goal of the analysis was not only to create knowledge and insight of the as-is data structure of the case company but also to evaluate the performance and efficiency of the existing maintenance structure and organization.

Model development

Based on best practice and the conclusions from the data analysis DTI has developed a future state model which will enable the case company to make significant improvements to the existing maintenance structure.

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The Effective Maintenance Structure - TEMS

Risk assessment

A key area to have in mind when maintenance is planned and performed is the scope of the needed maintenance. What are the consequences when a piece of machinery breaks down or an important function ceases to work?

The consequence level, the probability of an incident and the ability to detect a fault all influences on the level of maintenance actions needed.

In maintenance resources are typically short. You could always need more time, more money and more maintenance technicians. Therefore, it is important to assess the risk level of an equipment and plan and perform maintenance activities where needed and reduce the activity level where possible, in order to perform plant maintenance as effective as possible.

A well-known risk-based approach to defining needed preventive maintenance activities is provided through the Reliability Centered Maintenance (RCM) structure. In this structure a FMECA risk assessment forms a function-driven definition of maintenance activities for a piece of equipment.

The RCM structure was developed as a concept for developing technical plants with high reliability and a reasonable amount of needed maintenance activities. This makes sense in a design phase of a project. It can of cause make totally sense to apply the RCM concept to an important piece of machinery where a breakdown leads to ponderous consequences but applying the RCM concept on already established plants often leads to a prohibitive amount of work.

To define the maintenance activities for existing equipment another approach is beneficial. It is built up by:

- A risk screening, dividing the equipment in groups defined by the risk level of the equipment.
- A definition of how maintenance and production are cooperation in relation to various consequence levels
- A structure for the level of documentation, internal employee competences and availability, spare parts, firm agreements with sub-contractors and more.
- An assessment group, which consists of skilled and experienced maintenance technicians, for defining the most efficient maintenance activity structure for an equipment.

These elements are described in the following.

Risk screening

As described above, it is possible to define or redefine maintenance tasks on an existing plant, with a focus on optimal use of maintenance resources, easier than by using the RCM concept. This approach is based on a risk screening where plant units as compressors, lubrication units, pump units, centrifuges and the like are risk assessed in a cooperation between the production department and the maintenance department. This risk screening is a top-level assessment which evaluates the consequences of a breakdown in relation to strategic important areas e.g. safety, environment, costs, production and delivery performance.

As the purpose of the risk screening is to divide the equipment into various equipment consequence categories, it doesn't take the probability of the risk and the level of prewarning of an equipment breakdown into consideration, which usually are parts of a risk assessment. The two latter areas will be taken into consideration when it comes to defining the overall maintenance approach.

The needed maintenance activities, the need for employee competences, spare parts and firm agreements with sub-contractors will vary in relation to the defined equipment category. The example below illustrates why.

If a system is built with one 100 % pump to supply cooling water to an important cooling function, the pump must not break down. Therefore, the pump is maintained so it won't break down. If the system was built with three automatic controlled 50 % pumps, a breakdown of a pump can be accepted, which leads to reduced maintenance efforts and costs.

The risk screening forms a base for reducing the maintenance efforts on equipment with a low consequence rating. If the equipment isn't risk screened all units must be maintained with the highest standard. No breakdowns are allowed, and all downtimes must be optimized to a minimum. This approach only makes sense for equipment with a high consequence rating and would be too expensive to apply on equipment with a lower rating.

The risk screening can be performed in a meeting involving experienced persons representing operation/production and maintenance/engineering. Based on a factory layout drawing showing the placement of the equipment, such as a boiler, a centrifuge, a lubrication unit, a heat exchanger and the like, the consequences of a unit breakdown, which involves a loss of functionality, are assessed.

The structure for the discussion of the consequences is defined before or as the first part of the meeting. Typical areas to discuss are safety, environment, quality, costs and delivery.

Consequence classes

When it comes to sorting equipment units in consequence classes it is obvious that risk criterias must be defined prior to the assessment meeting. It is not so obvious that there also must be different equipment categories. Piece producing equipment, process equipment and utility equipment meet different demands. For piece producing equipment downtime is an important aspect. For process equipment batch quality is important and for utility equipment the maximum downtime affects which consequence class to choose.

