Selecting a Computerized Maintenance Management System (CMMS) for Corvus Energy

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How to choose an appropriate CMMS for Corvus Energy?

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Preface

We are two students from the “Industrial Engineering” study program who have their bachelor's thesis written at the Department of Mechanical and Marine Engineering at Western University of Applied Sciences (WNUAS) in Bergen. The discussed bachelor thesis is the ending stage of our adventure with a 3-year course.

Thanks to the courtesy and trust that Corvus Energy gave us, we managed to complete the task of choosing the appropriate CMMS, the aim of which was to improve the maintenance of the company.

Special thanks to both Frank Espeland and Hector Castillo from Corvus Energy for showing great commitment and assistance in the task. Many thanks also to our supervisor Maneesh Singh, without whom the task would have been much more difficult, and his help proved to be great and invaluable.

Abstract

This thesis studies how Corvus Energy should choose a computerized maintenance management system, to improve maintenance.

Corvus Energy does not currently have a maintenance system, which means that most of the maintenance is logged in Excel. This makes it difficult to predict when something will fail and why it fails. There are also difficulties in using the data and statistics that can be extracted from the production equipment and getting this used in a better way.

The aim of the project «Is to select an appropriate CMMS for Corvus Energy»

The assignment is based on ISO 5500x, which is the ISO standard for maintenance. Based on ISO 5500x, a survey has been made for the employees at Corvus Energy who work with maintenance. Based on this survey, various requirements and functions that Corvus Energy must have for a new maintenance system have been identified. Different maintenance systems are then analyzed regarding the requirements, in order to find the system/systems that are best suited for use.

Based on the results from the analysis, UpKeep is the system that suits the requirements best for Corvus Energy. It also emerges from the results that several of the systems are relatively similar, and what considerations Corvus Energy should consider when choosing a new system.

Sammendrag

I denne oppgaven blir det studert hvordan Corvus Energy skal velge et datastyrt vedlikeholdssystem, for å kunne forbedre vedlikeholdet.

Corvus Energy har i dag ikke vedlikeholdssystem, noe som medfører at det meste som blir gjort av vedlikehold blir loggført i Excel. Dette fører til at det er vanskelig å forutse når noe feiler og hvorfor det feiler. Det er også vanskeligheter med å bruke dataene og statistikken som kan bli hentet ut av produksjonsutstyret og få brukt dette på en bedre måte.

Problemstillingen ble da «Hvordan Corvus Energy skal velge et datastyrt vedlikeholdssystem»

Oppgaven tar utgangspunkt i ISO 5500x, som er ISO-standarden for vedlikehold. Utfra ISO 5500x er det blitt laget en undersøkelse til de ansatte hos Corvus Energy som arbeider med vedlikehold. Basert på denne undersøkelsen er det kommet frem til ulike krav og funksjoner som Corvus Energy må ha til et nytt vedlikeholdssystem. Ulike vedlikeholdssystem er deretter analysert med hensyn til kravene, for å finne frem til det systemet/systemene som er best egnet til å ta i bruk.

Basert på resultatene av analysen viser det seg at UpKeep er det systemet som er best egnet til Corvus Energy. Det kommer også frem av resultatene at flere av systemene er relativt like, og hvilke hensyn Corvus Energy skal ta ved valg av et nytt system.

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Nomenclature

CMMS	= Computerized maintenance management system
TPM	= Total productive management
ERP	= Enterprise resource planning
AIV	= Artificial Intelligence Vehicle
CM	= Corrective maintenance
PM	= Predictive maintenance
S.M.A.R.T.	= Specific, Measurable, Attainable, Relevant and Timely
KPI	= Key Performance Indicator
JIT	= Just In Time
SaaS	= Software as a service
API	= Application Programming Interface
REST	= Representational state transfer
EAM	= Enterprise Asset Management
APM	= Asset Performance Management
IoT	= Internet of Things
SAP	= System application and Products
OEE	= Overal Equipment Effectivity
MTBF	= Mean Time Between Failures
MTTR	= Mean Time To Repaire
MLDT	= Mean Logistics Delay Time
OA	= Operational Availability

1. Introduction

The growing complexity of production equipment and plants makes maintenance increasingly challenging. Nowadays, the development of technology is fast and rapid, and production plants are equipped with highly advanced technologies. The increasing degree of machine automation, the infinite number of sensors, and the use of many data simultaneously are examples of factors that the maintenance department must face in order to ensure maximum efficiency of machines and devices. The main objective of the maintenance department, in short, is to ensure the fullest availability of production equipment, utilities, and related facilities at optimal cost and under satisfactory conditions of quality, safety and protection of the environment.

The efficient functioning of the entire organization, including the production line, is possible only thanks to the responsible supervision of many areas at the same time. Therefore, the operation of maintenance services is increasingly supported by specialized IT systems. CMMS (Computerised Maintenance Management Systems) computer systems - which are the main subject of the discussed in this BA thesis - form these days the basis for supporting maintenance in manufacturing enterprises. Widely used, they are constantly improved and become part of digital management of all aspects related to functioning on the market and production.

While some organizations still use Excel spreadsheets and free computer programs, more and more companies are leaning towards introducing a professional and customized IT CMMS. With help of those systems, technical departments, and employees responsible for maintenance can comprehensively and efficiently receive information about, for example, the current state of the machine park, failures, and planned activities for a particular day. This type of applications usually contains modules responsible for areas of the company's operation, such as facilities (machines and devices), spare parts and materials warehouse, orders for parts and materials, records of current work (e.g. breakdowns) or planning and management of orders for preventive work.

Choosing the right system, however, is not a simple task, mainly since the selection and implementation of a new system brings with it huge changes in the company operation, for which the entire organization must be prepared. The implementation of each new solution in the enterprise should be properly planned and prepared. Especially when it comes to IT solutions, there are many potential problems that may result in the failure of the undertaken actions. It is crucial to remember that each company and each production plant have different needs and expectations, therefore, the scope of the desired functions differs depending on the concept and specification of the company's operation. Therefore, the main research question of the discussed work is "How to choose the right CMMS" which Corvus Energy will be fully satisfied with.

1.1 Corvus Energy

Corvus Energy is a company that provides purpose-engineered energy storage solutions and hydrogen fuel cell systems for the ocean space. By providing the first maritime battery which was cheap and safe, Corvus Energy have become pioneers in maritime energy storage systems and are setting the standard for zero emission shipping globally. Together with Toyota, Corvus Energy is developing a sustainable large-scale maritime-certified hydrogen fuel cell system. They believe that the fuel cell technology together with the battery technology is the solution to reach the goal of a zero-emission marine industry. [1]

The production at Corvus Energy consists of 9 different production cells where 7 of them are fully automated. The products get transported between the cells by autonomous intelligent vehicles (AIV). All products that get produced are equal, it`s therefore no variation or need to change the production equipment between the different batches. The production is based on an assembly line production, which means that the production has a high flow efficiency. On the other hand, the production is highly exposed if a breakdown or other unforeseen stops occurs. It`s only a matter of minutes before the whole production stops if one of the automated cells break down. A sudden stop in the production will ruin the flow. Some of the cells will then be filling up to the maximum capacity, and the other will be completely empty.

The production has got a capacity of 10 battery modules per hour. Because of occasional maintenance work and unexpected breakdowns, they plan for 7 modules per hour. This means that they produce an average of 420 modules per week.

1.2 Aim and scope of work

The aim of the work is to select an appropriate CMMS, which will be able to meet the requirements and lead Corvus Energy to the designated goals.

The key steps leading to the selection of the system that have been taken are:

- Defining needs and goals
- Determining the requirements
- Finding and analyzing potential suppliers
- Analysis of found solutions
- Choice and argumentation of the selected vendor

The theoretical part of the thesis contains information about:

- Key concepts of maintenance in industry
- Total productive maintenance (TPM)
- Computerized maintenance management system (CMMS)
- ISO 5500x standard: as the basis for decision making
    - Correlation between asset management and maintenance management
- CMMS class system selection prossess

The practical part of the work describes:

- Defining goals and objectives
- Survey creation (questions based on ISO 5500x standards)
- Survey analysis and determination of functional and non-functional requirements
- Selection of required system functions based on functional requirements
- Selection of a specific system based on non-functional requirements

2. Literature Review

This chapter addresses the relevant literature that was used to conduct the research. The purpose of this section is to explain the concepts of TPM and CMMS and to outline the relationship between them. The chapter describes the system selection process followed by the authors and the international standard ISO 5500x that turned out to be the foundation of the work.

2.1 Validity of maintenance in manufacturing enterprises

"*As in personal health care insurance, maintenance may be considered the heath care of our manufacturing machines and equipment*" [2]

As far back as the mankind began making devices that fulfilled their requirements there was the requirement for maintenance. Records of maintenance can be found already in the ancient Egypt. An old Egyptian document, dated 600 b.c. mentions a stoppage of supply of cedar wood required for the maintenance of sacred boat of Amun Ra. [3]

There are many different definitions regarding maintenance. The Swedish standard SS-EN 13306 defines maintenance as "*Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function*" [4]. On the other hand, ISO defines maintenance as "*set of activities performed during the operating life of a structure to ensure it is fit-for-purpose*" [5]. However, when it comes to maintenance management, the American Petroleum Institute in its publication describes it as "*all actions including inspection, adjustments, cleaning, lubrication, testing, and replacement of expendable parts, as necessary to maintain the serviceability of the equipment*" [6]

In summary, maintenance involves actions to (i) control or prevent the deterioration process leading to failure of an engineered object and (ii) restore the object to its operational state through corrective actions after a failure. The former is called preventive maintenance (PM) and the latter corrective maintenance (CM). [7]

The basic objectives of the maintenance management systems in the company are:

- Achieving the desired quality of products or services
- Maximizing the economic life of the production equipment
- Maximizing production capacity
- Minimization of interruptions in the production process
- Elimination of excessive stocks and delays,
- Improving the flow of information related to maintenance [8]

Maintenance management affects the functioning of the entire company, and therefore directly influences the continuity of production. Lack of maintenance or inadequate maintenance can lead to dangerous situations, accidents, and health problems as well as machine downtime, resulting in financial loss. [9]

2.1.1 Maintenance Strategies

Maintenance in manufacturing enterprise can be divided into three basic strategies:

- Corrective maintenance: This type of maintenance can be divided into planned and unplanned. Unplanned occurs after equipment failure or loss of performance, with no time for maintenance preparation services. Planned maintenance is a correction of lower performance than expected or failure, for a management decision, i.e. for lower performance from predictive tracking or decisions to act until failure.

- Preventive maintenance: It consists in planning and implementing various types of activities aimed at avoiding breakdowns and unwanted downtime. An important element of prevention are periodic inspections of the machine park, repairs and maintenance aimed at extending the failure-free operation of machines.

- Predictive maintenance: an effective and modern method based on the analysis of data related to the operation of devices. It allows to predict at what time intervals and after what period of use damage to machines occurs. [10]

Predictive maintenance is increasingly replacing the run-to-failure (corrective) method from the market. Predictive and preventive maintenance is also strongly correlated with CMMS, which is the main topic of this paper. The next part of the theoretical work focuses on describing CMMS as well as the impact of those systems on the TPM (Total Productive Maintenance), which uses both predictive and preventive strategies and which method is widely used all over the world by manufacturing organizations.

2.2 TPM and CMMS: A High Value Partnership

One of the main factors determining the success of a production enterprise is the stable operation of machines and devices used in the production process as well as knowledge about their real condition and capabilities. One of the most frequently used methods for this purpose has recently become the TPM method which, together with the help of CMMS`s, are able to significantly improve the functioning of the company.