It is not possible to generalize such a structure. It must be defined for each company. A way to begin could be to define three consequence categories: A, B and C.

The A-category defines the highest class with the highest maintenance structure applied. The B-category can cover a reduced maintenance approach and the C-category covers the lowest maintenance class where only basic maintenance activities as keeping the equipment lubricated, clean, tightened and inspected are applied. For equipment sorted into the C-category no parts are changed in advance to keep an equipment in shape to meet its functional demands.

The next step is to define which equipment categories the structure must cover and the sorting criteria for placing equipment in the various consequence categories.

Production and maintenance cooperation in relation to various consequence classes

A focus in maintaining equipment categorized with a high consequence is to obtain or gain an acceptable (high) level of reliability and reduce downtime to an agreed minimum. The reliability level is related to the level of preventive maintenance and the downtime is depending on the readiness of the maintenance department. How fast can competent employees, updated documentation, needed tools and spare parts be present.

In addition to this the equipment effectiveness must be supported by a cooperation between production and maintenance. When It comes to equipment availability both operators and technicians affect the outcome. The same can be said regarding the yield and the quality factors.

Based on the consequence classes different maintenance approaches can be applied. A setup can be:

- If A-categorized equipment breaks down immediate actions must be taken to repair it.
- If B-categorized equipment breaks down, it will be repaired within the following workday.
- If C-categorized equipment breaks down repair will begin within 14 days.

These approaches offer the opportunity to reduce the amount of used maintenance resources, as the operators doesn’t call for a maintenance technician’s immediate action on B- and C-categorized equipment. This leads to that incidents on B- and C- categorized equipment can be planned effectively.

Maintenance actions in relation to consequence classes

Sorting of equipment in different consequence classes based on the risk screening can lead to a focused use of maintenance resources. The equipment in the highest consequence class must be the first to examine to ensure high reliability, low downtime and high effectiveness in general.

Many areas are influencing on these factors.

Reliability

The reliability is depending on an effective preventive maintenance program and the skill level of the maintenance technicians. But areas as the competence level of the operators, the condition of the equipment, the suitability of the equipment for the job, the quality of the raw materials, and more are also important factors. All areas that must be investigated and developed to the desired level.

Downtime

The downtime is defined as the time an item can't perform a required function. The time used for the various actions in between must be optimized. This means that:

- notifying the maintenance technicians with an adequate amount of information
- transportation to the affected equipment
- acquisition of documentation
- fault finding
- picking up spare parts
- repairing the equipment
- testing the equipment
- putting the equipment back in operation

… all are areas for optimization.

Effectiveness

The effectiveness of an equipment typically relates to the availability factor, the yield factor and the quality factor. Areas that affect these three factors are also a mix of production related and maintenance related areas.

Availability of an equipment is depending on its reliability – how often it can't perform its function - and the downtime related to the breakdowns. As mentioned above reliability is affected by various maintenance and production issues and the downtime consists of a lot of different time-consuming activities.

Another aspect of availability relates to the time used for changing the setup to the next product. The optimization of this changeover time often involves both technicians and operators. A technical input to resolve a time-consuming part of the changeover will benefit the equipment effectiveness.

The yield is typically seen as depending on the operation of the equipment. But various groups of employees also affect this result. Is the operator skilled in operating the equipment? Is the equipment trimmed and ready for production? Is the quality of the raw materials within the limits?

The quality factor also consists of a lot of areas relating to different departments. And as mentioned above in relation to the yield, employee competences, technical performance and materials all affect the quality.

Maintenance focus areas

When the above aspects are taken into consideration a list of areas to improve can be made:

- Preventive maintenance plan – both specialized maintenance actions and operator's autonomous maintenance actions are defined to support equipment reliability effectively.
- Spare parts – lead time in relation to the need for spare part availability.
- Documentation – updated and available.
- Technician competences – the persons with the needed competences must be available when needed. If not possible inhouse – firm agreements must be developed with sub-contractors.
- Operator competences – to ensure correct use of the equipment and to make first repair actions upon a breakdown, to call for the right support when needed with adequate information.
- Effective breakdown response – to keep downtime at a minimum

This focus must be differentiated in relation to the consequence class of an equipment. A way for implementation can be to define the level of the listed areas above in relation to the various consequence classes – and then assess A-categorized equipment at first.

Assessment group

In the section *Risk assessment,* the RCM approach to effective maintenance plans on existing plants is described as too time consuming in relation to the outcome. Highly important equipment can benefit from the RCM approach as it is a very thorough way to define the needed maintenance actions – the resource consumption for the analysis might be high but the foundation for a high level of reliability is made.

An effective way of defining needed maintenance actions for existing equipment is an analysis performed by experienced maintenance technicians. This group will take the following list into consideration:

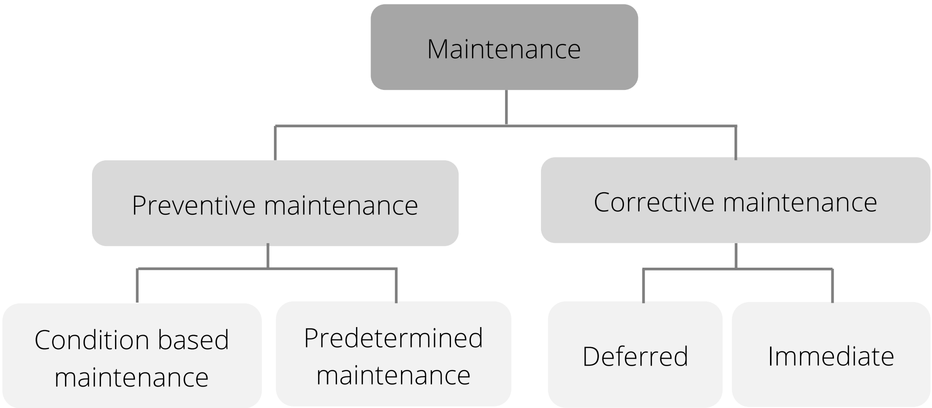
- The equipment consequence class
- The performance of the equipment
- Performed preventive maintenance activities
- Known faults and repair activities
- Possible and reasonable faults not seen before

On this basis the group defines needed repair of the equipment to gain full functionality, an effective level of maintenance activities – in a well-described maintenance plan, spare parts which must be present in the inventory and documentation that needs to be updated.

This approach is not as thorough as the RCM approach, but it is not as time-consuming, and it takes both historical actions and possible future problems into consideration. It is obvious that the group of maintenance technicians must consist of competent employees that are experienced in the examined equipment and knows the way to an effective maintenance plan.

Maintenance data

Maintenance data is often structured in maintenance management systems based on the definition from the DS/EN 13306 Maintenance terminology standard shown below.