As early as 1990, Olafsson presented his view on the interoperability of the TPM method with CMMS`s, in which he said that: "*an early prerequisite for TPM implementation in a company, is the development of a CMMS for collecting and recording the data for TPM implementation"* [11]

2.2.1 Total Productive Maintenance

TPM is a unique Japanese philosophy, which has been developed based on the Productive Maintenance concepts and methodologies. This concept was first introduced by M/s Nippon Denso Co. Ltd. of Japan, a supplier of M/s Toyota Motor Company, Japan in the year 1971. Total Productive Maintenance is an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns and promotes autonomous maintenance by operators through day-to-day activities involving total workforce. [12]

The TPM approach aims to significantly reduce or even eliminate the risk of production discontinuities, failures and unplanned downtime. The most important goals are to improve the stability of production processes, reduce costs related to maintenance and extend the life and use of machines and devices. TPM defines three main production states (ZERO) towards which the undertaken activities should be directed: zero breakdowns, zero accidents and zero defects

TPM consists of 8 pillars- Figure 1, each of them performs an important function and is irreplaceable

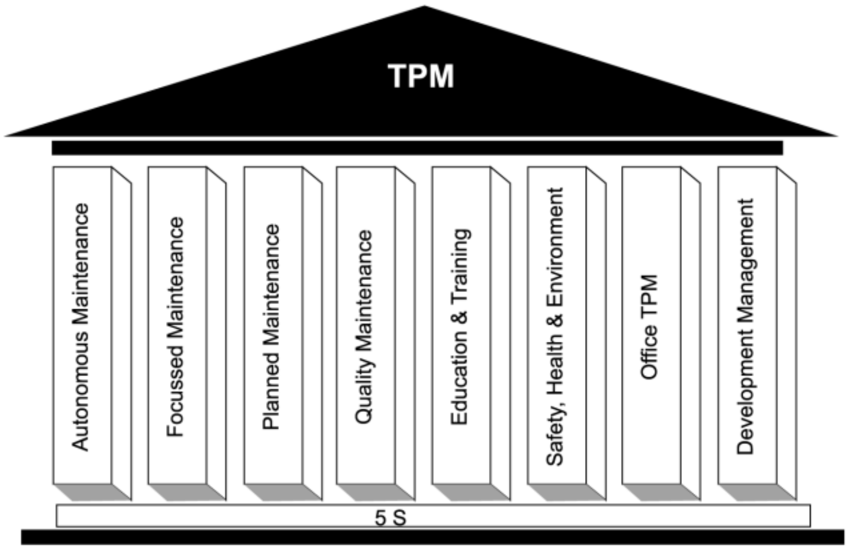

Figure 2.1. Eight pillars approach for TPM implementation [13]

The first of the eight TPM pillars is autonomous maintenance. Autonomous maintenance places the responsibility for routine maintenance, such as cleaning, lubricating and inspection in the hands of the operators. This results in that the operator gets a greater “ownership” of the equipment and a better understanding of how it works. Ensures that the equipment is cleaned and lubricated when needed. It could also help to identify emergent issues before they become failures. This will free time for the maintenance personal.

The second one is planned maintenance. It schedules maintenance tasks based on predicted and/or measured failure rates. This could help to reduce instances of unplanned stop time. It will also help to enable most maintenance to be planned for times when the equipment is not scheduled for production.

Next one is quality maintenance, which helps to detect and prevent design errors into production process. It could also help to apply root cause analysis to eliminate recurring sources of quality defects. Some of the benefits with quality maintenance is that it`s easier to specifically targets quality issues with improvement projects focused on removing root sources of defects. It`s also easier to reduce the number of defects and reduce the cost by catching the defects earlier.

The fourth one is focused improvement. Focused improvement often has small groups of employees work together proactively to achieve regular, incremental improvements in equipment operation. By doing this, recurring problems are identified and resolved by cross functional teams. Focused improvement also combines the collective talents of a company to create an engine for continuous improvement.

Early equipment management directs practical knowledge and understanding of manufacturing equipment gained through TPM towards improving the design of new equipment. New equipment could help to reach planned performance levels much faster due to fewer start up issues. Maintenance becomes simpler and more robust due to practical review and employee involvement prior to installation.

Training and education could help to fill in knowledge gaps necessary to achieve TPM goals. This applies to operators, maintenance personnel and managers. The benefit of training and education is that operators develop skills to routinely maintain equipment and identify emerging problems. Maintenance personnel also learn techniques for proactive and preventive maintenance. Managers will also be trained on TPM principles as well as on employee coaching and development.

Safety, health and environment are important factors to maintain a safe and healthy working environment. By focus on safety, health and environment it becomes easier to eliminate potential health and safety risks, resulting in a safer workplace. It makes it easier to specify new targets that results in an accident-free workplace.

The final of the eight TPM pillars is TPM in the administration. By applying TPM techniques to the administration functions, it becomes easier to address waste in the administrative functions. It will also help to support production through improved administrative operations. [12]

In summary, this methodology works well in factories around the world, increasing their efficiency, improving quality, reducing costs and, as a result, increasing profits. The concept of TPM (compared to the traditional preventive approach) assumes that the involvement of all employees in building an effective prevention system, systematic reduction of losses through problem solving and standardization are the key to success.

The most frequently used indicators that determine the effectiveness of the implementation of the TPM methodology are:

- OEE (Overal Equipment Effectivity) - device efficiency (it is the product of three parameters: machine availability, efficiency, and quality factor),
- MTBF - Mean Time Between Failures
- MTTR- Mean Time To Repaire
- MLDT - Mean Logistics Delay Time
- OA- Operational Availability [14]

2.2.2 CMMS: A system that facilitates the implementation of TPM

"*Computerized maintenance management systems assist in managing a wide range of information on maintenance workforce, spare-parts inventories, repair schedules and equipment histories. It may be used to plan and schedule work orders, to expedite dispatch of breakdown calls and to manage the overall maintenance workload. CMMS can also be used to automate the PM function, and to assist in the control of maintenance inventories and the purchase of materials. CMMS has the potential to strengthen reporting and analysis capabilities*" [13]

When implementing the TPM concept, it is often necessary to implement a CMMS class system supporting activities related to machine maintenance. In particular, the monitoring of the maintenance department's activity plays a decisive role in the successful implementation of TPM. The degree of credibility of the information obtained in the form of the above-mentioned indicators (chapter 2.2.1) is the basic condition for obtaining correct final reports. As a result, it facilitates making the right decisions regarding preventive actions.

Based on the widely available literature about CMMS class systems, it can be concluded that the main purpose of their use is the automation of work related to:

- Fixed asset management
- Technical inspections and machines maintenance
- Warehouse management as part of maintenance
- Order management for materials and spare parts
- Reporting and statistics generation

The main benefits of implementing CMMS are:

- Downtime reduction
- Increased reliability
- Work request processing
- Simplified record keeping
- Facilitating predictive maintenance through data collection
- Increased production capacity
- Ensuring the efficiency of machines in accordance with the quality requirement
- Ensuring workplace safety
- Improved quality of performed tasks
- Minimization of costs related to maintenance
- Improved inventory management
- Improved imformation flow
- Improved quality of the final products

In conclusion, CMMS`s not only collect data about facilities, failures, and inspections, but also help in managing the work of maintenance departments. They process information about the technical parameters of machines, staff and assigned tasks, spare parts, tools, consumables, and are carrying out cost analysis or calculations based on indicators. They help not only in the implementation of daily activities leading to the more efficient functioning of machines, but they also help to meet the requirements of the Machinery Directive. This is important because the machines, apart from the fact that they should run smoothly, must also be safe. The required documentation, all accident records or risk class assessments are also included in the CMMS class programs. However, in addition to the inventory capabilities, these systems also ensure quantitative and timely protection of all operational resources needed for maintenance and repair. [14]

2.3 ISO 5500x- Asset management

ISO - International Organization for Standardization, is a global non-governmental organization based in Geneva (Switzerland). Organization defines standards for products, services and management systems that play a pivotal role in facilitating foreign trade and international cooperation. ISO standards are documents developed by international experts in each field. Documents contain information and practical tips as well as good practices on many different aspects of the business. [15]

ISO 5500x is a set of standards covering management of assets of any kind. The ISO 5500x series of standards for asset management consists of the following three standards:

- ISO 55000: Asset management - Overview, principles and terminology. This provides an overview of asset management, the principles, standard terms and definitions applicable, and the benefits obtainable.
- ISO 55001: Asset management - Management systems – Requirements. This specifies what is required to set up, execute, maintain and improve a “management system for asset management.” In other words, it specifies the needs for the development of an integrated, effective management system for assets. However, it does not specify the design of the system.

- ISO 55002: Asset management - Management systems - Guidelines for the application of ISO 55001. This offers guidance on the design of the asset management system as well as on the implementation of the requirements in ISO 55001 (i.e. on the operation of an asset management system) [9]

International cooperation in the preparation of these standards has identified common practices that can be applied to the broadest range of assets, in the broadest range of organizations, across the broadest range of cultures.

This International Standard is primarily intended for use by:

- Those considering how to improve the realization of value for their organization from their asset base

- Those involved in the establishment, implementation, maintenance, and improvement of an asset management system

- Those involved in the planning, design, implementation, and review of asset management activities, along with service providers.

In a situation where professional knowledge and skills are required to implement a given management system, the only way to ensure the appropriate quality of the project implementation is to acquire the appropriate knowledge and skills. The ISO 5500x standard allowed the authors to gain the necessary knowledge in the context of maintenance management, and thus also in the field of asset management. The standard was intended to help in determining the path that supposed to lead the authors to identify the most important areas / elements of the company and those requiring the greatest attention and improvement. Thanks to this, the authors were able to define the requirements that had to be met.

2.3.1 The relationship between maintenance and asset management

This part will look at both relationship and differences between maintenance and asset management. Understanding it will be important when developing the use of maintenance management to improve asset management.

Asset management as defined in ISO 5500x is “*coordinated activity of an organization to realize value from assets.”* This includes coordinated and optimized planning, asset selection, asset acquisition/development, asset utilization, asset care (or maintenance), asset life extension (if applicable) and asset decommissioning/renewal. As shown in the figure below:

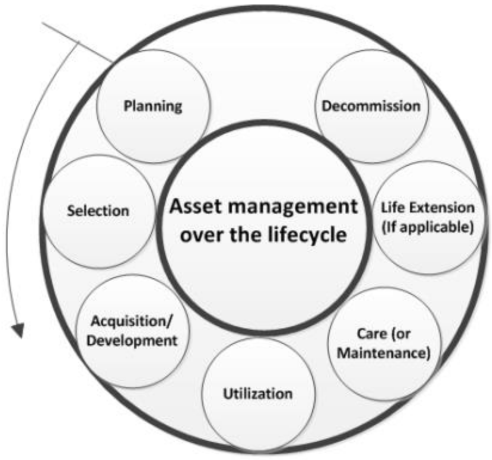

Figure 2.2. Maintenance management as part of asset management [9]

Asset management covers both physical and non-physical, whereas maintenance management is a part of physical asset management.

The following contains the different benefits of maintenance-based physical asset management:

- Sustained physical asset reliability
- Improved physical asset and production availability
- Reduced maintenance costs
- Improved product quality
- Improved safety record
- Reduced environmental impact
- Improved regulatory compliance
- Increased potential for life extension
- Improved lifecycle costs
- Optimized return on physical assets
- Sustainability

Maintenance is an important factor to physical asset management which is a part of the entire asset management concept. The definition of physical asset management could be described as *"The coordinated activities of an organization to realize the value from physical assets"*. [9]

The table below shows which of the factors that influence each other. Asset management and maintenance management influence each other directly by the physical asset management. It also shows how maintenance management influence the parent organization`s strategies, plans and decisions, and the relevant factors that must be considering when changing or improving the different aspects. [9]

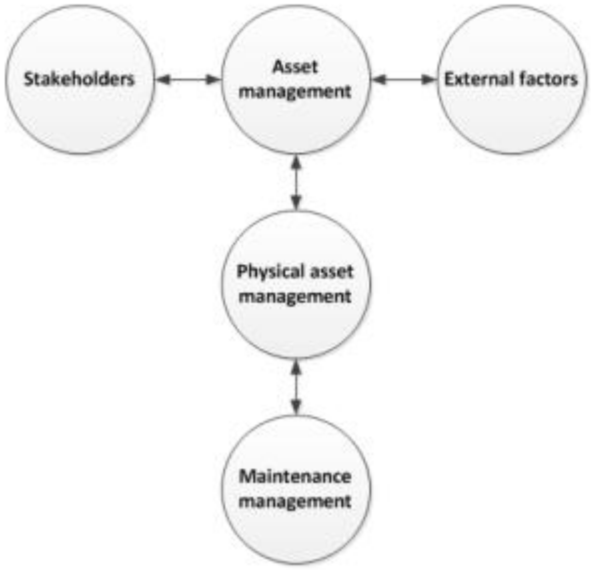

Figure 2.3. Interrelationship between asset management and maintenance management [9]

2.4 CMMS selection process

The described CMMS selection process mainly consists of:

1. Identification of needs and objectives

The first step in choosing a proper CMMS is to identify the needs and objectives regarding maintenance.