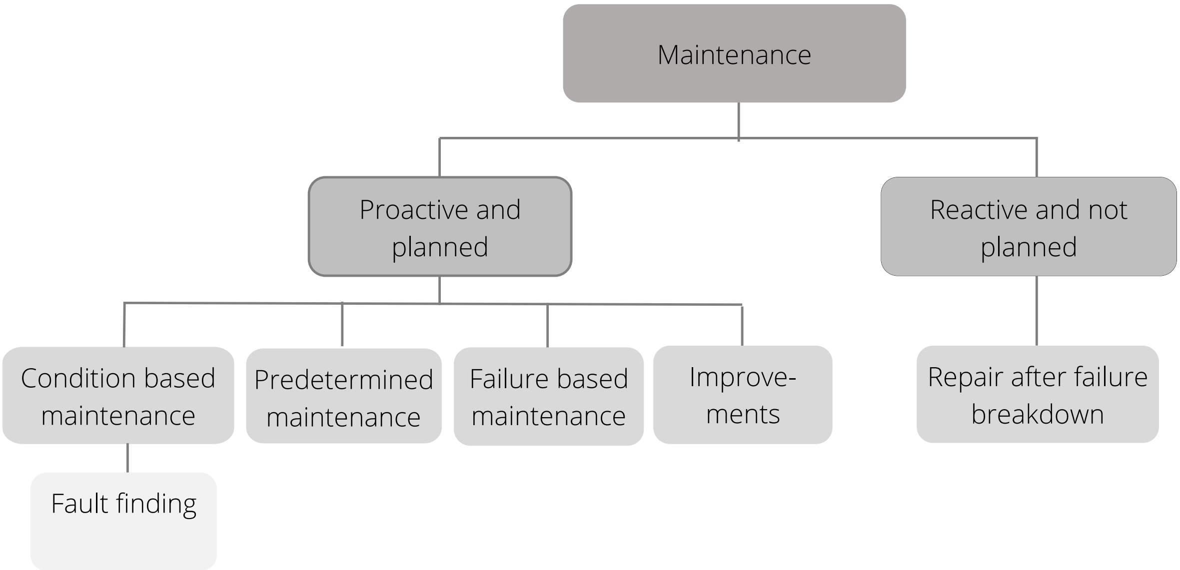


It is important to have in mind that the way maintenance data is recorded relates to the possible reports that can be drawn from the system. A link from the maintenance related strategic focus areas of a company to the data fed into the Maintenance Management System (MMS) must be developed. If not optimization of the area in focus can't be performed based on data.

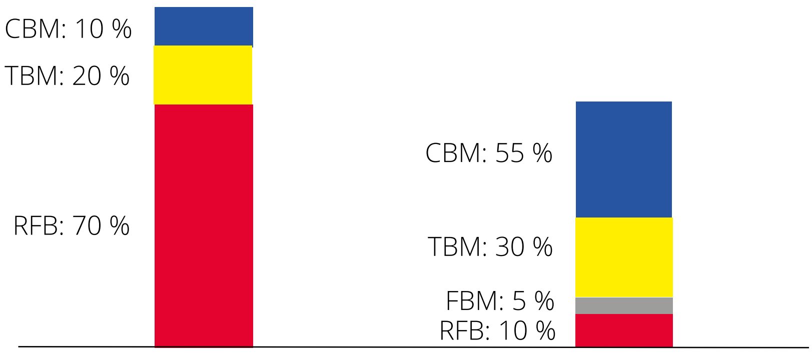
Looking into the data structure provided by the figure above it is seen, that the overall picture that can be shown is if maintenance employees have to perform preventive and planned maintenance activities or they have to be ready to get equipment up running again after breakdowns. This also indicates if the equipment is stable or not.

But it is not possible to know if the maintenance department is in control or not. Sometimes the most efficient way to perform maintenance can be to keep equipment in operation until breakdown. This must of cause be upon a thorough investigation of the consequences of a possible fault. In the structure shown above it is not possible to know if you are in control or not. You can only see if you're disturbed by breakdowns or not.

Another way of setting up a maintenance data structure can be based on a structure developed by Professor Emeritus Tim Zaal. This structure shown below provides the opportunity to assess organizational issues as readiness to repair or time to plan, prevent and optimize and it also supplies the opportunity to assess if the maintenance department is in control or not.



The desired development can be seen in the two columns below. The column at the left shows a maintenance organization where "firefighting" defines the day. The column at the right shows an organization with the opportunity to perform risk screenings to optimize the cooperation between maintenance and operations. It also shows an organization that optimizes equipment performance through targeted and databased investigations and developments.



CBM: Condition Based Maintenance
TBM: Time Based Maintenance (Activities structured by calendar, counters, operational hours and more)
FBM: Failure Based Maintenance
RFB: Repair after Failure Breakdown

When the desired maintenance data structure is developed and implemented it forms the basis for building reports that supplies data relating to the maintenance related strategic focus areas.

The build-up of these reports must be standardized, so it is possible to assess data that is retrieved in the same way. This makes comparisons possible.

Furthermore, the reports must be developed in a structured setup, maybe each week, each month, each three month or each year. This structure relates to the content of the report and must be decided for each one. A firm structure supports an ongoing optimization process.

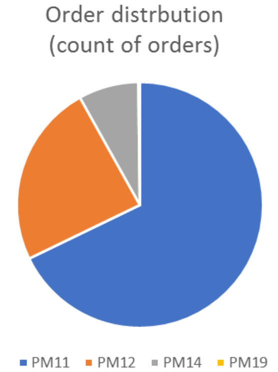
Description of used maintenance data

During the project a case study dataset consisting of 1013 maintenance orders has been analyzed. All maintenance orders in the dataset are completed during the period from start August to end of September 2019 in the same geographical location, but across departments.

The total of 1013 maintenance orders are divided into the following 4 different maintenance order types, with the respective distributions:

The below table and graph show the distribution of orders according to order type.
(PM19 orders are not visible in the graph because only two orders have been completed during the period.)