The definition of the “objective” created by L. Krzyżanowski says: “The objective is defined as the future, desired state or result of the organisation's operation, possible and planned to be achieved, within the period covered by the short-term or multi-annual action plan. " [16]

According to the S.M.A.R.T criteria, which supports the correct definition of objectives, goals should meet the following criteria and be:

S- specific: A clear statement of what our target is about. It should be clearly specified and defined. A well-formulated goal, in line with the specific principle, means that it is easy imagine and measure.

M- measurable: The goal of the project must be monitorable and measurable. Measurability allows to clearly determine whether the goal has been achieved

A- achievable: Defining a goal that is achievable by comparing the time, effort and costs it will require with its benefits, as well as considering other goals that may be priorities at the moment. It is also important that people who want to achieve a given goal should be able to obtain the necessary resources needed to achieve it.

R- Relevant: Defining an objective that is relevant to the company. It means, choosing a goal that the people who will pursue it will be able to identify with it. Therefore, it should be right and make sense to effectively pursue implementation.

T- Time-bound: Defining deadlines to achieve goals. When formulating a goal, it is necessary to define the final date of its achievement [17]

This stage of work focuses on defining the company's objectives as well as determining which areas require the biggest improvement and which of them require the greatest attention. It can be elements such as: too frequent, unexpected downtime; missing spare parts; failure to meet repair deadlines; lack of certain information obtained from machines. Finding critical areas will help in identifying the needs that have to be met in order to achieve the company's objectives

The objectives at work have been broken down into 3 different levels, these are:

1. *Strategic*: An element of the organizational strategy, it is determined at the highest organizational level. It sets the direction the company is striving for and the state it wants to achieve. The strategic goal is set over a very long period (3-5 years)

2. *Tactical*: A lower-level goal that clarifies strategic goals. It focuses on how to operationalize the activities that are necessary to achieve strategic goals. Determined at the middle organizational level

3. *Operational*: Concrete and precise solutions that will help to achieve the tactical goals. It is the operational objectives that will be achieved in the short term. Determined at the lowest organizational level [18]

The time that the authors spent on the conversation with both the maintenance leader and the production manager played the main role in determining the goals and needs of the company.

2. <u>Determining the requirements for the new system</u>

The purpose of this stage is to precisely determine the requirements for the new system. This is the stage in which the company's objectives are converted into specific system requirements that ensure their achievement.

The IEEE Standard 610 of 1990 defines a requirement as:

1. A condition or ability of a system that is needed by the user or customer to solve a problem or achieve an intended purpose

2. A condition that must be met or the ability that a system or part of a system must have in order to meet a contract, standard, specification or other formally adopted document [19]

Requirements can be divided into two distinctly different categories:

- Functional requirements - they describe what functions must be performed by the system, without specifying how it will perform them.

- Non-functional requirements - can be defined as restrictions that apply to services or activities performed by the system.

There are two subcategories of non-functional requirements:

- Quality Requirements - Identify the specific performance expectations stakeholders have for functional requirements; they provide context for determining how well the functional requirements meet stakeholder needs

- Constraints - These are the rules, dependencies, and boundary conventions within which all other requirements must be met [20]

It is important to realize that the requirements may change at any stage of the system implementation process.

The authors of the study decided to use the ISO 5500x standards as the basis for the assessment of the company's operations and identification of the previously mentioned critical areas. The standard was used to create a survey with questions that are intended to lead to the determination of the requirements that the new system must meet so that the company's objectives can be achieved.

3. Selection and analysis of functions

To determine the superior functions, an Excel table was created that systematizes the knowledge about the influence of selected functions on specific requirements. A hybrid of the qualitative and quantitative methods was used.

The qualitative method is a research method that does not specify numerical parameters. Instead, the studied phenomenon or the research object is characterized in a descriptive way. The quantitative method is a research method in which the numerical parameters characterizing the studied phenomenon or the research object. Qualitative method generates ideas or hypothesis for later quantitative research. [21]

The exact structure and characteristics of the Excel table are described in subsection 4.2.2.

4. Assessment of selected suppliers

The evaluation and selection of suppliers consisted in confronting their offer with previously defined critical functions. The purpose of the analysis was to select the systems with the greatest number of functions.

5. System selection

The choice of the system was based on comparing the functionalities of individual systems with respect to non-functional requirements

A detailed description of the analysis is provided in subchapter 4.4.

3. Experimental method

"*Experimental research is a scientific approach to research, where one or more independent variables are manipulated and applied to one or more dependent variables to measure their effect on the latter.*" [22]

This section describes the effect of the requirements on the importance of the various functions. The importance of a function is understood as the extent to which a given function can cover the requirements. The independent variables in this case are the requirements and the dependent variables are the "validity-level" of the functions.

The aim is to identify the most important functions that are required to be present in the new system. This approach will enable the selection of the final system by eliminating those systems that have the least number of required functions.

The requirements were identified through a survey which was developed based on ISO 5500x standards. The results of the analyzes are presented in the next chapter

3.1 Maintenance in Corvus Energy

Corvus Energy uses an ERP-system called Microsoft Dynamics 365. ERP-system means enterprise resource planning and is used in several of the key operations in the company. The aim of the system is to handle the company information and satisfy the need for management and administration. The system includes production planning, logistics, sales, supply and economy. Corvus Energy also uses Microsoft Azure as a local server to save data. The data stored in Microsoft Azure is provided by a system called Scada. Scada is a system that register information sent by different sensors which is placed on the production equipment. If one of the sensors register that something is not within tolerance, or of something is wrong, it sends a message to the Scada database. The message tells what the fault is and for how long it`s been there. Microsoft Azure is a sub-system in Microsoft Dynamics 365, it`s therefore desirable that a new maintenance system will be able to cooperate with these two systems. Corvus Energy uses an external program called Atlassian to assign maintenance work to the responsible workers.

The operator-controlled maintenance at Corvus Energy get registered by filling out the work tasks on a paper. By doing this, it`s difficult to get the overview, which is needed to optimize the preventive maintenance. It`s also difficult to see what's been done before and to see how often the different components fail and the average lifespan of each component. All the disadvantages with this approach will be highlighted later in the report.

3.2 Needs and objectives

The authors used the interview method to obtain information about the needs and objectives of the company. The interviews were semi-standard and were conducted in the form of casual conversations with both the head of production and the head of maintenance. The authors also sought the opinion of machine operators to deepen their knowledge of the operational field.

The table shows the results of the interviews. Objectives have been sorted according to 3 types which were described in the theoretical part of the work. For the task, the table contains only those goals that are crucial to maintenance and on which Corvus intends to place the greatest emphasis in the near future.

	1				2			3		
Strategic Goals	Increasing production efficiency				Increasing the quality of processes and manufactured products			Maximize on time delivery to the customer		
Tactical Goals	Increasing the number of modules produced per week to 460				2% or less products total failures (In-house and filed failures)			95% or higher customer on time delivery		
Operational Goals	Reduction of production downtime to a maximum of 5% by the end of 2023 by implementing an IT system	Reduction of machine failures by implementing the use of Key Performance Indicators by the end of the year	Within a year, switch from using Excel to using a more computerized alternative to gain a better overview of the machine park	Introduction of an IT system by the end of the year, that will improve the management of spare parts	Increased control during production- Introduction of an IT system that will improve the control of processes, machines and products		By the end of the year, introduction of the KPIs for the analysis and control of production and products	Introduction of computerized management of warehouse space	Introduction of a computerized register of incoming and outgoing products to / from production	Implementation of a system that allows the analysis of indicators regarding sales, number of orders, complaints, returns

Table 3.1. Objectives

As the table shows, the strategy of operations is based on increasing production efficiency; improving the quality of processes and manufactured products; maximizing deliveries on time to customers. These are strategic, long-term goals that Corvus plans to achieve in the future, and which set the direction for the development of the entire production department.

The tactical goals that are designed to lead the company to the implementation of strategic goals are: Increasing the number of modules produced per week to 460; 2% or less products total failures (In-house and filed failures); 95% or higher customer on time delivery. These goals have been specified based on the S.M.A.R.T Principle and will be used as a milestone to identify whether strategic goals have been achieved.

Objectives that will be implemented in the short term, the so-called operational goals are: Reduction of production downtime to a maximum of 5% by the end of 2023 by implementing an IT system; Reduction of machine failures by implementing the use of Key Performance Indicators (KPI) by the end of the year; Within a year, switch from using Excel to using a more computerized alternative to gain a better overview of the machine park; Introduction of an IT system by the end of the year, that will improve the management of spare parts; Increased control during production- Introduction of an IT system that will improve the control of processes, machines and products; By the end of the year, introduction of the KPIs for the analysis and control of production and products; Introduction of computerized management of warehouse space; Implementation of a system that allows the analysis of indicators regarding sales, number of orders, complaints, returns; Introduction of a computerized register of incoming and outgoing products to / from production.

As can be noticed, the operational goals are strongly targeted and correlated with the implementation of the CMMS. Therefore, at this early stage, it is possible to identify some requirements that the company has for the new system. Additionally, it is possible to identify the needs that arise from the objectives listed in the table, they are:

- Minimizing machine failures – focus on preventive and predictive maintenance
- Reduction of machine downtime to minimum
- Effective use of KPI (Key Performance Indicators)
- Transition to a more computerized administration

3.3 ISO 5500x analysis and survey creation

When planning the survey, it should be considered what result is desired and what questions it should answer.

What questions it should answer?
The purpose of the survey was to answer questions about the functioning of the company in terms of maintenance.

What is the expected result of the survey?
The result of the survey was to understand the functioning of each of the elements of the organization to determine the critical areas and activities that require the greatest attention and improvement.
Thanks to this, the authors was able to clearly define the requirements that the CMMS must meet, so that the previously mentioned areas and activities will improve, and the company's goals can be systematically achieved.

The questions were made based on the ISO 5500x standards - Asset management. The set of standards has been slightly modified for the purpose of the assignment. The ISO 5500x standards includes 7 elements of the asset management system, but the described survey includes 4 of them: context of the organization, leadership, planning. The survey was also supplemented with an element called "the scope of the maintenance system", the purpose of which was to define the scope and boundaries of activities for which the new system is to be responsible.

Important! The ISO 5500x standard was created to manage all assets in the company. Thanks to it, it is possible to identify <u>all</u> resources company possess and what is to be achieved thanks to them. However, for the purposes of this task, the standard was limited only to the management of a single asset, which is the CMMS authors are looking for. Therefore, the questions created for the purposes of the survey were strongly focused only on finding the requirements of the system sought and are limited only to identifying those areas and activities that are important for finding and implementing the system.

The questions that were included in the survey along with the division into individual elements are:

1. Context of the organization

"The organization shall determine external and internal issues that are relevant to its purpose and that affect its ability to achieve the intended outcome(s)." [23]

Questions:

- What modules are most critical to your business now, regarding maintenance?
- Which of the previously mentioned modules require the most improvement?
- What is the organizational structure regarding maintenance?
- What factors contribute to the production downtime in your factory?

2. Determining the scope of the maintenance system

"Identifying the area and its boundaries for which the maintenance system will be responsible-determine the scope of activities" [23]

Questions:

- What is the purpose of the new system regarding maintenance?
- What information is crucial for the company that they want to obtain from a particular device?

3. Leadership

"It is the responsibility of top management to develop asset management policies and objectives, and to align them with organizational objectives. Top management is also responsible for ensuring that the company complies with laws, regulations and regulations." [23]

Questions:

- What are applicable laws, legislations, and regulations that the company must comply with, regarding maintenance?

4. Planning

"The organizational objectives provide the overarching context and direction to the organization's activities, including its asset management activities. The organizational objectives are generally produced from the organization's strategic level planning activities. Top management and leaders at all levels are responsible for ensuring that appropriate resources are in place to support the asset management system. These resources include appropriate funding, adequate and competent human resources, and information technology support" [23]

Questions:

- How much time does the company plan to spend on implementing a new system?
- What is the amount of money the company is willing to spend on the new system?
- What other systems does the new system need to be compatible with?

5. Operation

"The organization shall plan, implement and control the processes needed to meet requirements, implement actions, and the corrective and preventive actions by" [23]:

- Establishing criteria for the required processes.
- Implementing the control of the processes in accordance with the criteria.
- Keeping documented information.
- Treating and monitoring risks.

Questions:

- What maintenance types are most used in the company right now?
- How often are machine inspections performed?
- How often is maintenance work performed?
- Does the company have a clearly defined daily checklists routines? How are those procedures recorded and saved?
- How does the company control and determine the production efficiency?
- At what point are spare parts ordered?
- How does the company control the quantity of spare parts they possess?

- Does the company monitor the course of preventive tasks?
- Does the company keep records of used spare parts during the implementation of maintenance tasks?
- Does the company use condition-based monitoring?
- Does the company plan predictive maintenance work or any other according to the machine mileage?
- How does the company collect and maintain a historical record of data about a particular device?
- What historical information about each device is collected and stored?

4. Results

4.1 Survey analysis- Defining Requirements

This part of the work consists of describing the current state of the company's operations in specific areas regarding maintenance. This chapter will also define the risks and limitations of this approach. The aim is to determine what functional and non-functional requirements the new system must meet to minimize the defined limitations and reduce the risk in order to obtain more efficient functioning of maintenance management. The answers, risks, limitations, and requirements are listed in the excel table. Individual lines that are at the same level are not assigned to each other and do not necessarily mean a direct response to a given risk or limitation.

4.1.1 Critical areas and factors

<table>
<tr><th>Answers</th><th>Errors and limitations</th><th>Requirements</th></tr>
<tr><td>The most critical modules for maintenance are:
reporting,
log data (digital),
work orders,
spare parts</td><td rowspan="2">Failure of any equipment or part results in downtime of the entire production</td><td rowspan="2">Implementation of the CMMS system to gain greater control over these critical modules</td></tr>
<tr><td>Factors influencing production downtime are:
Machine jams and part failures;
Spare parts delivery time;
Bad documentation and reporting</td></tr>
</table>

Table 4.1. Critical areas and factors defined by management

The survey shows that, according to the production management, the main areas that affect the proper functioning of the enterprise are reporting, log data, work orders and spare parts management.

In addition, the management through a survey identified the factors that largely affect production downtime, they are machine jams and part failures; delivery time of spare parts; bad documentation and reporting.

Defining the assessment and vision of those in charge of production was the starting point for further analysis. Thanks to this, already at the very beginning of the analysis authors were able to identify the problems and elements requiring the greatest attention. However, it was important to look at the problem as a whole and not be limited only to the mentioned areas. The elements of the organization and production processes are closely related and each action of one area creates a response to another one.

The responses from the survey were sorted into the following areas:

1. Maintenance strategy
2. Checklists
3. Production efficiency evaluation
4. Spare parts
5. Storage and saving of data

6. Information flow and work orders
7. Reporting and data analysis

4.1.2 Functional Requirements

This section describes the defined requirements that result from the responses provided by management. The analysis of the responses helped in obtaining information on the current operational state. Consequently, the authors were able to identify the related risk, which in turn made it possible to define the requirements.

The requirements that have been found and described in this section are functional requirements.

1. <u>Maintenance strategy</u>

Reactive maintenance	The type of maintenance that is most commonly used in the company is reactive maintenance (≈70%)	high failure rate of the machine park;	Implementation A real-time operating system that measures critical parameters for the proper functioning of the production line
		frequent occurrence of unplanned production downtime;	increase in the efficiency of production processes - by using the OEE indicator
		no scheduling of maintenance services;	reduction of the number of failures and downtime - use of the MTBF indicator (Mean Time Between Failures)
	Part replacement time is based on the manufacturer's suggestions attached to the purchased part	high rate of production unpredictability	Increasing the availability of machines and processing capacity
		ineffective use of resources - including human resources	Introduction of KPIs
		long time to restore the efficiency of machines and devices	

Table 4.2. Functional Requirements - Maintenance strategy

The survey shows that the most used maintenance strategy in the company is a corrective/reactive maintenance. This situation brings with it several unwanted possible events that Corvus must deal with on daily basis. The problems and limitations associated with using this type of maintenance are:

- High failure rate of the machine park
- Frequent occurrence of unplanned production stoppages
- No schedule of maintenance services
- High production unpredictability
- Ineffective use of resources - including human resources
- Long time to restore the efficiency of machines and devices

Requirements:

The answer to these risks and limitations is to move to a more preventive maintenance strategy. The requirements that the company must fulfill for this to happen are:

- Implementation of a real-time operating system that measures critical parameters for the proper functioning of the production line
- Introducing the use of metrics or KPIs (Key Performance Indicators) that will help in:
    - increasing the efficiency of production processes - by using the OEE indicator
    - reducing the number of failures and downtimes - using the MTBF (Mean Time Between Failures) indicator
    - Increasing the availability of machines and processing capacity

2. <u>Checklists</u>

Checklist	The company has specific daily procedures (Checklists) which are written down on a piece of paper and stored.	Paper checklists provide staff with no guidance on how they should be doing it or what to do if readings are out of range;	the ability to add notes, images and attach documents to work orders
		It takes valuable time to create, modify, check and analyze checklists;	Automate and computerize the creation, modification and analysis of checklists to save time
		Zero visibility	Increased control over analyzing problems and resolution of issues
	Daily, weekly, monthly, 1/2 yearly and annually inspections are performed	Paper checklists provide no data-difficult to compare and analyse	Checklists can be easily managed and completed from a computer or mobile device.
		Connectivity issues	Automatic notifications about a new order
		Paper checklists are frequently modified	

Table 4.3. Functional Requirements- Checklist

The company is using paper-based checklists. Checklists are a simple tool that allows for correctness control and / or assessment of the degree of completion of a given project. However, in a paper form, not connected to any IT system, this approach has many disadvantages.

The disadvantages that can be noticed at Corvus are:

- Paper checklists do not guide employees, they only define the task
- Creating, modifying, checking, and analyzing paper checklists takes valuable time that the production manager could use in a better way.
- Analysis of paper checklists is time-consuming and inaccurate, and is therefore often overlooked
- Zero Visibility - There is nothing on the paper to remind employees when they should conduct an inspection or to alert managers that an important inspection has not been carried out.
- Paper checklists do not provide data and are difficult to compare and analyze
- Difficult communication. Valuable data is hidden in drawers, creating silos where information cannot be shared, analyzed, or collaborated.

Requirements:

It is required to correct each of the above-mentioned limitations through the implementation of a system that will:

- Enable faster and more efficient creation, modification, and analysis of checklists to save time.
- Improve control over problem analysis and problem solving
- Improve information flows by:
    - Checklists that can be easily managed and filled from a computer or mobile device.
    - Automatic notifications about a new order

3. Production efficiency evaluation

Production efficiency	The company controls and determines the production efficiency on the basis of a production plan, which is defined based on the quantity of modules purchased	Inability to identify areas requiring improvement;	Introduction of KPIs
		It is not possible to evaluate the implemented improvements and modifications;	

Table 4.4. Functional Requirements - Production efficiency evaluation

Corvus determines periodic production efficiency based on the production plan, which in turn is determined based on the orders placed. This practice, however, has many imperfections and limitations, such as:

- Inability to identify areas for improvement and correction to achieve greater efficiency and reduce downtime risks
- It is not possible to evaluate the improvements and modifications introduced

The company is using the Just-in-Time (JIT) strategy, which is based on providing each production process with all the necessary elements at the required time and in the required quantity. The strategy itself is very good, but without appropriate measurement systems, it is very risky.

Requirements:

The solution that will cover the above-mentioned limitations is the introduction of the key performance indicators (KPI). KPIs refer to a set of quantifiable measurements used to gauge a company's overall long-term performance. They allow for the ongoing assessment and improvement of the company's performance, as well as the expansion of knowledge.

Required indicators:

- Overall Equipment Effectiveness (OEE) of critical machines
- Mean Time to Repair (MTTR)
- Lost Time

4. Spare parts

Spare parts	Spare parts are ordered manually when one of them is used for corrective / preventive activities - JIT inventory system	Risk of Running Out of Stock	change to JIC inventory type
		Dependency on Suppliers	
		More Planning Required	
	The company controls the amount of spare parts in its possession using an Excel document filled in manually	Risk of making a mistake in filling in or updating data manually	implementation of an IT system for spares management
		No real-time inventory data	Real-time inventory data
		Not efficent inventory management	Automatic generation of inventory requirements based on the achieved minimum stocks of parts and materials
		No transaction history	Easy access to historical data about particural parts
		Difficult to attach images, warranty information, manuals, descriptions of products, and more to products and assign each product a location in warehouse	Spare parts automatically assigned to the correct machines
		No parts history	

Table 4.5. Functional Requirements - Spare parts

The company uses the JIT- inventory system. It is a strategy that aligns raw material orders from suppliers directly with production schedules. Spare parts are ordered immediately after they have been used for maintenance or repair work. The company only receives goods when they are needed in the production process.

This method, however, requires accurate demand forecasting. There is a great risk of running out of stocks if demand is not properly specified. Another factor worth noting is the influence of suppliers on the production flow. This strategy is based on getting the required raw materials on time. If a raw-materials supplier has a breakdown and cannot deliver the goods promptly, this could conceivably stall the entire production line.

In addition, the company uses Excel to control its spare parts in possession. The consequence of such a solution is several possible limitations and errors that can occur, these are:

- Risk of making a mistake when adding or updating data manually
- Forgetting to update the inventory
- No real- time inventory management
- No insight into the history of parts
- Difficult to attach photos, warranty information, manuals, product descriptions and other items to products and assign each product a location in a warehouse

Requirements:

Considering the above-mentioned limits and risks, a suitable solution may be switching to the Just-in-Case (JIC) system, which involves keeping larger stocks at hand. This is an appropriate strategy for companies that have difficulties with forecasting demand or experience large sales volumes at uncertain times. To implement a just-in-case system, it is needed to have an orderly warehouse with all items in place, especially when storing large amounts of inventory. This requires the use of software to automate the management of the location of spare parts. The system must be able to track the product and prevent errors during the collecting phase.

When it comes to keeping control over spare parts, it is advisable to move from Excel to a computerized inventory management system. This solution will give company more control through the ability to track inventory data in real time, view the history of parts or the ability to assign parts to individual machines.

An additional solution is the implementation of maintenance metrics that enable monitoring of indicators such as inventory turns, stockouts or storeroom records.

5. <u>Storage and saving of data</u>

<table>
<tr><td rowspan="4">Storage and saving of historical data</td><td rowspan="4">The company collects and stores historical records of data about a specific device or part on a website that can be accessed by all employees (Atlassian)</td><td>Company has no uniform way to enter data;</td><td rowspan="2">Improved data entry and easier data searching
Use of filtering and sorting mechanisms</td></tr>
<tr><td>Data is easly lost among other information;</td></tr>
<tr><td>It's hard to find historical data about a specific machine / part</td><td rowspan="2">More transparent production structure in the system

Tree mapping of the production structure in the database</td></tr>
<tr><td>Data about a specific machine scattered among many posts- there is no specific input location for a given machine or part</td></tr>
</table>

Table 4.6. Functional Requirements - Storage and saving of data

One of the company's main problems that arise from the survey is the way the data is saved and stored. Corvus Energy uses an external platform called Atlassian. This platform is used for both communications, reporting and work ordering. Atlassian is not adapted to such an advanced structure of the production line that the company has at its disposal. As a result, key information related to work orders or individual parts is spread over many threads and places, and none of them is assigned to one individual location. In addition, the company does not have a uniform strategy for entering information, which means that one problem may have many names. It often happens that a given problem has been solved earlier, but since the company does not have a uniform system of creating threads, it is almost impossible to find a solution to a given problem in earlier discussions. This has a big impact on work efficiency.

Requirements:

The recommended solution is to implement a system that will allow to create a treemap of the production to achieve a more transparent production structure. Thanks to this, individual threads regarding a given part or machine will be discussed in a specific place under a specific card. This method will enable easier data entry. Additionally, due to the possibility of filtering and sorting data, searching for data will be much easier. As a result, the risk of losing valuable information will be reduced and the time spent on searching for information will be shorter.