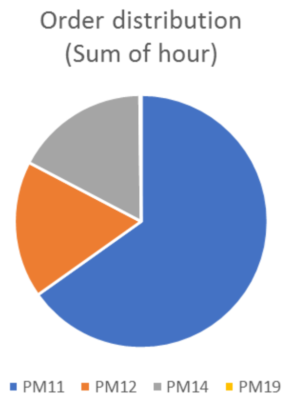
Order type	Sum of orders	%
PM11 – Maintenance Breakdown order	687	68%
PM12 – Maintenance Planned Repair order	244	24%
PM14 – Maintenance Preventive order	80	8%
PM19 – Maintenance Improvement order	2	0%
Total	1013	100%



The 1013 maintenance orders are executed on 303 individual equipment units each with their own unique equipment identification number.

There are in total used 4393 hours on maintenance during the period with the following distribution:

Order type	Hour	%
PM11 - Maintenance Breakdown order	2863	65%
PM12 - Maintenance Planned Repair order	769	18%
PM14 - Maintenance Preventive order	752	17%
PM19 - Maintenance Improvement order	8,5	0%
Total	4393	100%



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Comment

In the case study less than 10% of the completed maintenance orders has been conducted as Maintenance Preventive orders (PM14) or more than 90 % of the completed maintenance orders has been conducted as Breakdowns orders (PM11) or Maintenance Planned Repair orders (PM12).

Best practice within optimizing and organizing maintenance departments are showing that the optimal balance between preventive orders and breakdown/repair orders must at least be 85/15 in favor of preventative maintenance. Which is more or less the opposite balance compared to the case study.

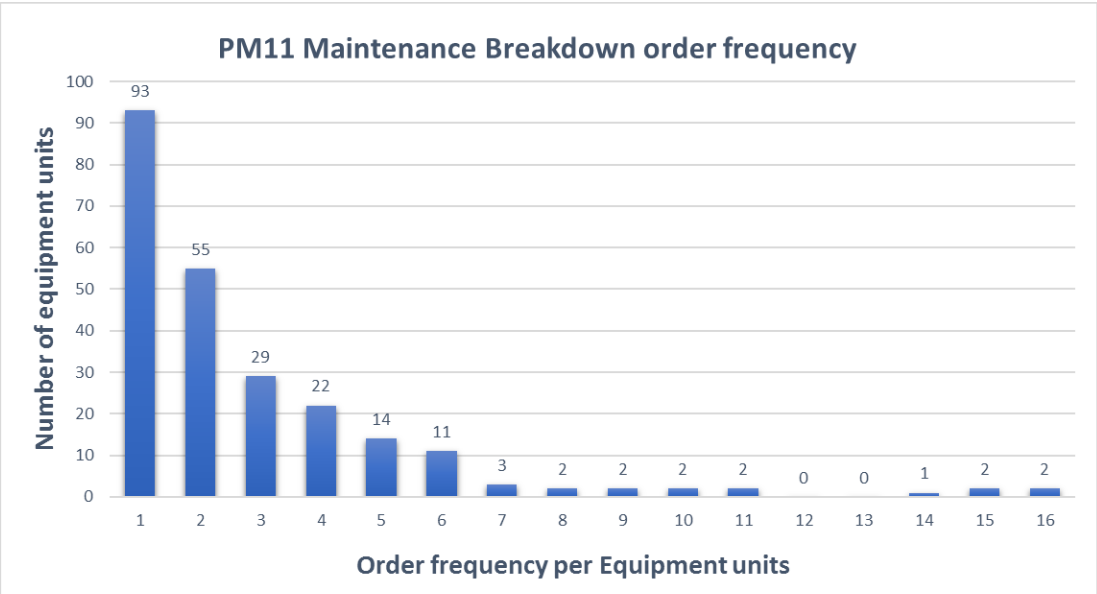
PM11 – Maintenance Breakdown order

Maintenance Breakdown orders are created as corrective maintenance when an equipment is breaking down and unavailable for use.

In the case study 687 Maintenance Breakdown orders has been completed on 240 different equipment units. The frequency of how often a Breakdown order has been conducted on different equipment varies a lot.

147 Equipment units or more than 60% of the 240 equipment units have had more than one Maintenance Breakdown and 41 Equipment units or 17% have had 5 or more Breakdown orders in the period.

Below graph shows the distribution of Maintenance Breakdown order frequency.

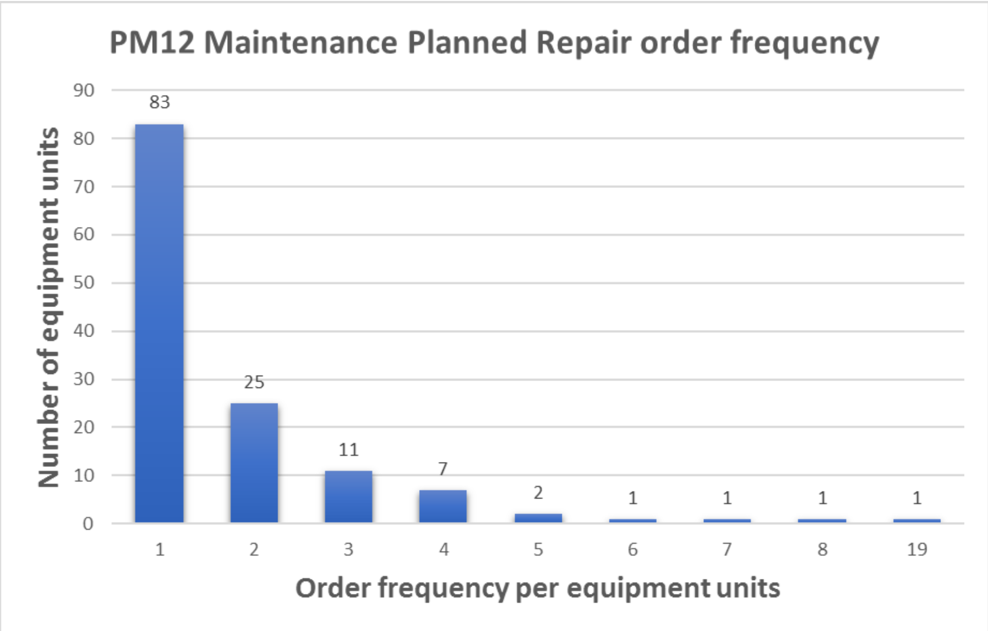


PM12 – Maintenance Planned Repair order

Maintenance Planned Repair orders are created as corrective maintenance when an equipment is breaking down but still available for use.

244 Maintenance Planned Repair orders has been completed in the period and involving 132 individual equipment units.

Below graph shows the distribution of Maintenance Planned Repair order frequency.



PM14 – Maintenance Preventive order

Maintenance Preventive orders are created to carry out preventive maintenance in order to: reduce number of breakdowns, increase efficiency of the equipment and ensure that maintenance due to statutory requirement is carried out.

80 Maintenance Preventive order has been completed in the period and involving 71 individual equipment units.

69 out of 71 equipment units have had one maintenance preventive order and 2 out of 71 equipment units have had more than one Maintenance Preventive orders in the period.

Efficiency of Preventive maintenance

By analyzing the case study data it is possible to compare unique equipment units in relation to preventive maintenance activity (PM14) versus Maintenance Breakdown activities (PM11).
By comparing the 2 different order types it gives an indication of whether the Preventive maintenance program is effective due to the fact that an effective preventive maintenance system will reduce the risk of Maintenance Breakdown.

Data shows that PM11 Maintenance Breakdown orders have been executed on 40 out of the 71 equipment units (56%) where preventive maintenance also has been carried out.
That leads to an overall preventive maintenance effectiveness of 44%

On the 40 equipment's where both PM11 and PM14 orders have been executed there has been conducted in total 145 PM11 orders, which gives an average of 3,6 Maintenance Breakdown order per equipment unit.

Breakdown time and Mean Time Between Failure (MTBF)

In the case study equipment breakdown time are measured on Maintenance Breakdown orders (PM11).
The total equipment breakdown time in the period are measured to 1135 hours.
(34 orders (5%) out of the total 687 PM11 orders has no breakdown time registered.)