6. Information flow and work orders

Information flow and work orders	Information and work orders are usually communicated through checklists- for urgent orders through physical meetings. (intern communication = maintenance manager -> production manager-> shift manager -> machine operators)	Inefficient / slow flow of information	Introduction of a system that enables communication directly at all levels
		Information may be distorted when passing through the entire channel	
		Some information may be lost during transmission	Automatic tasks notifications
		Slow reaction to critical events	
	The company does not monitor the progress of the work orders	no real-time tracking of work order status	Tracking of work order status
		no possibility of visualizing work completion times and reaction times	

Table 4.7. Functional Requirements - Information flow and work orders

The internal flow of information in the company runs vertically- a linear system where information flows from one person to the next based on their titles. Information about work orders is usually transferred in form of daily checklists and physical appointments are applied for urgnent problems.

The internal flow of information that does not have an IT alternative is exposed to many threats, such as ineffective information flow that results in a slow reaction to critical events; the risk of distorting or omitting certain information. In addition, the result of such information system is the inability to track the status of work in progress, which in turn results in the inability to analyze the response time and the time needed to complete the particular task.

Requirements:

To make the flow of information and work orders more effective, it is required to implement a system that will enable communication directly at all levels; will be able to track the status of work orders in real time and enable the analysis of reaction time to unplanned events.

7. Reporting and data analysis

Reporting and data analysis	All the automatic production lines have monitoring system, but they are not connected to a maintenance system	No warning in case of disrupting processes, trends, tendencies etc.	Creating charts for data analysis
	No use of condition based monitoring - information sent by sensors is not analyzed	slow and ineffective detection of the causes of problems and changes in processes	Automatic recording of production data to a transactional database
	The company does not create periodic production reports	no possibility of correcting production processes on a regular basis	Real-time work analysis and daily report generation

Table 4.8. Functional Requirements - Reporting and data analysis

One of the biggest problems of the company, is the inability to analyze data coming straight from the machines. The company has a fully automated production that is not connected to any maintenance system that deals with data analysis. A such situation results in the absence of a warning in the event of disrupted processes/ trends/ tendencies, etc. as well as in slow and ineffective detection of the causes of problems and changes. This situation also affects the creation of reports. If the production is not connected to any system, then it is impossible to create production reports which will describe the operation of the machines. This results in the inability to immediately correct production processes.

Requirements:

The required solution is the implementation of a system that will enable the transfer of information from machines to the transaction base, which in turn will enable the creation of both periodic reports and real-time work analyzes based on KPI

4.1.3 Non-functional requirements

Non- Functional Requirements	
Quaility requirements	***Constrains***
The purpose of the new system regarding maintenance:	Other systems with which the CMMS system must be compatible are:
Improved communication at all maintenance levels	Microsoft Dynamics 365
More effective management of technical assets - machine operation analysis	Azure
Gaining more control over the warehouse and spare parts	Microsoft Office
Better control by creating analysis reports	

Table 4.9. Non-functional requirements

Quality requirements- Stakeholders expect from the new system an impact on:

- Improving communication
- Improving the efficiency of technical asset management
- Improving inventory management

Constrains- the only constrains resulting from the survey that the system must meet is compatibility with the following systems:

- Microsoft Dynamics 365
- Azure
- Microsoft office

Furthermore, authors specified additional constrains that the system must meet. These restrictions are based on the recommendations of various suppliers. These mentioned constrains are:

1. *Availability and Scalability*
    - The solution should automatically scale the resources to accommodate varying throughput at different times of the day.
    - The solution is built with fault tolerance architecture and capabilities to automatically recover from any single point of failure
    - The system provides for high availability through means such as redundant backup servers, cloud nodes, or other methods.
    - The solution should be horizontally and vertically scalable.
2. *Deployment Options*
    - Offer as a SaaS solution
3. *Integration and Extensibility*
    - The solution offers API integration capabilities using REST or other methods to build custom integrations with other systems.
    - The solution integrates with popular accounting platforms
    - The solution integrates with popular data integration tools like Microsoft, etc
4. *License Type*
    - Solution offers a free trial
5. *Platform Security*
    - The solution maintains a record of administrative and user actions and generates a report on such activities.
    - The solution allows creating and editing security groups and assigning users to those groups to ensure access is limited and only to those areas and fields of information that match the necessary user roles and responsibilities.
6. *Professional services and maintenance*
    - Vendor offer software implementation services, including solution evaluation and installation, to minimize the on-premise expertise required to implement the solution
    - Vendor offer maintenance contracts for supported software to ensure that updates, upgrades, and maintenance services are regularly received
    - Vendor offer in-product help and suggestions within the application to help the user get started using the product
7. *Training*
    - Vendor offer training material to help configure and use various features and functionalities of the product
8. *User Support*
    - Vendor offer 24x7 technical support to be able to address off-hour issues

- Vendor offer help desk support via instant message/chat
- Vendor offer help desk support via telephone and email

9. *Vendor information's*
   - Vendor have a broad customer base in the industry
   - Vendor is financially stable
10. *Mobile CMMS*
    - "Offline Access- The solution allows technicians to access their work orders, log labor hours and notes, record work completion, and enter condition monitoring readings offline. The data gets synced automatically when the device connects to a network"
    - Android App
    - The solution allows users to collaborate within the CMMS mobile app via in-app messages, group chats, and other collaboration methods.

Non-functional requirements play an important role in the task because, it is based on these requirements the final system will be selected.

4.2 Selection and analysis of CMMS features

The next stage which supposed to bring the authors closer to the selection of the appropriate system, was to define the key functions that the searched system must have to meet the requirements. Defining the key functions allowed for the subsequent selection of the system.

This stage consists of 3 sub-stages:

1. Searching for available functions and defining their belonging to appropriate areas of the company's operation.
2. Determining the importance of a function in relation to a particular requirement
3. Selection of key functions

4.2.1 Available CMMS features

This step describes and systematizes the knowledge about the most popular functions that can be expected to be present in CMMS`s.

The analysis of the functions of the maintenance support systems makes it possible to identify which functions were considered the most important by the system manufacturers. This can be an indication of what users want. It can be assumed that the results come from interviews with users or are built based on functional requirements specifications generated by system users. For this purpose, a ranking comparing CMMS`s widely available on the Internet was used. These rankings describe the available functions in each of the systems. The authors also contacted individual suppliers to learn more about the offers.

The functions found were sorted in such a way so that they correspond to the company's areas with which they are most associate. These areas are:

- Work order
- Preventive tasks
- Technical Asset Management
- Spare parts- Warehouse
- Reporting

This division also enables readers, including Corvus Energy production managers, to better understand which areas a function is responsible for. Assigning a given function to a given area was also helpful in further determining the importance of each function for individual requirement.

Selected features with divisjon are presented in the table below.

Features
Work order
To-Do-List / Chesklists
Sending of notifications with information about assigned tasks to be performed (Alerts/Notifications)
Sharing reports of faults and breakdowns via a mobile application (Mobile app)
Obtaining information in the present time about ongoing and completed tasks (Activity Tracking)
Assignment of a technician to a failure (Employee Scheduling) (Automated Scheduling)
Tracking the status of a work order (Status Tracking)
E-mail notifications (Alerts/Notifications)
Photos attached to work orders
Failure codes sorted by type
Keeping track of "work in progress" (Real-time Updates)
Categorization of work types (Prioritization)
Logging in / out - automatic work time register (Check-in/Check-out)
Configurable checklists (Task Management)(Work Order Management)
Possibility to create own inspections, controls and audits (Inspection Management)
Mobile access
Mobile Alerts

Preventive tasks
Automatically sent e-mail and SMS notifications about upcoming inspections or tasks (Reminders and Calendar/Reminder System)
Monitoring of preventive tasks whether they were performed on time (Status tracking)
Reports with division into machines and type of maintenance work (Customizable Reports)
Possibility to view the history of machine and device maintenance tasks (Service History)
Automatic saving of the history of machine and device maintenance tasks (Data Capture and Transfer)
Records of used spare parts during the implementation of preventive tasks (Inventory Tracking)
Links to documents required to plan the work order
Adding spare parts for repetitive work (Inventory Management)
Planning of predictive and other works according to the work of the machine (Maintenance Management)
Machine maintenance based on condition monitoring (data readings)
Downtime monitoring (Downtime Tracking)
Automatic generation of preventive works (Maintenance Scheduling)
Repair Tracking
KPI Monitoring

	Technical Asset Management
	Possibility for adding a notification by operators (Alerts/Notifications)
	Linking spare parts to a machine or device (Asset Planning)
Asset structure	Possibility of building a multi-level structure of devices
	Key asset information and photos
	Creating visible connections and dependencies between assets and child-assets
Work order summary for the given device	View of all work orders and fault reports (Real Time Monitoring) (Monitoring)
	Preview of unrealized work orders
	History of work orders for the device (Historical Reporting)
	Visualization of implementation status and reaction (Data Visualization)
Costs incurred on devices	Summary of internal and external costs (Cost Tracking)
	Purchase summary (Purchase Order Management)
	Cost summary by type of work
Counters	Graphical and numerical data analysis of the machine's workflow (Reporting/Analytics)(Data Visualization)
	Defining various data for device analysis (Predictive Maintenance)
	Counter-based preventive work (Preventive Maintenance)
Analysis	Built-in analytical charts (Reporting/Analytics)
	Built-in damage analysis (Root Cause Analysis)

Table 4.10. CMMS Features 1/2

	Spare parts- Warehouse
	Record of used parts in work orders (Inventory Tracking)
	Setting the minimum quantity for individual spare parts (Inventory Optimization)
	Purchase Order Management
Stock Items	Division into: Part categories, sections, groups, subgroups
	Pictures of parts
	location of the spare part in the shelves (Warehouse Management)
	Availability of parts usage information: tracking; part movements; use in work orders (Inventory Tracking)(Invetory Control)
	Division into stocked and non-stocked parts
Suppliers	List of suppliers (Supplier Management)
	Preferred Suppliers
	Links to suppliers' websites
Order	Purchases in various currencies (Multi-Currency)
	Automatic generation of orders
	Automatic dispatch of the order to the supplier
	Invoice registration (Invoice Management)
	Order approval
	Order status tracking (Order Tracking)
	Automatic stock replenishment

	Reporting
Reports for work orders	Real-time downtime reporting (Real Time Data) (Downtime tracking)
	Analysis of selected work orders (Reporting/Analytics)
	Analysis of the current amount of work (Reporting/Analytics)
	Overall work order load (Reporting/Analytics)
	Priority of work orders (Prioritization)
	Analyzes of downtimes (Downtime tracking)
	Analysis of the number of works (Reporting/Analytics)
	Maintenance effectiveness Analysis (Maintenance Management)
	Multiple criteria selection for creating each report (Customizable Reports)
Warehouse Reports	Report of urgent activities (purchases) (Purchase Order Management)
	Quantity and value stocks
	Turnover reports with various suppliers (Vendor Management)
	Transaction table
Asset management reports	Pareto analyzes for the plant
	Periodic equipment efficiency (Maintenance Management)
	Charts
	Cost summary for devices (Cost Tracking)
	Device failure reports (Real Time Reporting)
	Selection of criteria for the creation of reports (KPI Monitoring)
	Forecasting

Table 4.11. CMMS features 2/2

It is also important to mention that such a division, illustrates very well the strong correlation between the functions and the requirements resulting from the survey, which were also divided into similar areas. However, it is worth remembering that one function can affect many requirements.

4.2.2 Identification of critical functions based on the functional requirements

Further step was to determine the importance of individual functions in the overall improvement of the maintenance efficiency.

For this purpose, an Excel table was constructed. It was designed to illustrate how big influence a given function has on a particular requirement (Requirements described in chapter 3.2.3). The validity of the function was determined by using a 3-point scale that combines quantitative and qualitative analysis. The analysis determines the importance of the functions using a qualitative scale: High-Medium-Low, where each value has a numerical determinant, sequentially: 3-2-1. The purpose of the numerical determinant was to clearly define the meaning of a given function, not only for a specific requirement but for the functioning of the entire organization.