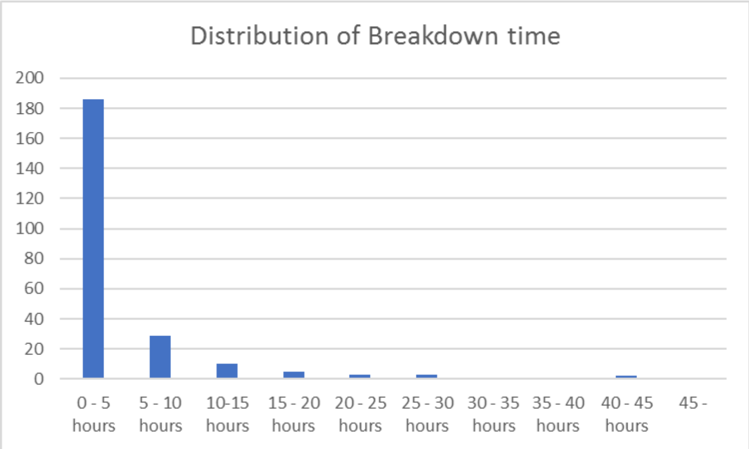
Based on the number of PM11 orders and the breakdown time the MTBF are calculated.
In the case study the following formula has been used to calculate the MTBF:

MTBF= (Total time available – Breakdown time)/number of orders per equipment unit

Total time available is in this case equal to total numbers of hours available per month. (fx: 30*24=720 hours) By using this approach the case study company does not take into account the planned use of each individual equipment unit and therefore not able to make prioritized decisions based on data, as MTBF is calculated based on total time available and not total operating time for each equipment unit.

Below table and graph shows the distribution of number of equipment units according to sum of breakdown time per unit in the period.

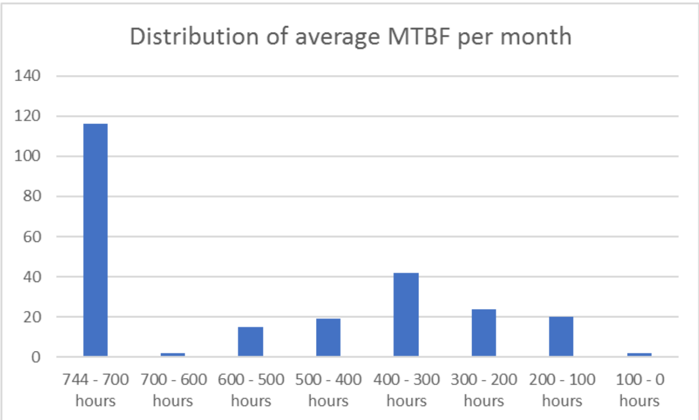
Sum breakdown time	Number of equipment units
0 - 5 hours	186
5 - 10 hours	29
10-15 hours	10
15 - 20 hours	5
20 - 25 hours	3
25 - 30 hours	3
30 - 35 hours	1
35 - 40 hours	0
40 - 45 hours	2
45 -	1
Total	**240**



In 78% of the cases the total breakdown time in the period is less than 5 hours. The highest breakdown time is 204 hours.

Below table and graph shows the distribution of number of equipment units according to average MTBF per month.

Average MTBF per Month	Number of equipment units
744 - 700 hours	116
700 - 600 hours	2
600 - 500 hours	15
500 - 400 hours	19
400 - 300 hours	42
300 - 200 hours	24
200 - 100 hours	20
100 - 0 hours	2
Total	**240**



Maintenance cost

Maintenance cost are recorded and distributed to Internal Wages and Internal Materials accounts.

The total maintenance cost used on all maintenance activities (PM11, PM12, PM14, PM19) in the period is registered to 1.647.299 Dkr.

Maintenance cost are registered and assigned to the 301 different equipment units.
(8% of the total maintenance cost are not assigned to an equipment unit.)

Recommendations for case maintenance setup

The case company shows a potential in the performed maintenance. With a distribution that shows 83 % of the performed maintenance time used for PM11 and PM12 (Breakdown and repair orders) and 17 % of the time used for preventive orders, planning is hard and it is difficult to organize a proactive maintenance approach, with risk screenings and prioritized optimization of maintenance plans.

A recommendation is to prioritize risk screenings. This involves the definition of the consequence classes and the following structure of how to cooperate between production and maintenance. Furthermore, the needed actions in the maintenance department – in relation to the various consequence classes must be defined.