Each of the requirements has been assigned a letter, which was placed in the appropriate column in the Excel table, thereby determining the importance of a given function for a given requirement. The table below shows which letters have been assigned to the different requirements.

Table 4.12 Requirements with assigned letters

Maintenance strategy- Preventive maintenance **(X)**	Checklists **(S)**	Production efficiency evaluation **(Z)**	Spare parts **(W)**	Storage and saving of data **(T)**	Information flow and work orders **(G)**	Reporting and data analysis **(A)**
Implementation of a real-time operating system that measures critical parameters for the proper functioning of the production line	the ability to add notes, images and attach documents to work orders	Introduction of KPIs	change to JIC inventory type	Improved data entry and easier data searching Use of filtering and sorting mechanisms	Introduction of a system that enables communication directly at all levels	Creating charts for data analysis
increase in the efficiency of production processes - by using the OEE indicator	Automate and computerize the creation, modification and analysis of checklists to save time		implementation of an IT system for spares management	More transparent production structure in the system Tree mapping of the production structure in the database	Automatic tasks notifications	Automatic recording of production data to a transactional database
reduction of the number of failures and downtime - use of the MTBF indicator (Mean Time Between Failures)	Increased control over analyzing problems and resolution of issues		Real-time inventory data		Tracking of work order status	Real-time work analysis and daily report generation
Increasing the availability of machines and processing capacity	Checklists can be easily managed and completed from a computer or mobile device.		Automatic generation of inventory requirements based on the achieved minimum stocks of parts and materials			
Introduction of KPIs	Automatic notifications about a new order		Spare parts automatically assigned to the correct machines			

To better illustrate the authors' thinking process and the idea behind the table, one of the functions was thoroughly analyzed. This function is shown in the table below:

Feature	Importance			
	High (3)	Medium (2)	Low (1)	
Work order				SUM
Obtaining information in the present time about ongoing and completed tasks	XSG	ZA	W	14

Table 4.13 Feature analysis- Example

The described function allows for obtaining information in the present time about the commissioned works. As can be seen, according to the authors, this function is the most crucial for the requirements of such areas as: Maintenance strategy; Checklist; Information flow and work orders.

This can be explained by the fact that a given function directly affects the improvement of production efficiency through the possibility of correcting the work organization and enables the control of the highest priority works, which results in a reduction of downtime. It also positively influences the flow of information from operators to superiors. This feature also makes it more effective to modify checklists and work orders as superiors can do it based on unfinished work.

The function also influences the evaluation of the production efficiency and the data analysis. However, the impact is not as great as in the previously mentioned areas because it does not directly contribute to improvement but acts more as a supplement. Thanks to this feature, company can determine how quickly corrective or preventive activities are performed and analyze which of them require improvement in terms of response.

This function has also an indirect effect on spare parts. Checklists analysis allows to determine whether the spare part will be needed in the future for the task or if it was needed for a task that has already been completed. This also applies to the equipment needed to perform the activity.

As it can also be notice, the "storage and saving of data" were not covered by this feature, it means that this feature has no effect on this requirement.

The next stage of the analysis was to determine, using a numerical value, how a given function affects the global improvement of the organization's functioning. For this purpose, each of the letters received values consistent with the column in which it was found. The described function has a score of 14, it results from the fact that 3 requirements have been defined as "Very important", which is equivalent to the number 3, two requirements have received the "medium" priority, which means the value of 2 and the last requirement has been placed in the "low" column which corresponds to the number 1. So, the equation looks like this: $3 * 3 + 2 * 2 + 1 = 14$. The equation can be written as: $3 * a + 2 * b + 1 * c$, where a, b, c is the number of requirements in the given column.

This approach allowed the authors to define the most important functions that the system must have. The scale used for the final evaluation of a given function is as follows:

- Insignificant: 0-5,
- Significant: 6-9,
- Required: 10-21

As we can see, the described function has a score of 14 and is ranked as "required", so this is a function that a new system must have.

This is how each function has been analyzed and the results are described in the next section. However, the disadvantages of this analysis are that the choice of columns in which given requirements are placed is subjective. Therefore, there is a chance that the results may not be 100% accurate. But the purpose of such an approach was to define an indicator on which the choice of the system will be based.

Key functions

The following table shows the results of an analysis of key functions.

Feature	Importance			
	High (3)	Medium (2)	Low (1)	
Work order				**SUM**
To-Do-List / Chesklists	XSG		WZ	**11**
Sending of notifications with information about assigned tasks to be performed (Alerts/Notifications)	SGA	X		11
Sharing reports of faults and breakdowns via a mobile application (Mobile app)	GA	XSZ		12
Obtaining information in the present time about ongoing and completed tasks (Activity Tracking)	XSZ	GA	W	14
Assignment of a technician to a failure (Employee Scheduling) (Automated Scheduling)	S	X	G	6
Tracking the status of a work order (Status Tracking)	XSZ		G	10
E-mail notifications (Alerts/Notifications)	XSG			9
Photos attached to work orders	S	XW		7
Failure codes sorted by type	XS		G	7
Keeping track of "work in progress" (Real-time Updates)	XSZ	A		11
Categorization of work types (Prioritization)	XS	G		8
Logging in / out - automatic work time register (Check-in/Check-out)		G	XS	4
Configurable checklists (Task Management)(Work Order Management)	XS	G		8
Possibility to create own inspections, controls and audits (Inspection Management)	XS			6
Mobile access		SG		4
Mobile Alerts	XSG			9
Preventive tasks				
Automatically sent e-mail and SMS notifications about upcoming inspections or tasks (Reminders and Calendar/Reminder System)	XSGA		W	13
Monitoring of preventive tasks whether they were performed on time (Status tracking)	XZ	A	G	9
Reports with division into machines and type of maintenance work (Customizable Reports)	XZA		S	10
Possibility to view the history of machine and device maintenance tasks (Service History)	XSA	G	W	12
Automatic saving of the history of machine and device maintenance tasks (Data Capture and Transfer)	XSTA	Z	WG	16
Records of used spare parts during the implementation of preventive tasks (Inventory Tracking)	XSWT	GA		16
Links to documents required to plan the work order	X	G	A	6
Adding spare parts for repetitive work (Inventory Management)	XW	S		8
Planning of predictive and other works according to the work of the machine (Maintenance Management)	XA	SW	G	11
Machine maintenance based on condition monitoring (data readings)	XSA	Z		11
Downtime monitoring (Downtime Tracking)	XZA		W	10
Automatic generation of preventive works (Maintenance Scheduling)	XS	G	W	9
Repair Tracking	XZG	A		11
KPI Monitoring	XZA		SW	11

Table 4.14. Features analysis 1/2

	Technical Asset Management				
	Possibility for adding a notification by operators (Alerts/Notifications)	XSGA	W	Z	15
	Linking spare parts to a machine or device (Asset Planning)	XSW			9
Asset structure	Possibility of building a multi-level structure of devices	XTA	W		11
	Key asset information and photos	SG		W	7
	Creating visible connections and dependencies between assets and child-assets	XSGA			12
Work order summary for the given device	View of all work orders and fault reports (Real Time Monitoring) (Monitoring)	XGA	SZW		15
	Preview of unrealized work orders	XSGA		Z	13
	History of work orders for the device (Historical Reporting)	XSGA	W		14
	Visualization of implementation status and reaction (Data Visualization)	XA	S	G	9
Costs incurred on devices	Summary of internal and external costs (Cost Tracking)		XA	G	5
	Purchase summary (Purchase Order Management)	W	A	XG	7
	Cost summary by type of work		A	XG	4
Counters	Graphical and numerical data analysis of the machine's workflow (Reporting/Analytics)(Data Visualization)	XZGA			12
	Defining various data for device analysis (Predictive Maintenance)	XZGA			12
	Counter-based preventive work (Preventive Maintenance)	XZGA			12
Analysis	Built-in analytical charts (Reporting/Analytics)	XZGA			12
	Built-in damage analysis (Root Cause Analysis)	XZGA			12
	Spare parts- Warehouse				
	Record of used parts in work orders (Inventory Tracking)	XSWGA			15
	Setting the minimum quantity for individual spare parts (Inventory Optimization)	XW		S	7
	Purchase Order Management	W	XSG		9
Stock Items	Division into: Part categories, sections, groups, subgroups	SWA	X	G	12
	Pictures of parts	SW	X		8
	location of the spare part in the shelves (Warehouse Management)	SW	X	G	9
	Availability of parts usage information: tracking; part movements; use in work orders (Inventory Tracking)(Invetory Control)	SWA	X		10
	Division into stocked and non-stocked parts	XSW			9
Suppliers	List of suppliers (Supplier Management)	XWA			9
	Preferred Suppliers	W	XA		7
	Links to suppliers' websites	W	XA		7
Order	Purchases in various currencies (Multi-Currency)	W		X	4
	Automatic generation of orders		XW		4
	Automatic dispatch of the order to the supplier		W	X	3
	Invoice registration (Invoice Management)		XW		4
	Order approval	W		X	4
	Order status tracking (Order Tracking)	XWGA			12
	Automatic stock replenishment		XW		4
	Reporting				
Reports for work orders	Real-time downtime reporting (Real Time Data) (Downtime tracking)	XZGA	S		14
	Analysis of selected work orders (Reporting/Analytics)	XSZGA	W		17
	Analysis of the current amount of work (Reporting/Analytics)	XZA	SG	W	14
	Overall work order load (Reporting/Analytics)	XZA	G	S	12
	Priority of work orders (Prioritization)	XSGA		Z	13
	Analyzes of downtimes (Downtime tracking)	XZGA			12
	Analysis of the number of works (Reporting/Analytics)	XSZA	G		14
	Maintenance effectiveness Analysis (Maintenance Management)	XSZA	G	W	15
	Multiple criteria selection for creating each report (Customizable Reports)	XZTGA		W	16
Warehouse Reports	Report of urgent activities (purchases) (Purchase Order Management)		XWGA	S	9
	Quantity and value stocks		SWA	X	7
	Turnover reports with various suppliers (Vendor Management)	ZA	X	S	3
	Transaction table	A		XS	5
Asset management reports	Pareto analyzes for the plant	XZA			9
	Periodic equipment efficiency (Maintenance Management)	XZA			9
	Charts	XZA	G	S	12
	Cost summary for devices (Cost Tracking)	A	XSZ	W	10
	Device failure reports (Real Time Reporting)	XSZA	WG		16
	Selection of criteria for the creation of reports (KPI Monitoring)	XSZTGA			18
	Forecasting	XGA	S	W	12

Table 4.15. Features analysis 2/2

Required functions

As it can be seen, most of the functions classified as the “required” (9-21) come from three following areas: reporting, technical asset management and preventive tasks. This is understandable due to the strategic goals of the company described in Table 3.1. The aforementioned areas have a direct impact on the improvement of production efficiency and the improvement of the quality of production processes and final products. Moreover, each of these functions influences directly on the predetermined factors that create production downtime.

Most of the required functions are related to the analysis of data and the use of KPIs. This is because company are struggling with monitoring, analyzing and creating charts or reports related to, among others, the condition of machines or preventive activities. Many of the critical functions also have a direct impact on the ability to obtain real-time data, which improves response time, communication and work orders.

Significant functions

Functions with less criticality, but also very important (6-9), also significantly affect the possibility of achieving the company's goals. These are functions with a slightly lower priority because they are standard functions that most systems are offering.

As it can be seen, most of these functions come from the “work orders”. They are strongly correlated with the possibility of configuring checklists and the creation of clearer and more accurate work orders. They influence the flow of information and communication. Many of these features also enable more effective work through more organized and transparent access to the necessary data. These features also include options to help to choose the right supplier, which in turn can result in better cooperation and on-time delivery.

Insignificant functions

Functions that have been identified as “low importance” functions (0-5), are the type of functions that do not directly contribute to the achievement of the company's goals but can act as a supplement. The presence of these functions in the system is not a necessary condition, although having them is an advantage. These functions are mostly correlated with the administrative tasks of spare parts procurement.

4.3 Vendors selection

As mentioned earlier in the report, the selection of system functions was based on information found on the manufacturer's website. In this chapter, the report will present the evaluations of selected CMMS`s that are best rated on all internet rankings. The purpose of this section is to analyze individual systems and their functions to determine which of them best suits the requirements.