It is a comprehensive job to execute, but a risk screening supplies the opportunity to differentiate the focus on the various consequence classes and reduce the resource consumption for performing maintenance and keep up a high reliability where needed.

Recommended approach

- Definition of how the risk screening process can be applied
    - Definition of equipment consequence classes
    - Definition of the cooperation between the operation and maintenance departments
    - Definition of the needed levels for maintenance activities, spare parts, documentation, maintenance employee competences and availability, sub-contractor agreements and more.
    - Plan for implementation
- Definition of needed data developed through the maintenance management system
    - Which reports based on maintenance data supports strategic important areas and which data is needed to develop these reports.
    - Develop the data structure to support the needed data. (Is the maintenance department working proactive and planned or reactive and not planned?)
    - Setup the report structure and support an automated development of the reports. A standardized and systematic approach to reporting supports continuity in the optimization work.
- Optimizing the maintenance plan
    - The structure of the maintenance assessment group and how it must work must be defined.
    - Based on the risk screening the assessment of equipment maintenance plans must be planned. This plan must among other take the consequence level of the equipment and the available resources for the assessment into consideration.

- The maintenance technicians in the assessment group must hold competences to define an effective maintenance plan and define the maintenance activities in the maintenance management system.

As seen in the supplied data many equipment units experience breakdowns even though preventive maintenance actions are performed. Some equipment is having many breakdowns and a limited amount of preventing activities. Some equipment is performing well, based on a well-performed maintenance plan – but can the maintenance work on these units be reduced?

A development as the one described above isn't performed overnight. As other comprehensive organizational changes this development must be owned by top management and the implementation must be performed as a project – taking employees, management processes, competences, communication, systems, cooperation processes, standardization, data structure and many more areas into consideration.

The benefits of such a development are clear. The reliability and the effectiveness of the equipment will be optimized in relation to the consequences of a breakdown. This will ensure that focus is high on the important units and reduced focus where possible. Important equipment will be ready for production or for performing its function when needed and doing so effectively.

This overall effectiveness for important equipment is not only a technical matter. It is developed through assessment of needed competences, spare parts, documentation, tools, sub-contractors, maintenance activities – both specialized and basic, communication, approaches for elimination of repetitive errors, effective fault finding and much more.

This strategic approach to use of maintenance resources will in parallel to improved equipment performance support a reduction of the overall maintenance budget.

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Conclusion

The project objectives and the overall goal about creating a generic model as basis for maintenance improvements has been reached.

One of the main project conclusions is, to run an effective maintenance organization with an optimum level of maintenance compared to production downtime and cost, an organization need to change the traditional way of performing and organizing maintenance and start using a risk-based approach. The risk-based approach will give the maintenance organization the opportunity of prioritizing the maintenance resources and allocate resources where needed the most. By having a risk-based approach maintenance data will also play a greater role in the day to day work, because the use of maintenance data will change from being reactive to proactive and organizations will be able to use data to support risk management.

The project structure where DTI has worked as experts within Asset management and statistics together with the project partner's great knowledge of how the maintenance organization is driven today, has not only given the opportunity of reaching the project goal but has also shown to be extremely effective.

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Standards

- DS/EN 13306 Maintenance - Terminology
- DS/EN 13460 Maintenance - Documentation for maintenance
- DS/EN 15341 Maintenance - Maintenance Key Performance Indicators

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The authors

Palle Grøndahl has a background as marine engineer. He supplied this polytechnical education with a Master of Engineering in Maintenance and Asset Management from the University of Applied Sciences HU. Alongside he has achieved a certification as European Expert in Maintenance Management by the European Federation of National Maintenance Societies.

Through his career he has been focusing on management of technology in roles as head of department for a diesel driven power plant, lecturer and senior lecturer at marine engineering collages, as head of Knowledge Centre of Asset Maintenance Management, as partner in his own consultancy and now as team manager for a digitalization, productivity and quality optimizing consultancy team at Danish Technological Institute.

Michael Stæhr has a background as mechanical engineer and are holding a certification in Six Sigma Black Belt project management along with an education in industrial statistics and business intelligence.

During his career he has led several quality departments across industries with the special focus on data driven business improvement. Today Michael is senior consultant at Danish Technological Institute and are working within the area of combining digitalization and data collection with business improvement along with his consulting activities within the quality area.

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