The initial phase of the vendor analysis was based solely on the functional requirements.

The selected systems are:

UpKeep

UpKeep is an asset management solution which provides CMMS, EAM and APM in one package and has been highly awarded for their solutions. The software is a cloud-based application and provide support for Industrial IoT devices. UpKeep got within industries such as healthcare, manufacturing and plants, property management, facility management and more. The asset operations management platform combines maintenance, operations and reliability data to help the maintenance personal to improve their work and make important decisions for the company. One of UpKeeps customers is the Norwegian company Intek. Intek is a company that provides robots and automation solution to production plants and has provided almost all the production equipment at Corvus Energy. [24]

Dynaway

Dynaway is an asset management solution that's been built inside Microsoft Dynamics 365. Since 2018 Dynaway has been a been a part of the standard package of Microsoft Dynamics 365 for finance and Operations Supply Chain Management. They are also a part of EG A/S which is a Scandinavian technology partner with more than 1,400 employees working from 15 different locations in Scandinavia. This means that they are already experienced with the Scandinavian market and can provide support. They also collaborate with different partners that help companies implement Microsoft Dynamics 365. [25]

The Asset Guardian (TAG)

TAG is a world leader and a specialist in CMMS as well as EAM and APM. Their goal is to provide the best solution for their customers and to help effortlessly leverage the power of Industry 4.0 technologies. They got experience within different industries such as power and utility, production and hotel and hospitality. TAG perfectly integrates with Microsoft technology, and they have a 15-year track record for managing assets. TAG only have one support office in Europe, that is based in Paris. They also don't have any experience with Scandinavian or Norwegian customers. [26]

LimbleCMMS

Limble is a CMMS that got established in 2015. LimbleCMMS is considered as one of the best systems in the business and has received several awards for their system. Today LimbleCMMS got customers all over the world in industries like government, manufacturing, mining, hospitality, office facilities, religious parishes, energy, restaurants, agriculture and more. Their most well-known customers are McDonalds, Pepsi, DHL, Nike etc. [27]

MaintainX

Like the other options MaintainX is a CMMS that delivers solutions to different industries like manufacturing, facility management, schools etc. MaintainX is trusted by operational leaders across the globe and got customers like McDonalds, DHL, Burger King and more. [28]

4.3.1 Vendors Assessment and Evaluation

The table below shows the results of the analysis of the above-mentioned vendors against selected features.

Table 4.16 Vendor evaluation based on available functions in possess 1/5

Feature	Importance: High (3)	Importance: Medium (2)	Importance: Low (1)						
Work order				**SUM**	**Dynaway**	**The asset guardian**	**UpKeep**	**MaintainX**	**LimbleCMMS**
To-Do-List / Chesklists	XSG		WZ	**11**	11	11	11	11	11
Sending of notifications with information about assigned tasks to be performed (Alerts/Notifications)	SGA	X		11	11	11	11	11	11
Sharing reports of faults and breakdowns via a mobile application (Mobile app)	GA	XSZ		12	12		12	12	12
Obtaining information in the present time about ongoing and completed tasks (Activity Tracking)	XSZ	GA	W	14	14	14	14	14	14
Assignment of a technician to a failure (Employee Scheduling) (Automated Scheduling)	S	X	G	6	6	6	6	6	6
Tracking the status of a work order (Status Tracking)	XSZ		G	10	10	10	10	10	10
E-mail notifications (Alerts/Notifications)	XSG			9	9	9	9	9	9
Photos attached to work orders	S	XW		7	7	7	7	7	7
Failure codes sorted by type	XS		G	7	?	?	?	?	?
Keeping track of "work in progress" (Real-time Updates)	XSZ	A		11	11	11	11	11	11
Categorization of work types (Prioritization)	XS	G		8	8		8		8
Logging in / out - automatic work time register (Check-in/Check-out)		G	XS	4		4	4	4	4
Configurable checklists (Task Management)(Work Order Management)	XS	G		8	8	8	8	8	8
Possibility to create own inspections, controls and audits (Inspection Management)	XS			6	6	6	6	6	6
Mobile access		SG		4	4	4	4	4	4
Mobile Alerts	XSG			9			9	9	9

Table 4.17 Vendor evaluation based on available functions in possess 2/5

Preventive tasks										
Automatically sent e-mail and SMS notifications about upcoming inspections or tasks (Reminders and Calendar/Reminder System)		XSGA		W	13	13	13	13	13	13
Monitoring of preventive tasks whether they were performed on time (Status tracking)		XZ	A	G	9	9	9	9	9	9
Reports with division into machines and type of maintenance work (Customizable Reports)		XZA		S	10	10	10	10	10	10
Possibility to view the history of machine and device maintenance tasks (Service History)		XSA	G	W	12	12	12	12	12	12
Automatic saving of the history of machine and device maintenance tasks (Data Capture and Transfer)		XSTA	Z	WG	16	16	16		16	
Records of used spare parts during the implementation of preventive tasks (Inventory Tracking)		XSWT	GA		16	16	16	16	16	16
Links to documents required to plan the work order		X	G	A	6	6	6	6	6	6
Adding spare parts for repetitive work (Inventory Management)		XW	S		8	8	8	8	8	8
Planning of predictive and other works according to the work of the machine (Maintenance Management)		XA	SW	G	11	11	11	11	11	11
Machine maintenance based on condition monitoring (data readings)		XSA	Z		11	11	11	11	11	11
Downtime monitoring (Downtime Tracking)		XZA		W	10	10	10	10	10	10
Automatic generation of preventive works (Maintenance Scheduling)		XS	G	W	9	9	9	9	9	9
Repair Tracking		XZG	A		11	9		11	11	11
KPI Monitoring		XZA		SW	11	11	11	11	11	11

Table 4.18 Vendor evaluation based on available functions in possess 3/5

	Technical Asset Management									
	Possibility for adding a notification by operators (Alerts/Notifications)	XSGA	W	Z	15	15	15	15	15	15
	Linking spare parts to a machine or device (Asset Planning)	XSW			9	9	9	9	9	9
Asset structure	Possibility of building a multi-level structure of devices	XTA	W		11	11	11	11	11	11
	Key asset information and photos	SG		W	7	7	7	7	7	7
	Creating visible connections and dependencies between assets and child-assets	XSGA			12	12	12	12	12	12
Work order summary for the given device	View of all work orders and fault reports (Real Time Monitoring) (Monitoring)	XGA	SZW		15	15	15	15	15	15
	Preview of unrealized work orders	XSGA		Z	13	13	13	13	13	13
	History of work orders for the device (Historical Reporting)	XSGA	W		14	14	14	14	14	14
	Visualization of implementation status and reaction (Data Visualization)	XA	S	G	9		9	9	9	
Costs incurred on devices	Summary of internal and external costs (Cost Tracking)		XA	G	5		5	5	5	5
	Purchase summary (Purchase Order Management)	W	A	XG	7		7	7	7	7
	Cost summary by type of work		A	XG	4		4	4		4
Counters	Graphical and numerical data analysis of the machine's workflow (Reporting/Analytics)(Data Visualization)	XZGA			12	12	12	12	12	12
	Defining various data for device analysis (Predictive Maintenance)	XZGA			12	12	12	12	12	12
	Counter-based preventive work (Preventive Maintenance)	XZGA			12	12	12	12	12	12
Analysis	Built-in analytical charts (Reporting/Analytics)	XZGA			12	12	12	12	12	12
	Built-in damage analysis (Root Cause Analysis)	XZGA			12	12	12	12	12	12

	Spare parts- Warehouse									
	Record of used parts in work orders (Inventory Tracking)	XSWGA			15	15	15	15	15	15
	Setting the minimum quantity for individual spare parts (Inventory Optimization)	XW		S	7			7		7
	Purchase Order Management	W	XSG		9	9	9	9	9	9
Stock Items	Division into: Part categories, sections, groups, subgroups	SWA	X	G	12	12	12	12	12	12
	Pictures of parts	SW	X		8	8	8	8	8	8
	location of the spare part in the shelves (Warehouse Management)	SW	X	G	9			9		9
	Availability of parts usage information: tracking; part movements; use in work orders (Inventory Tracking)(Invetory Control)	SWA	X		10	10	10	10	10	10
	Division into stocked and non-stocked parts	XSW			9	9	9	9	9	9
Suppliers	List of suppliers (Supplier Management)	XWA			9			9		9
	Preferred Suppliers	W	XA		7					7
	Links to suppliers' websites	W	XA		7	7	7	7	7	7
Order	Purchases in various currencies (Multi-Currency)	W		X	4					
	Automatic generation of orders	XW			6	5		5		5
	Automatic dispatch of the order to the supplier	W		X	4		3	3	3	3
	Invoice registration (Invoice Management)		XW		4	4	4	4		4
	Order approval	W		X	4	4	4	4	4	4
	Order status tracking (Order Tracking)	XWGA			12			12		12
	Automatic stock replenishment		XW		4					

Table 4.19 Vendor evaluation based on available functions in possess 4/5

Table 4.20 Vendor evaluation based on available functions in possess 5/5

	Reporting									
Reports for work orders	Real-time downtime reporting (Real Time Data) (Downtime tracking)	XZGA	S		14	14	14	14	14	14
	Analysis of selected work orders (Reporting/Analytics)	XSZGA	W		17	17	17	17	17	17
	Analysis of the current amount of work (Reporting/Analytics)	XZA	SG	W	14	14	14	14	14	14
	Overall work order load (Reporting/Analytics)	XZA	G	S	12	12	12	12	12	12
	Priority of work orders (Prioritization)	XSGA		Z	13	13		13		13
	Analyzes of downtimes (Downtime tracking)	XZGA			12	12	12	12	12	12
	Analysis of the number of works (Reporting/Analytics)	XSZA	G		14	14	14	14	14	14
	Maintenance effectiveness Analysis (Maintenance Management)	XSZA	G	W	15	15	15	15	15	15
	Multiple criteria selection for creating each report (Customizable Reports)	XZTGA		W	16	16	16	16	16	16
Warehouse Reports	Report of urgent activities (purchases) (Purchase Order Management)		XWGA	S	9	9	9	9	9	9
	Quantity and value stocks		SWA	X	7					
	Turnover reports with various suppliers (Vendor Management)	ZA	X	S	3	3	3	3	3	3
	Transaction table	A		XS	5					
Asset management reports	Pareto analyzes for the plant	XZA			9	9	9	9	9	9
	Periodic equipment efficiency (Maintenance Management)	XZA			9	9	9	9	9	9
	Charts	XZA	G	S	12	12	12	12	12	12
	Cost summary for devices (Cost Tracking)	A	XSZ	W	10	10	10	10	10	10
	Device failure reports (Real Time Reporting)	XSZA	WG		16	16	16	16	16	16
	Selection of criteria for the creation of reports (KPI Monitoring)	XSZTGA			18	18	18	18	18	18
	Forecasting	XGA	S	W	12			12		12
					SUM	720	705	796	729	794

Description of the results

The analysis shows that the systems that have the greatest value and impact on the requirements are both UpKeep and LimbleCMMS. Both systems obtained a very similar value for the final result, respectively 796 and 794. The lowest number was collected by The Asset Guardian with a score of 705. Both Dynaway and MaintainX obtained similar values, 720 and 729 respectively.

The results were achieved by summing up all the function values that the system has. The value of a given feature corresponded to the amount of influence that the function has on the overall goals and requirements. The authors decided on such a solution because some of the functions had a low level of overall impact on the requirements, but at the same time some of the requirements were placed in the column of high importance. Thanks to this method, the authors were able to clearly define which of the systems are the most complete and meet all requirements at the same time, and not only focus on particular one. The red colour in the column means that the system does not have the specified function.

As can be seen and inferred from the results, both Dynamics 365, MaintainX and TAG have deficiencies in many functions, which mainly come from the "Spare parts- Warehouse" area. These are mostly correlated with functions of lower importance. However, this has ramifications for the overall assessment of utility, which is the main selection criterion. Therefore, all 3 systems were not considered in the further parts of the analysis.

Another important step of the analysis was to determine whether the deficiencies in the functionality of individual systems are acceptable. After the initial analysis and selection of two systems, which are UpKeep and LimbleCMMS, the next step was a more detailed analysis of the deficiencies of these systems

UpKeep

As the table shows, the only shortcomings of the system are the ability to automatically save the history of service tasks for machines and devices and, the ability to monitor KPIs. This is important as both functions are classified as "required".

UpKeep does not have automatic data logging however it logs meter readings by manually entering it through the handheld device or website. It is also possible to automatically download information through an external system which UpKeep can be integrated with (System integration possibilities are described in chapter 4.4).

As it also can be seen, the column labelled "Selection of criteria for the creation of reports (KPI monitoring)" is included in the total score, but at the same time is highlighted in red. This is because the system has no KPI monitoring but uses metrics to track the performance of specific business activities or processes. These are very related functions but are not the same. In short, KPI can be seen as a collection of metrics that have an impact on goals achievement. KPIs need to be exclusively linked to targets or goals in order to exist, and metrics measure the performance of specific business actions or processes. Suppose a company wants to sell 20% more next year, the main KPI will be the number of products or subscriptions sold to date. Now, in order to monitor progress towards this goal in detail, it is needed to track various metrics such as the number of website visitors, the best performing sales channels, the performance of company's sales agents, and anything else that will help to understand which actions are contributing to achieving goals and what could be improved.

LimbleCMMS

The system, just like the previous one, does not have automatic data recording in the database and does not have the data visualization function.

However, Limble enables users to create meter reading for an asset and update the "Hours Run" by manually entering a value. As in the case of UpKeep, the Limble system allows the use of API code to integrate with the system that enables automatic data transfer. It also allows users to view past meter readings (More about API in chapter 4.4).

During the search, the authors were able to find several differences that do not result directly from the analysis and that may turn out to be important for the final selection, they are:

Automatic Downtime Update

UpKeep Software automatically tracks downtime when an asset is marked as non-operational. It allows users to add it manually whet the asset is operational again.

Limble can track Assets downtime through Unplanned Work Orders and Work Requests. In Limble CMMS, once the task is completed, the technician will be asked to record the time spent completing the task and if the asset caused any unplanned downtime. For unplanned downtime the technician must record the asset's downtime by providing the number of hours and minutes. The process is not an automatic process as the technician must manually provide the hours/minutes of downtime of an asset.

Parts Quantity Estimate

UpKeep has a built-in data analysis tool called "Analytics". The tool registers such data as:

- Total consumption Cost
- Total Quantity of all Parts Consumed
- Table breakdown of the Parts Consumed
- Consumption Cost trends between Reactive and Recurring work orders

These tools are used to more accurately determine the number of parts needed, but the employees must analyze the data themselves. This does not happen automatically.

Limble CMMS displays forecasting for a part and shows how many parts may be used every month over the next year. It also shows the total quantity of a part expected to be used in the next twelve months at the total estimated cost.

Given these shortcomings and substitutes, Corvus Energy must decide if they are willing to accept these alternatives. However, based on the analysis performed, it is not possible to clearly determine which of the two systems is better. Therefore, the next stage of the work concerns checking the compliance of both systems with the constraints found at an earlier stage

4.4 System selection

The final decision was based on comparing the suppliers against non-functional requirements. For this purpose, an Excel table has been created, which systematizes the knowledge about given systems in relation to "constraints". It is especially important that the chosen system meets the specific non-functional requirements, as they influence the success of the project in further stages. The aforementioned constrains are related, among other things, to the vendor's assistance in the selection and implementation of software; the availability of support in the event of unexpected failures or system problems; the possibility of increasing the scale of the system's operation.

The complete list of constrains specified by the authors and the result of the analysis are presented below.

	Non- Functional Requirements		
	Constrains		
	Other systems with which the CMMS system must be compatible are:	**UpKeep**	**LimbleCMMS**
	Microsoft Dynamics 365	1	1
	Azure	1	1
	Microsoft Office	1	1
	Additionally		
Availability and Scalability	The solution should automatically scale the resources to accommodate varying throughput at different times of the day.	1	1
	The solution is built with fault tolerance architecture and capabilities to automatically recover from any single point of failure	1	1
	The system provides for high availability through means such as redundant backup servers, cloud nodes, or other methods.	1	1
	The solution should be horizontally and vertically scalable.	1	1
Deployment Options	Offer as a SaaS solution	1	1
Integration and Extensibility	The solution offers **API integration capabilities** using REST or other methods to build custom integrations with other systems.	1	1
	The solution integrates with popular accounting platforms	1	0
	The solution integrates with popular data integration tools like Microsoft, etc	1	0
License Type	Solution offer a free trial	1	1
Platform Security	The solution maintains a record of administrative and user actions and generates a report on such activities.	1	0
	The solution allows creating and editing security groups and assigning users to those groups to ensure access is limited and only to those areas and fields of information that match the necessary user roles and responsibilities.	1	1

Table 4.21 UpKeep and LimbleCMMS analysis – Constrains 1/2

Professional services and maintenance	Vendor offer software implementation services, including solution evaluation and installation, to minimize the on-premise expertise required to implement the solution	1	1
	Vendor offer maintenance contracts for supported software to ensure that updates, upgrades, and maintenance services are regularly received	1	1
	Vendor offer in-product help and suggestions within the application to help the user get started using the product	1	1
Training	Vendor offer training material to help configure and use various features and functionalities of the product	1	1
User Support	Vendor offer 24x7 technical support to be able to address off-hour issues	1	0
	Vendor offer help desk support via instant message/chat	1	1
	Vendor offer help desk support via telephone and email	1	1
Vendor Information	Vendor have a broad customer base in the industry	1	1
	Vendor is financially stable	1	1
Mobile CMMS	**Offline Access**- The solution allows technicians to access their work orders, log labor hours and notes, record work completion, and enter condition monitoring readings offline. The data gets synced automatically when the device connects to a network	1	1
	Android App	1	1
	The solution allows users to collaborate within the CMMS mobile app via in-app messages, group chats, and other collaboration methods.	1	0
	SUM	23	18

Table 4.22 UpKeep and LimbleCMMS analysis – Constrains 2/2

According to the final analysis, the system that turned out to be more adapted to the “constrains” is UpKeep. This system responds to all specific author-defined restrictions.

However, the choice of the appropriate system, and above all, the choice between such similar systems, may raise some doubts. Therefore, the report will briefly describe all the differences between the systems resulting from the table. The purpose of this is to enable Corvus Energy to make a more informed decision.

Conclusions and differences resulting from the analysis based on non-functional requirements:

1. Integration

One of the biggest drawbacks of the LimbleCMMS is the built-in possibility of integration and communication with other systems. LimbleCMMS has only two systems for which no integration code is needed, these are the ERP-SAP system and the QuickBooks accounting system. LimbleCMMS is also not integrated with any data integration tool.

In turn, UpKeep has several systems with which it can connect without the need for an IT code - exactly 42 such integrations. These are ERP, EAM systems, accounting, and communication systems and much more. This system can also integrate with the Zapier system. It is a data integration tool which in turn allows for easier connection with many other systems.

However, each of the two systems has a built-in API (Application Programming Interface) function. This is the so-called "bridge" that allows different systems or databases to be connected and information transferred between them through the previously mentioned code. Problems begin when one of the systems not only does not provide API, but also hinders other forms of data exchange. Another important issue related to API is also money. Any system integration that requires a code generates extra costs related to, firstly, the purchase of the system and, secondly, its implementation. Additionally, after implementing the API integration, it will still require some overhead. Software evolves, and it is needed to make sure that API keeps up with developments in CMMS as well as all other integrated software.

2. 24x7 Technical Support

Both UpKeep and LimbleCMMS are American companies with headquarters in that country. Therefore, a very important factor influencing the choice of one of these two systems is the quality of support. UpKeep offers 24/7 support. There is a separate line serving foreign customers, so the time difference is not a problem. UpKeep also offers a 24/5 Live-Chat which is open from Monday to Friday. This is a good option when the telephone line is busy.

LimbleCMMS offers technical support Monday through Friday from 7 am to 7 pm MT (Mountain Time), which is 7h different from UTC (Coordinated Universal Time) used in Norway. This is a factor that may hinder and significantly affect the quality of the aid and the response time.

3. User Collaboration in Mobile App

UpKeep mobile application supports in-app messaging and enables users to chat with team members. It also helps to create group chat, involves multiple people, or has a direct and private message with just a single person.

Limble CMMS does not allow users to collaborate within the mobile application.

4. Financial Stability

An important factor when choosing a company is to check its financial stability. The aim is to limit the risk of cooperation with a company that may go bankrupt and close at any time. Leaving the client on their own without any help.

Each of these companies is a large enterprise that has been in operation for a long time. UpKeep's revenue for 2021 was $13.9M and Limble CMMS was $2.9M [29].

5. Customer Base

The number and quality of customers tells a lot about the company and how they care for customers. UpKeep, according to its official website, has +4,000 companies that use its software, including Yamaha, SubWay, McDonalds and Pepsi. LimbleCMMS looks no worse in this field. This system is also used by McDonalds and Pepsi branches as well as companies such as DHL and Nike.

5. Discussion

Research shows that the system that turned out to best meet the requirements is UpKeep. However, LimbleCMMS and UpKeep obtained very similar results both in the analysis of features based on functional requirements and in the analysis of functions based on non-functional requirements.

Considering the previously discussed differences between the two systems, Corvus must decide which system is more able to meet stakeholder expectations. These systems are equipped with many functions that facilitate maintenance and make it possible to achieve goals and requirements. However, compromising and accepting some of the shortcomings is inevitable, both when choosing UpKeep or LimbleCMMS.

The authors note that the reliability of the analysis may be affected by the fact that the prioritization of functions in the analysis presented in Table 4.14-15 was based on the subjective choice. This fact generates the possibility of a wrong assessment of the importance of a given function. However, this fact does not significantly affect the results of the research, as both systems had most of the functions present in the analysis.

An important factor that may also slightly changes the accuracy of the results is the fact that the authors did not have a chance to test any of the systems. An important element when choosing a new system is the possibility of interacting with it for a longer time through a free trial version or a demo presentation. This allows stakeholders to gain a broader perspective about the operation of the device and determine the accessibility of the interface. This is especially important because the chosen system will stay with users for a longer time. Therefore, it is crucial to choose a system that will be easy and pleasant to use.

Another issue that works to author's disadvantage is the limited access to information about individual systems. The authors mainly relied on official suppliers' websites. Such websites are characterized by the fact that they promote their products and do not mention any drawbacks. This may lead to the overlooking of a significant functional deficiency that the system possesses. That is why the previously mentioned demo presentation is so important for the overall evaluation of the product.

A final point that has not been discussed yet in detail in this report is the scalability of the systems. When choosing an IT system, it is necessary to consider its scalability, i.e. system's ability to increase in performance. It is wise to choose a program that will be able to adapt to changes on an ongoing basis. Otherwise, over time, it may be necessary to change the software used, which will needlessly consume time and money. In theory, both systems are horizontally and vertically scalable.

The scalability of the system is in some way related to the ability to integrate systems with other systems. Based on analysis performed, this is the biggest drawback of the LimbleCMMS that can be noticed. Lack of integration possibilities may lead to insufficient efficiency of data processing, analysis, and reporting. As a result, system changes may be required due to insufficient functionality.

According to the analysis, the biggest disadvantage of the UpKeep system is the lack of KPI monitoring- which was described in detail in the previous part of the report. In case the substitute in the form of metrics turns out to be insufficient, this may significantly affect the possibility of achieving the strategic goals set by management.

6. Conclusion

As a result of the research, UpKeep was found to be the best adapted system among the analyzed ones. It has all the necessary functions to meet the requirements- both functional and non-functional. However, the difference between UpKeep and LimbleCMMS is marginal, therefore managers should decide autonomously which of the systems best meets their expectations. It is suggested to contact company representatives for a demo presentation. It will enable to gain a greater understanding about system's appearance and its usage characteristics. This is important because those system specifications are very difficult to classify, and the evaluation is often subjective.

The report shows that the crucial stage in choosing a CMMS is the proper definition of the requirements. By doing it incorrectly and inaccurately, the company condemns itself to failure. The inaccurate definition of the requirements leads to selection of an incomplete system that will not be able to fully cover the expectations, which will result in ineffective management of certain operational areas.

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